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Support to oil spill emergencies in the Bonifacio Strait, western Mediterranean

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Abstract. An innovative forecasting system of the coastal marine circulation has been implemented in the Bonifacio Strait area, between Corsica and Sardinia, using a numerical approach to facilitate the rapid planning and coordination of remedial actions for oil spill emergencies at sea by local authorities. Downscaling and nesting techniques from regional to coastal scale and a 3-D hydrodynamic numerical model, coupled with a wind wave model, are the core of the integrated Bonifacio Strait system. Such a system is capable of predicting operationally the dispersion of hydrocarbon spills in the area, both in forward and backward mode, through an easy-to-use graphical user interface. A set of applications are described and discussed including both operational applications aimed at providing rapid responses to local oil spill emergences and managing applications aimed at mitigating the risk of oil spill impacts on the coast.

1 Introduction

The marine transport is one of the main sources of petroleum hydrocarbon in the Mediterranean Sea, crossed every year by about 220 000 vessels of more than 100 GRT (Gross Register Tonnage) each as estimated by the European Environmental Agency (EEA, 2006). These vessels approximately discharge 250 000 t of oil due to shipping operations such as deballasting, tank washing, dry-docking, and fuel and oil discharges. In addition, approximately 80 000 t of oil have been spilled between 1990–2005 from shipping accidents. Finally, accidents at oil terminals, together with routine discharges from land-based installations, are estimated at 120 000 t year^{-1}, thus leading to elevated oil concentrations in their vicinity (EEA, 2006).

Due to its strategic position at the centre of the western Mediterranean Sea, between Corsica and Sardinia, the Strait of Bonifacio (SoB hereafter) is annually crossed by an average of 3500 vessels, mainly solid bulk cargo ships and roll on/roll off passengers (Ro/Pax), with a gross tonnage ranging between 500 and 25 000 t (Sorgente et al., 2012), as calculated from 2000–2009 data acquired by the local vessel traffic service named Bonifacio Traffic (this despite the limitations from early 1990s as Italian and French Ministerial Decrees, IMO Assembly Resolutions, the institution of national and international marine protected areas and parks or the recognition by IMO of the Bonifacio Strait as the first Mediterranean Particularly Sensitive Sea Area in July 2011).

Hazards crossing the Strait are due to the presence of hundreds of reefs, over seventy large or small islands, a strict eastern opening of about 6 km, and sea conditions that can suddenly change due to large-scale evolving weather patterns, often associated with the topography of Corsica and Sardinia that generates weather conditions often unexpected and unpredictable, increasing the local maritime risk. Detailed descriptions of the water circulation in the SoB and of the morphological features of the area can be found in Cucco et al. (2012) and in De Falco et al. (2011).

Numerical modelling is a valid tool for the prediction of oil spill movement and allows decision makers to promptly respond to environmental crises. Many operational systems, based on trajectories models linked to hydrodynamic and

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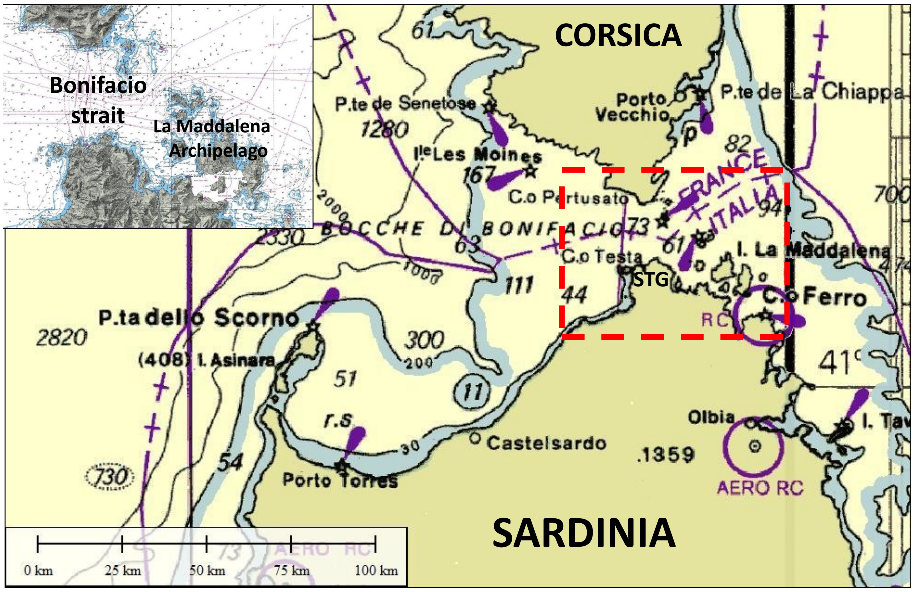

Fig. 1. Geographical setting.

meteorological ones, have been developed in order to analyse the dispersion of oil spill in European seas (e.g. Garcia and Flores, 1999; Brickman and Frank, 2000; Huggett et al., 2003; Ferrer et al., 2004; Gonzáles et al., 2008; Pinardi and Coppini, 2010).

These systems are generally not adequate in coastal waters as they use a fixed spatial resolution generally not lower then few kilometres (Chen et al., 2007). So, multiple nesting techniques to downscale the larger hydrodynamic model solutions are necessary to forecast sea currents and waves in the coastal area. In any case, these techniques must be overcome when simulated oil droplets leave the high resolution restricted domain to enter into an extended domain (Wang et al., 2008). Unstructured grid models are a solution as they allow both to reproduce the fluid motion and the oil slick transport processes over different spatial scales, and to adopt simplified nesting techniques to downscale the open ocean model solutions to the coastal areas (Cucco et al., 2012).

An approach of an oil spill prediction system for coastal areas, based on the use of operational finite element numerical models, has been applied to the SoB (Fig. 1).

In 2009, an innovative forecasting system of the coastal marine circulation was developed, using a numerical approach, within the framework of the European Integrated project MyOcean and the Italian project SOS – Bonifacio. This system was developed in order to facilitate the rapid planning and coordination of operations by the marine authorities to tackle pollution during oil spill emergencies.

The system allows users to obtain real time simulations to predict the fate of different types of oil at sea and forecasts of their dispersal in the marine environment within a time lag of 3 days. The main objective of this system is to provide assistance in the prevention and/or limitation of damages and therefore the conservation of marine resources in coastal waters, especially the most vulnerable areas of high environmental value typical of the Strait.

The description of the Bonifacio Oil Spill Operational Model (BOOM hereafter) system and the evaluation of its accuracy in predicting both the surface transport and the 3-D water circulation in the SoB is reported in Cucco et al. (2012).

In this paper, a detailed description of the model operational usage and an overview of the main applications aimed at supporting the response to local oil spills emergencies and reducing the risk of environmental damage from oil spills in the coastal area are provided.

2 The BOOM system

The BOOM system is composed of a hierarchy of different nested numerical forecasting models covering from basin to coastal scale through a downscaling technique (Fig. 2). It is based on both structured and unstructured grids aimed at providing a prognostic tool for managing oil spill emergencies in the Strait of Bonifacio. The system is fully detailed in Cucco et al. (2012). In the following a brief summary of the adopted numerical models techniques are reported.

The coastal element of the system is composed of a set of finite element numerical models, including a three-dimensional hydrodynamic model (SHYFEM3D; see Umgiesser et al., 2004; Cucco and Umgiesser, 2006; Bajo et al., 2007; Bellafiore et al., 2008; Cucco et al., 2012) coupled with a phase averaging wind-wave model (SHYFEM3D-WWM; see Roland et al., 2009; Ferrarin et al., 2008), and

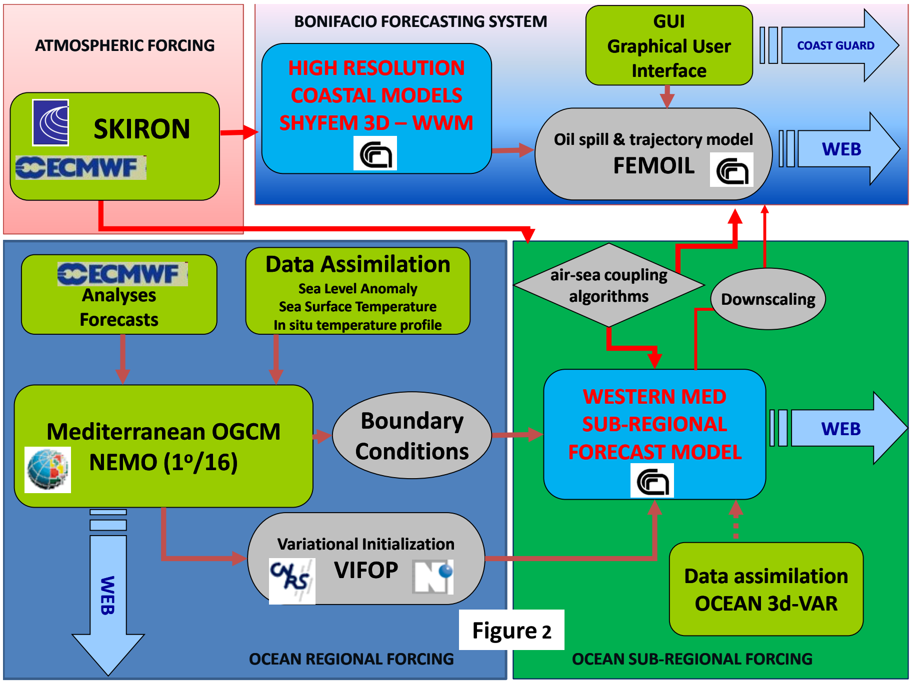

Fig. 2. Scheme of the whole system with different nested numerical forecasting models covering from basin to coastal scale, oceanographic and atmospheric.

a Lagrangian trajectory module with a "weathering" module (FEMOIL, see Cucco et al., 2012) offline coupled with the SHYFEM3D-WWM.

Such numerical models are aimed at operationally reproducing the hydrodynamics and transport processes in a restricted domain corresponding to the Bonifacio Strait area. The domain has been reproduced by means of adaptive mesh generator onto a finite element grid composed by 33 563 nodes and 64 292 elements (see Fig. 3 in Cucco et al., 2012).

The coastal system is nested to a sub-regional ocean forecasting system applied to the western Mediterranean Sea and named WMED (Sorgente et al., 2011). WMED, based on the Princeton Ocean Model (Blumberg and Mellor, 1987; Mellor, 1991), is a three-dimensional model covering part of the western Mediterranean area, between 3° E and 16.5° E. It uses a uniform horizontal orthogonal grid with a resolution of 1/32° (about 3.5 km) in longitude and latitude while vertically it is discretized by 30 sigma levels. At its lateral open boundaries it is nested with daily mean fields computed by the MyOcean-OPA regional model for the whole Mediterranean Sea, with a horizontal resolution of 1/16° implemented at INGV in Bologna (Tonani et al., 2009).

The SHYFEM3D is nested to the WMED through an interface for managing forcing and boundary data in real time, which allows receiving daily both high resolution atmospheric and hydrological data along the domain boundaries for the following 3 days.

Atmospheric conditions for the coastal component are provided by the very high resolution meteorological forecasting system named SKIRON, developed by the University of Athens (Kallos et al., 1997; Kallos and Pytharoulis, 2005), while for the sub-regional component the forecasting system developed by the MyOcean key-user ECMWF.

The BOOM system currently produces, daily and operationally since the end of 2010, a 3-days forecast of wind and wave fields, 3-D water circulation, temperature, salinity and of the fate of the oil slick at sea in the Bonifacio area. A graphical user interface (GUI; Ribotti et al., 2012) provides a user-friendly accessibility, usability and interaction with the BOOM system by setting up scenarios, running simulations and analyzing the produced consequences of an oil spill.

3 The operational usage

The forecasting system based on the SHYFEM3D-WWM produces daily and operationally the datasets needed by FEMOIL to forecast the fate of the oil spill. In this paragraph a description of the BOOM operational setup is reported. Furthermore, the accessibility to FEMOIL throughout the GUI and its usage for providing a prediction of the oil spill fate in both forward and backward mode are described.

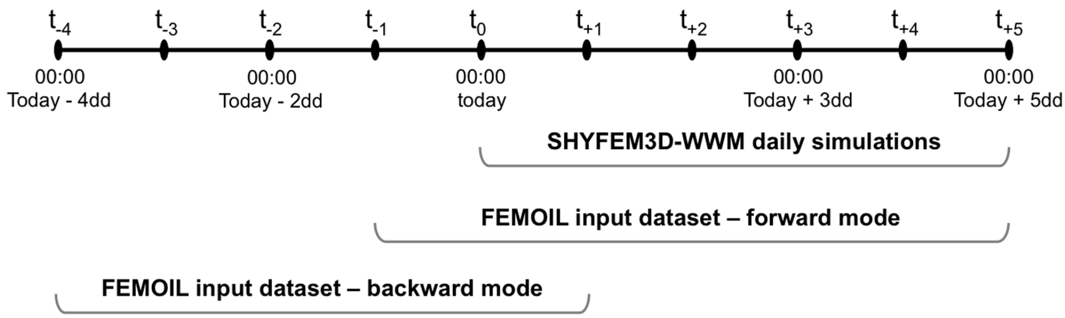

Fig. 3. The BOOM forecasting chain.

3.1 The model forecasting chain

Wind data fields from SKIRON forecasting atmospheric model, water levels time series and interpolated T, S fields from WMED regional ocean model are provided daily to the SHYFEM3D-WWM. All the forcing datasets regard 5-days forecasting simulations.

Then daily, a 5-day hydrodynamic and wind wave model run for the SoB area is performed. The integration time step of the flow module SHYFEM3D was set to be variable and top limited by a Courant number threshold equal to 0.8. On the other hand, for the wave simulations, the time step was set to be fixed and equal to 300 s. Synchronization between the two processes is guaranteed by the coupling scheme.

A warm start procedure was implemented to avoid the use of an additional spin-up time needed when model variables initialization is made with homogeneous or non realistic spatial distribution. Simulation starting time (t_0) and ending time (t_{+5}) respectively correspond to the 00:00 of the present day and to 00:00 of the 5th day forward respectively (Fig. 3).

The computational time demand is variable and depending on the values of the flow model time steps. On average, it was estimated to be about 2.5 h when computation is carried out on a 4 Intel Core 2 Quad CPUs of a 3.00 GHz workstation.

At the end of the model run, the computed surface water current, wave drift, wind speed and surface T fields are saved to an external file. The dataset is organized to include data starting from the time t_{-1}, corresponding to 00:00 of the 1st day backward to the time t_5 with a temporal frequency of 1/300 s. Finally, a further procedure is carried out to obtain a dataset of water current, wave drift and wind speed vector fields with both inverse temporal sequence and inverted vector directions and starting from the time t_{+1}, corresponding to 00:00 of the 1st day, forward to the time t_{-4}, corresponding to time 00:00 of the 4th day backward. The data needed to generate the datasets corresponding to the past days from t_{-1} to t_{-4} are provided by the previous days operational simulations. These two sets of external files constitute the two forcing datasets needed to run the off-line FEMOIL module both in forward and in backward mode (Fig. 3).

The results obtained by the SHYFEM3D-WWM numerical simulation are made available daily on www.seaforecast.cnr.it in the form of snapshots of the surface currents intensity and direction and of the wind wave significant height and propagation direction is computed every 6 h for the next 72 h forward (from t_0 to t_{+3}).

3.2 Forward and backward analysis

The simulations of the oil spill fate were initialized, set up and run using a graphical user interface communicating with the FEMOIL. The GUI is a software tool, written in Java programming language, that makes it easy for a user to create simulations of oil-spill emergencies. In particular, it allows a user to interact directly with the FEMOIL through a set of interactive panels.

The GUI guides the user through the creation of an oil spill scenario, launching a simulation and analysis of the results generated.

The user specifies the emergency scenario by using a control panel, composed of a series of user friendly sub-panels which allow selection of: the date and hour of the last detection of the oil spill between the time t_{-1} and t_{+1}; the geographical location of the last detection of the oil spill; the direction of integration, if forward or backward; the amount and type of oil spilled; the mode of spilling, if instantaneous or continuous; the output data location and to launch the FEMOIL model run.

Results generated by the numerical simulation are stored in an archive selected by the user and displayed in the form of animations and snapshots. In the case of forward run, results consist of the trajectories and the density of the oil dispersed at sea, with the impacted parts of coast highlighted on the map.

In the case of a backward run, results include only the trajectory followed backward in time by the oil spill. No weathering processes and oil stranding at coast are included in the backward simulation.

Both advection and diffusion processes are taken into account in the backward mode in order to simulate both the mean trajectory followed back in time and the area of possible location of the pollutant source.

The system allows to run the simulation of the oil spill fate even if the dataset by the daily SHYFEM3D-WWM operational model simulation is still not ready. In this case, the input dataset of the day before is used instead, adjusting the reference t_0 to the time t_{+1}, therefore partially remedying to the delay in the generation of the updated prediction.

4 Applications

The system has been used to provide support to local authority during emergencies due to oil spill accident occurred in the SoB. Furthermore, a set of scenarios analyses was performed to evaluate in advance the risk induced by hypothetical impacts of hydrocarbons in the coastal areas of the Bonifacio Strait. The results of these activities have been included in the "Local emergency operations plan against marine pollution by oil and other harmful substances" of the Coast Guard at La Maddalena. This plan is activated on the basis of art. 11 of the Italian Law 979/82 of the "Regulations for the protection of the sea" in case of pollution or imminent threat of pollution of the sea caused by dumping, accidental event of oil or other harmful substances.

In the following, the results obtained by the application of the system during two different oil spill emergencies are reported and discussed. Finally, the results obtained by a selected simulated scenario and risk analyses are reported.

4.1 Response to emergency

In this sub-section, two different examples of applications of the BOOM system as a response to oil spill emergencies are reported. In the first case, the system was applied to backtrack the trajectory followed by an oil slick detected in the SoB, in order to individuate the potential source of pollution. In the second case, the system was used to predict the trajectory followed by the oil released in the water during an accident that occurred in the SoB.

4.1.1 Backward investigation

When accidents occur that lead to large oil spills, national authorities are usually quick to respond and identify those responsible. Nevertheless, most of the "small" oil spill events are caused by the common illegal practice of refuelling or pumping oily bilge water overboard. Even if they constitute small spills, their intense frequency can have significant negative effects on the marine environment. In these cases, identification and quantification of the responsibles is very difficult and often quite impossible.

In order to provide support to the local Italian Coast Guard for detecting the responsibilities for such events, a numerical tool for carrying out the so-called "backward investigation" was developed. The system, based on the BOOM, aims at tracking back in time the probable path followed by the oil dispersed in the water.

The method consists of performing a sequential run of 2 simulations, one "forward" and the other "backward". In the forward run, the hydrodynamic and wave models reproduce the water circulation and wave field in a selected period (DT) before the time (TF) when the oil slick has been detected in its final position (XF). The obtained results are stored in external files and processed in order to invert both the temporal order of the fields sequence and the direction of current and wave propagation. The "backward" run is then performed and the Lagrangian advection model used to transport and diffuse a quantity of particles representing the amount of oil spill detected in the final position XF at time TF. The simulation runs to a time corresponding to DT using, as input, the stored and processed current and wave data. Therefore, the obtained results provide a tracking of the detected oil spill from the moment TF and the final position XF, back in time to $\mathrm{TI} = \mathrm{TF} - \mathrm{DT}$ and to the initial most probable position (XI).

An example of a backward analysis carried out to backtrack a fuel oil slick of about 30 m^3 detected in XF at noon of the 27 August 2008 is shown in Fig. 4. The first frame refers to time TF, whereas the last to time TI, 6 days before, then 21 August. At time TI the position of the slick is located on the main maritime traffic route (XI), where the release probably occurred. In particular, for the simulated event, comparison between the numerical results and traffic data reveals that the hydrocarbon spill detected on 27 August was probably generated in the recommended route area, corresponding to the position XI. During this period, 21 transits of Ro/Pax, Ro/Ro ships, cargos and cruise ships through the Strait are recorded. Furthermore, considering the kind of ship and their routes, the number of those possibly responsible can be reduced to 15 vessels, therefore increasing the probability of its identification.

4.1.2 Forward investigation

The system simulation has been qualitatively verified in early January 2011 during a case study when an oil spill occurred in the harbour of Porto Torres (PT), north-western Sardinia.

During the operation of oil transfer from a ship tanker at the off-shore pipe station in front of PT harbour, about 50 m^3 of heavy crude oil (API 19.7°) were released into the sea. The oil spilled out continuously for about 18 h, starting from 10 January 2011 at the 10:18 p.m. of local time.

The slick moved north-eastward for about 5-days, intersecting the coast at several locations between the villages of PT and Santa Teresa di Gallura (Fig. 5). On 17 January at 12:00 a.m. LT, 7 days after the accident, an oil spill was found during an air survey in the coastal waters at the entrance of the Bonifacio Strait (Fig. 5). The local authority, in order to verify the connection between the pollutant and the PT accident and to exclude further sources of spills in

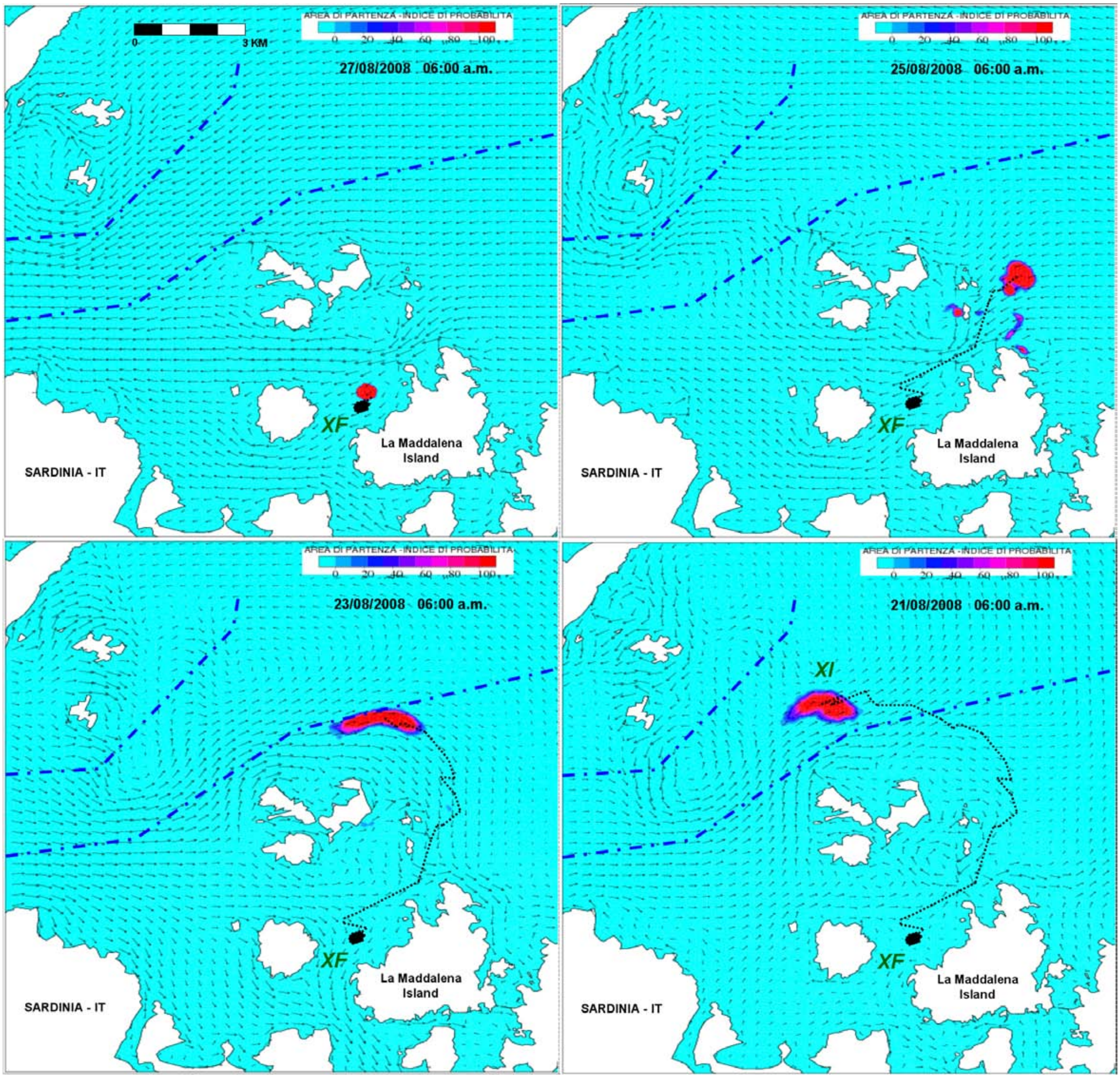

Fig. 4. Results of the backward investigation: XF and XI are the final and the most probable initial positions of the oil slick respectively at time TF (27 August 2008 at 06:00 a.m.) and at time TI, which corresponds to 6 days before TF (21 August 2008 at 06:00 a.m.). The areas between the blue dashed lines correspond to the maritime traffic route through the Strait of Bonifacio.

the area (e.g. tanks cleaning bilge waters), ran the BOOM in backward mode. The obtained results revealed that the provenience of the spilled oil was from the PT area. Samples of floating oil were successively collected and chemically analyzed in the laboratory, certifying its origin from PT.

Subsequently a new simulation was carried out to verify the model capability in reproducing the fate of the occurred spill in forward mode. The model domain was extended to the interested area, increasing the mesh resolution to reproduce the local bathymetric and morphodynamic features (Fig. 6). A 9-day simulation run was performed, releasing the oil in continuous mode for about 20 h starting from 10 January at 10:00 p.m. The atmospheric field produced from SKIRON for the first day of prediction was used to force the model domain. The model was initialized with water levels and current speeds generated by the BOOM system and open boundary data from WMED were used.

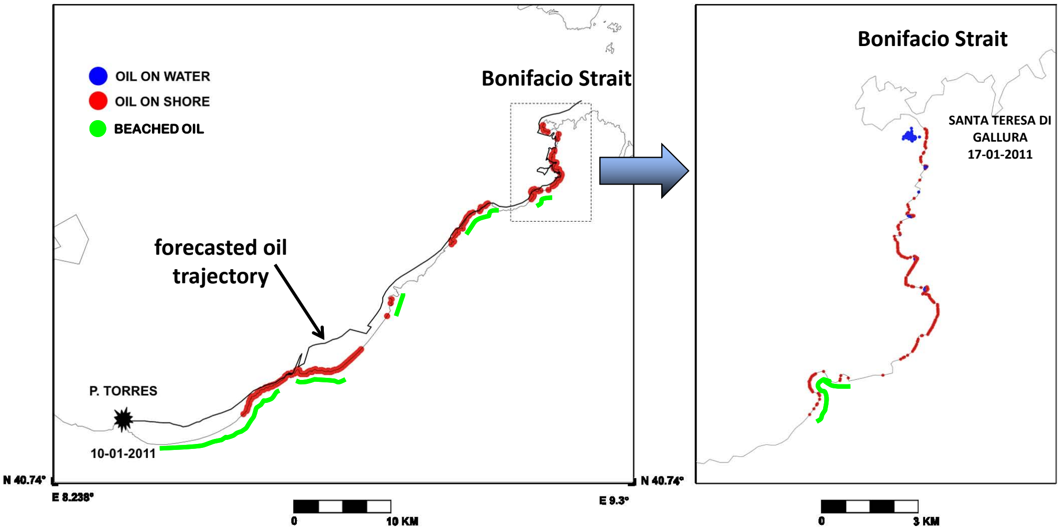

Fig. 5. Map of the area where the accident of Porto Torres occurred in January 2011 and the hindcast simulation results. Red lines indicate tracts of coastal area impacted by the simulated oil; green lines the sampled beached oil. The blue circle indicates where the oil at sea was detected by airborne surveys close to the entrance of the Bonifacio Strait. In the left panel the black line indicates the average trajectory followed by the particles on water. In the right panel a snapshot of model results at the 12:00 a.m. of 17 January 2011.

The model reproduced fairly well the probable trajectory followed by the spilled oil during the whole period. This is evidenced by the position of the oil particles beached on the shore, which mainly corresponds to the coastal area impacted by the pollutants during the event, as reported in Fig. 5. Furthermore, the model was able to reproduce the fate of the oil in water, simulating the presence of oil particles on water at the entrance of the Strait during the 7 days after the released time at PT location, in agreement with the experimental evidence.

4.2 Hazard mitigation

In this sub-section two different types of applications aimed at mitigating the risk of environmental damage due to impact of oil spills in the coastal area are reported. In the first case, the system was used to produce, by means of ad hoc scenarios analysis, essential information aimed at preventing the oil spill impacts on the coast. In the second case, the system was applied to individuate in advance, by means of ad hoc risk analysis, the traits of coast more subjected to the potential impacts of oil spills.

4.2.1 Scenarios analysis

A series of numerical simulations was carried out in order to reproduce the most probable pollutant scenarios, and the areas with the highest risk of accident, affecting the Strait of Bonifacio. These scenarios have been chosen considering local climate condition, maritime traffic and historical maritime emergency records for the last 16 years. Six main macro-scenarios have been defined, differing by the spilling

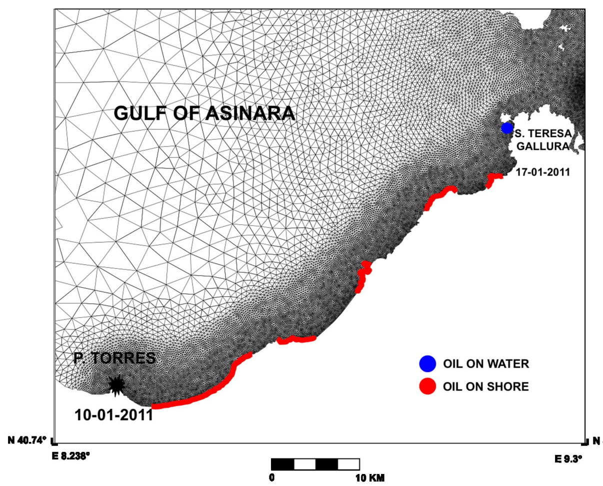

Fig. 6. The extended model domain. In red and blue the sampled beached oil.

area and the type and amount of hydrocarbons released. For each macro-scenario, eight simulations are carried out in order to consider the seasonal variability of wind regime and water temperature. For all the simulations, stationary open boundary conditions and wind forcing are defined and a spin-up time of 3 days is selected to eliminate the noise generated by the imposed initial conditions. Wind-wave propagation and the 3-D water circulation is reproduced for the Strait area. For each considered macro-scenario, a defined quantity of numerical particles are initialised in the selected area of the oil spill. Each particle represents a quantity of oil released in the water with an associated density, depending on

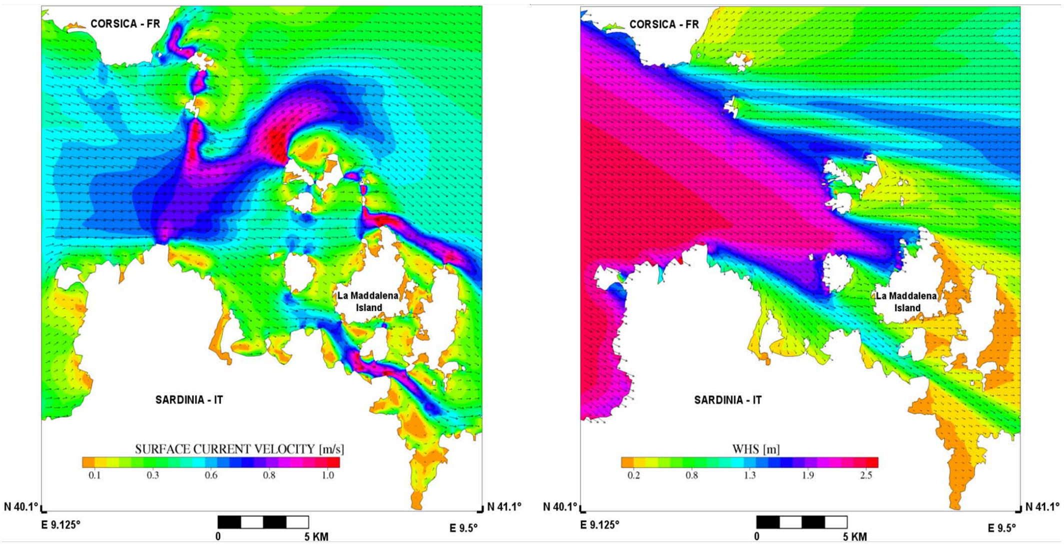

Fig. 7. Surface current speed and significant wave height induced by a 13 m s^{-1} Mistral wind in the Bonifacio Strait and La Maddalena archipelago area.

the type of oil considered. The amount of oil released varies between 10 000 kg and 100 kg, and oil density is representative of fuel oil, marine diesel and crude oil.

About 50 scenarios are considered and the following results are obtained:

- wave and surface current velocity fields;
- hourly field of oil slick depth;
- hourly field of Lagrangian particle position and impacted areas on shore;
- time series of oil quantity dispersed at sea or beached.

Here we show the results obtained for a scenario simulating a real accident with hydrocarbon spillage that occurred in 1994, involving the French ferry Montestello, on the route Livorno–Barcelona, run aground inside the La Maddalena Archipelago during a strong Mistral wind storm. The simulated accident is set in the same period and with the same original weather conditions and an initial spill of 30 m^3 of fuel oil. The surface water circulation and the wind wave field computed by the model are shown in Fig. 7. The strong Mistral wind (13 m s^{-1}) generates an eastward water circulation with current velocities reaching about 1 m s^{-1}. The wind induced wave field is moved south-easterly with a significant wave height (HS) decreasing eastward. Maximum values of significant wave height (HS) reaching 3 m are found outside the Strait, while inside the La Maddalena Archipelago the HS is always less than 0.8 m.

The Lagrangian particles released are quickly transported eastward due to the combined effect of wave, water currents and wind drift. Six snapshots, illustrating the computed particles distribution in the water, are shown in Fig. 8. Seven hours after the release, all the particles reach the coast, particularly around the islands of La Maddalena and Caprera (see green dots in Fig. 8).

The temporal variation in the total amount of oil, split between quantity still in the water and quantity beached, is shown in Fig. 9. The oil mass dispersed in the water (green close symbols curve) quickly decreases during the first 3–4 h due to high evaporative processes. After this period, the recorded reduction is due to the oil reaching the coast, as shown by the increase in the green curve. After the beaching, the total quantity is still diminishing due to evaporative and emulsification processes occurring on the oil that re-enters the sea due to the wind-wave impacts on the shore.

4.2.2 Risk analysis

The BOOM system has been used to produce probabilistic estimates of the oil impact on the coast as a function of oil type. Three different kind of accidents are considered involving an oil-tank vessel, a cruise-ship and a ferry boat, and the quantity of oil contained in the bunkers of each of the three vessels.

For each category, a one-year simulation is carried out, forcing the hydrodynamic and wave model with wind and open boundary data provided by the meteorological and the oceanographic models. Each simulation is initialised with an amount of particles statistically sufficient to cover the paths corresponding to the maritime traffic routes followed by the considered ship categories crossing the Strait.

The "seeding" of particles is repeated daily in order to take into account the influence of the meteorological variability on the Lagrangian transport. Each particle represents a possible spill event of a defined quantity and type of oil,

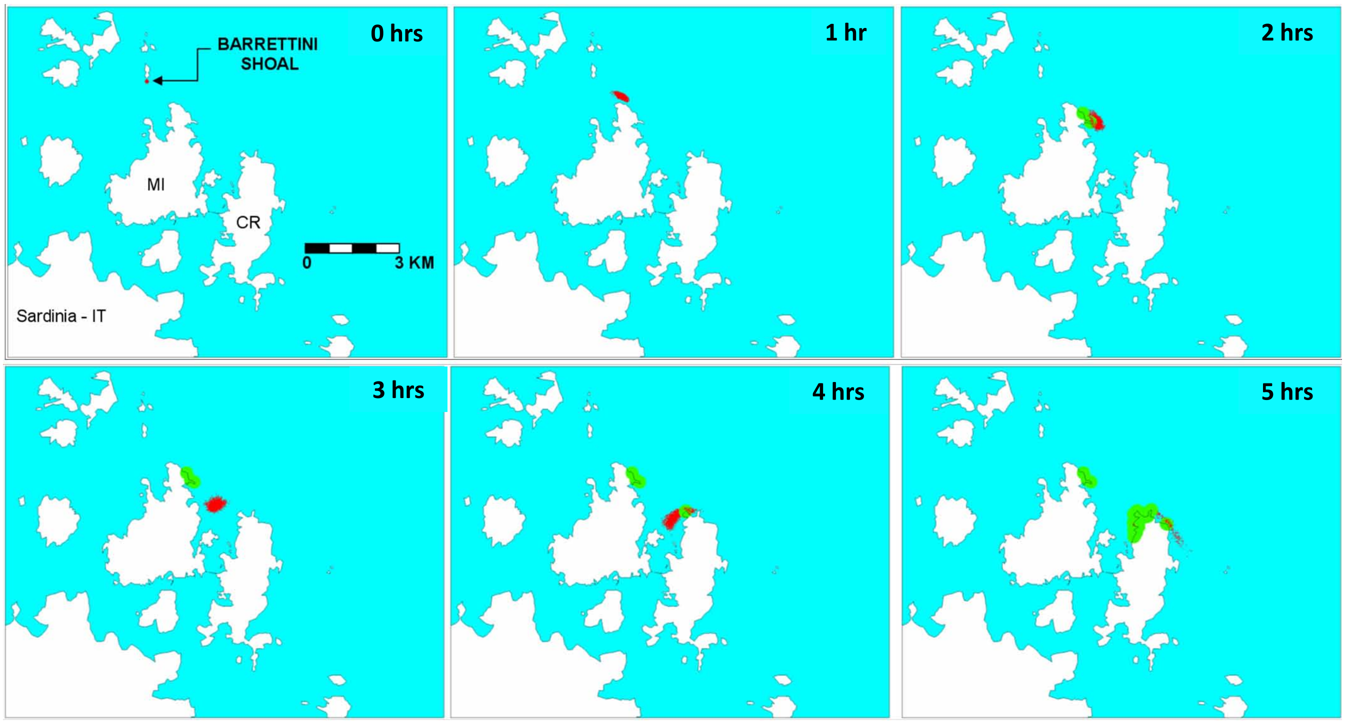

Fig. 8. Snapshots of oil particles distribution dispersed in the water (red dots) and beached on the shore (green dots).

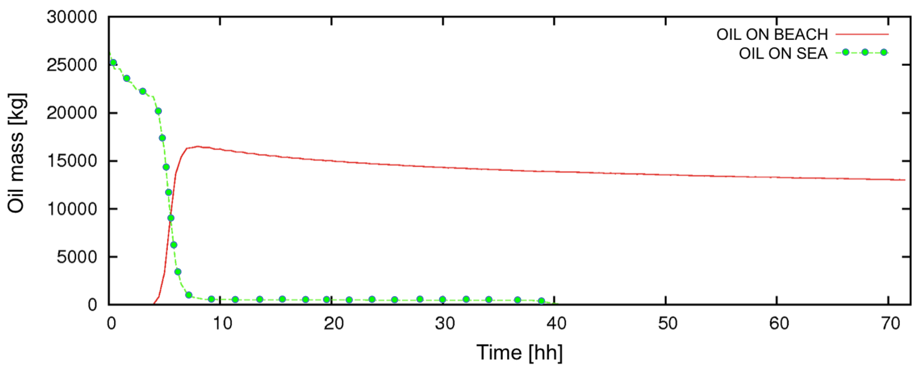

Fig. 9. Temporal variation of the total amount of oil quantity dispersed in the water column (green close symbols curve) and beached on the shore (red curve).

which could occur anywhere along the whole maritime route and at any time of the year. The computed water currents, wave propagation and wind drift transported all the particles within the numerical domain. Each particle is also influenced by weathering and stranding processes, leading to a reduction in the quantity of oil at sea.

At the end of each model run, the quantity and the number of oil particles beached on the coast are computed. The coastline is divided in 200 m cells and, for each cell, the total amount of oil beached during each month of the simulated year is calculated. The cell values are then normalized to the maximum quantity of oil beached on a cell during the considered month and, for each category, 12 maps consisting on the distribution of a relative risk index which ranges between 0 and 1 are produced.

The derived risk index aims at describing, in a probabilistic way, the risk of oil spilled reaching the coast, as a function of a geophysical forcing only. Neither vulnerability aspects (biological resources, environmental values, anthropic values, etc.) nor accessibility of the coast have been considered.

As an example, the yearly map of risk induced by the impact of oil on the coast, as released by cruise ships travelling through the Bonifacio Strait, is reported in Fig. 10. The maximum risk of impact is found along almost the whole length of the channel between Sardinia and the La Maddalena Archipelago.

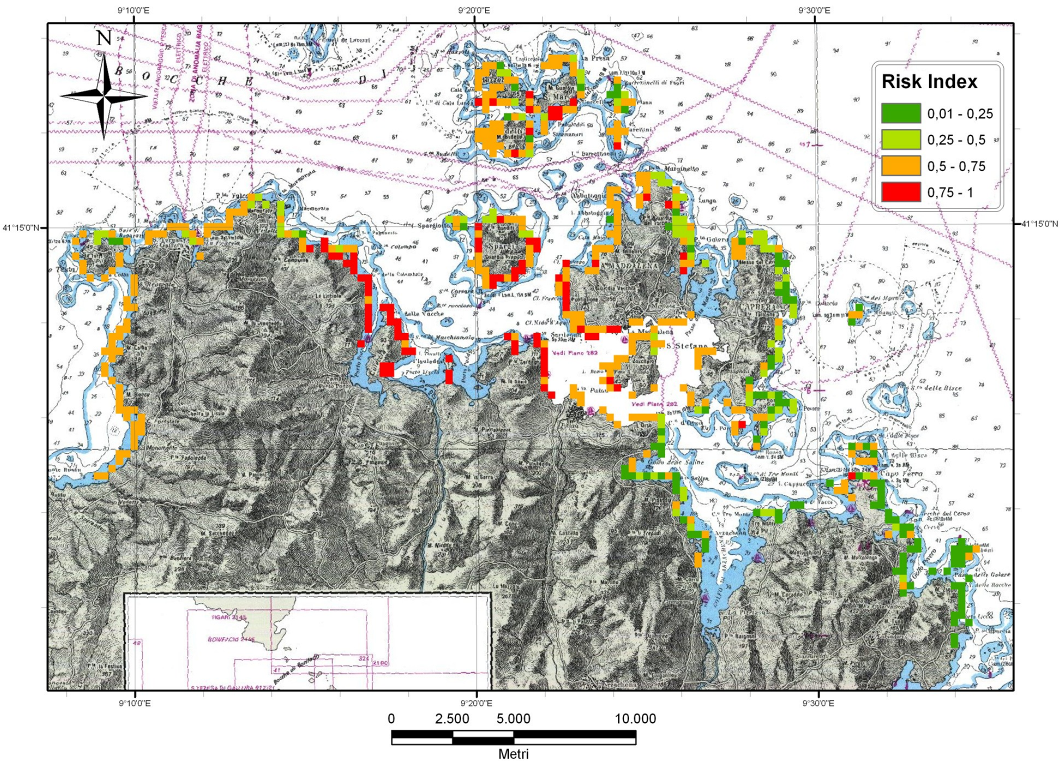

Fig. 10. Risk map of oil impact on the coast as consequence of a potential release from cruise-ships.

5 Conclusions

The BOOM represents an innovative operational system developed to provide support to the Italian Coast Guard in managing oil-spill emergencies in the coastal area of the Strait of Bonifacio.

This is an integrated numerical tool whose coastal core is organized in a set of fully coupled high resolution numerical models based on the finite element method. The models include a 3-D hydrodynamics model, a wind-wave model, a Lagrangian trajectory model and a module for reproducing the main weathering processes impacting the oil slick. BOOM has been fully operational and utilized since the end of 2010 by the Italian Coast Guard in La Maddalena island (Sardinia, Italy), realized within the frameworks of the Italian project "SOS-Bonifacio" and the European project MyOcean. The system allows, through the interaction with an easy-to-use GUI, the user to operationally forecast the fate of oil spills in the whole area of the Bonifacio Strait and La Maddalena Archipelago.

The innovative approach consists of the use of operational finite elements numerical models with a spatial resolution up to 10 m, fully nested with an open ocean operational model based on the finite differences method (WMED) to reproduce the transport processes occurring in coastal areas characterized by a complicated geometry.

Currently the system produces, daily and operationally, a 3-day forecast of wind and wave fields, 3-D water circulation, temperature and salinity for the area of interest. Furthermore, it has been used to investigate the consequences of oil-spill events, to produce risk maps identifying the most exposed areas to the risk of oil impact in relation to both period of the year and type and quantity of spilled oil, and as a tool for tracking back the surface trajectories of oil slicks. The operational validation of the system was realised in January 2011 when an oil spill occurred from the harbour of Porto Torres. The results of the simulations were well comparable with beached oil and with oil slick positions at sea, giving valuable information to the Coast Guard on their origin and on the area affected by the accident.

Simulation results of oil spill scenarios can provide the local Coast Guard with information on the fate of oil spills and those most probable in the area. In particular, the hourly maps of oil slick position and those showing which areas would be most probably impacted, as a function of different meteorological conditions, provide a useful tool to improve the management of oil spill emergencies at sea. For these reasons, the local Coast Guard in La Maddalena has inserted the simulated scenarios in its "Local anti-pollution plan for 2009" requested by the Italian Ministry for Environment. These simulations will be used to predict in advance the trajectory of the oil, then permitting decision makers to plan the optimal remedial action for minimizing oil pollution and reducing time response and costs.

Further information is also provided by the risk analysis, which allows the local Coast Guard to identify the most exposed areas to the risk of oil spill impact during the year. This is also useful for the identification of the most suitable areas where instruments and resources should be concentrated.

Finally, even if the backward investigation cannot exactly pinpoint the initial position of the oil spill, it still provides information on the most probable path followed by the oil slick since its detection.

The tools described above define the BOOM as a useful instrument for any local Coast Guard in the management of oil spill events in coastal areas like those of the Bonifacio Strait and La Maddalena Archipelago, characterized by a wonderful marine and terrestrial environment daily threatened by the passage of tens of vessels. Finally, the daily forecasts of currents and waves in the area are used by local final users (fishermen, sportsmen, SMEs, etc.) during their activities, as proved by contacts received since the activation of the system on the web.

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