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A high-resolution real-time forecasting system for predicting the fate of oil spills in the Strait of Bonifacio (western Mediterranean Sea)

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ABSTRACT

The Strait of Bonifacio is a long and narrow area between Corsica and Sardinia. To manage environmental emergencies related to the spill of oil from vessels, an innovative forecasting system was developed. This tool is capable of operationally predicting the dispersion of hydrocarbon spills in the coastal area of the Bonifacio Strait, either from an instantaneous or continuous spill and either in forward or backward mode. Experimental datasets, including ADCP water current measurements and the trajectories of drifter buoys released in the area, were used to evaluate the accuracy of this system. A comparison between the simulation results and experimental data revealed that both the water circulation and the surface transport processes are accurately reproduced by the model. The overall accuracy of the system in reproducing the transport of an oil spill at sea was estimated for both forward and backward prediction mode and in relation to different forecasting time lags.

1. Introduction

Oil-spill events in the marine environment generally cause a wide range of long-term adverse consequences on both the marine ecosystem and human activities such as fisheries, aquaculture and tourism.

This convention is particularly true for the Mediterranean Sea, where the annual maritime transport of crude oil and refined products was estimated to be 20% of the total world oil maritime transport (IMO/UNEP, 1998), corresponding to approximately 360 million tons. Approximately 1 million tons of this oil is discharged into the sea (Le Lourd, 1977) as a result of both maritime accidents and continuous release from marine or land-based operations. Consequently, a large percentage of the Mediterranean coastline is impacted annually by oil pollution.

To reduce pollution generated by oil-spills, during the last 2 decades, most Mediterranean countries have sustained a strong scientific, political and technological effort to develop adequate pollution contingency plans.

Operational forecasting systems, which are capable of predicting ocean and weather conditions in addition to oil-spill trajectories, provide a rapid and efficient tool that allows decision makers to promptly respond to environmental emergencies on the basis of technical assessment and risk analysis procedures.

A wide variety of numerical systems that are based on trajectory models linked to hydrodynamic and meteorological models have been developed to analyze and predict the dispersion of oil-spills in European sea waters (see NRC, 2003 for a review and as examples Pollani et al., 2001; Jordi et al., 2006; Carracedo et al., 2006; Caballero et al., 2008; Sotillo et al., 2008; Coppini et al., 2011). The hydrodynamic parameters are commonly provided by structured grid ocean models based on the finite difference method. These systems are generally adequate in the open sea or shelf waters, where the geometry is regular or smooth. However, for irregular and complex geometries, such as in coastal areas, these operational tools are not sufficient to provide information concerning the fundamental variables controlling the oil-spill event and to forecast the oil dispersion (Chen et al., 2007).

As a partial solution, nesting procedures are widely used to improve the accuracy of numerical model predictions along coastal areas. Such techniques are efficient to downscale hydrodynamic model solutions, but these techniques are not well suited for tracking oil particles (Wang et al., 2008). In particular, problems arise when simulated oil droplets leave the high-resolution, restricted domain and enter the coarse-resolution, extended model domain. In this case, a two-way nesting procedure is needed to downscale and upscale the trajectory model solution, leading to a reduction in numerical model accuracy and an increase in both computational time and operational system complexity.

An alternative approach is provided by the use of numerical models based on an unstructured grid, which allows for the

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reproduction of the fluid motion and the oil slick transport processes over different spatial scales without adopting complicated and computational time-demanding multiple nesting procedures (Umgiesser et al., 2004; Cucco and Umgiesser, 2006; Chen et al., 2007; Wang and Shen, 2010).

However, many forecasting systems for operationally predicting water currents and waves in the open ocean often still used structured grid numerical models. These models are well tested against measurements, and their accuracy is generally high, especially when reproducing water surface temperature fields (Tonani et al., 2009; Sorgente et al., 2011).

Therefore, an optimal approach for predicting the fate of oil-spills in coastal and shelf areas would consist of the adoption of nesting procedures combining high-resolution numerical models in coastal areas, based on an unstructured grid, and coarse-resolution numerical models in open ocean and shelf areas, based on a structured grid. This approach is particularly advantageous when the forecasting is performed for restricted domains and within a reduced forecasting time lag, ranging between a few hours and several days.

For these cases, in fact, the exclusive use of numerical models based on a structured grid would require multiple nesting procedures to downscale the prediction from open ocean to coastal areas, with the consequent need to upscale the trajectory model solutions to obtain a correct simulation of the oil-spill.

Alternatively, the exclusive use of numerical models based on an unstructured grid would provide a numerical solution over an extended domain, including open ocean and coastal areas, leading to an increase in both computational time and complexity of the forecasting system architecture. In contrast, the coupling between structured grid based and unstructured grid based numerical models can take place far from the areas of interest without the need of multiple nesting procedures. This reduces the risk of particles leaving the unstructured grid domain toward the structured grid domain and benefits the advantages provided by the already existing and well tested open ocean forecasting systems based on structured grid.

In this study, a novel approach to an oil-spill operational system is presented. The method involves the use of an open ocean numerical model, based on the finite difference method, to provide offshore boundary conditions nested within operational finite element numerical models for predicting surface currents and wind waves in coastal areas and coupled to a trajectory and weathering model, to reproduce the fate of hydrocarbons released at sea.

The integrated system was applied to the Strait of Bonifacio (hereafter SoB), a coastal area located in the western Mediterranean Sea (see Fig. 1) between Sardinia and Corsica, which is characterized by the presence of several small islands, rocks, banks and shallow channels.

This paper describes the numerical system, named the Bonifacio Oil-spill Operational Model, (hereafter BOOM), the operational usage for managing oil-spill emergencies, and an evaluation of the accuracy of the model in reproducing the water circulation, as measured by an ADCP probe and the paths of Lagrangian drifters released within the area of interest.

2. Study area

The SoB separates two distinct Mediterranean sub-basins, the Tyrrhenian Sea and the Algero-Provençal (see Fig. 1).

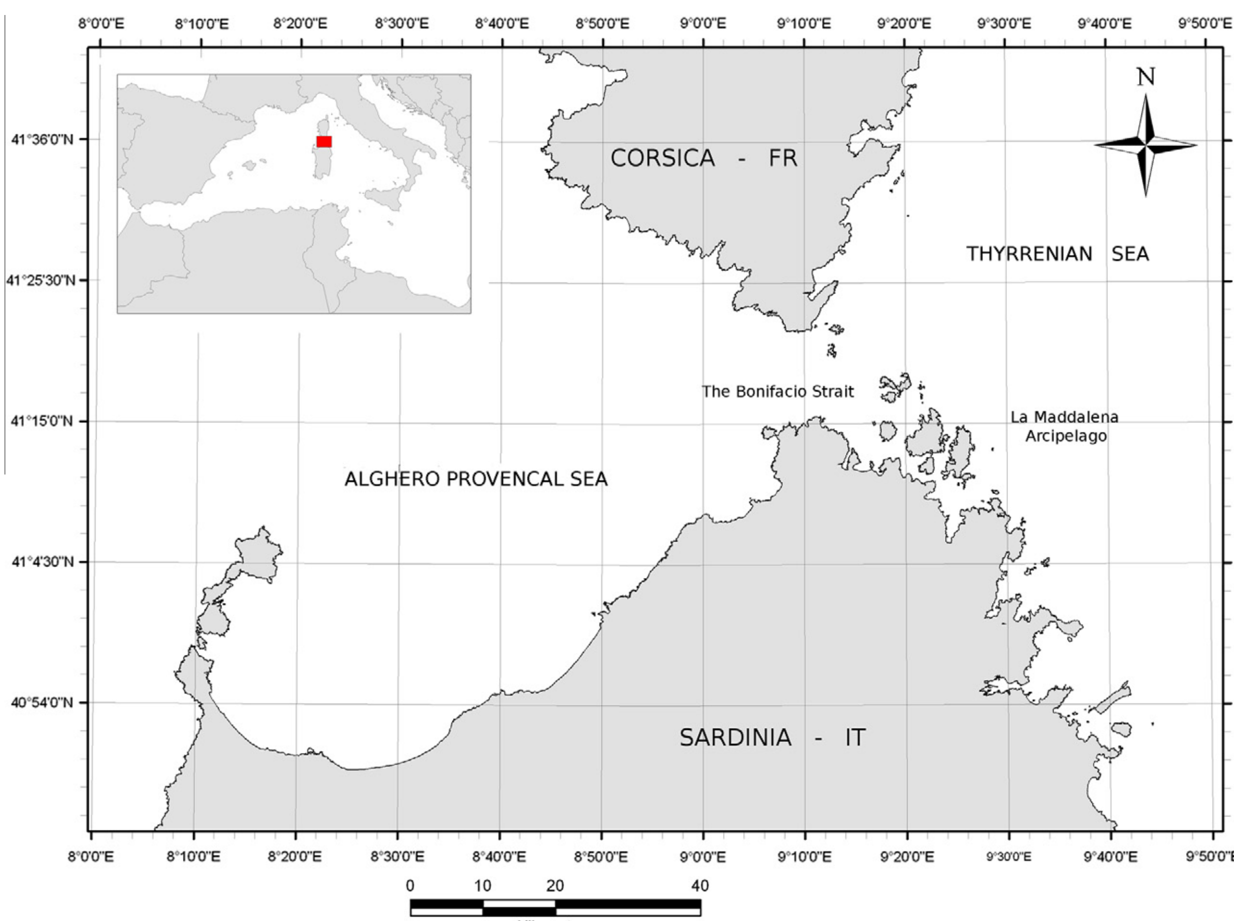

Fig. 1. Geographical settings.