Emergency activities support by an operational forecast system – The *Prestige* accident

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1 Introduction

Marine pollution events are a major concern nowadays. Although there are a number of regulations in place, the problems of ship structural weaknesses, traffic control systems and others are still to be solved. All those unsolved problems have direct influence on the risk of accident.

All maritime countries agree on the necessity of putting in place tools to better respond to marine pollution emergencies. These tools aim to provide the best possible information and decision support systems for spill response organizations.

The Decision Support Systems (DSS) are usually based on:

i. Emergency planning (risk assessment, command chain, decision trees, communications,…);

ii. Environmental information (ecosystems, geomorphologic, human occupations, economics, …);

iii. Logistical and infrastructure for emergency response;

iv. Models (operational or ran for a number of scenarios);

v. Informatics (GIS and database platform) .

This text refers mostly to the ivth item and its interactions with all the other items.

A specific emphasis is given to the Prestige case.

2 Hypothesis and objectives

Modelling of oil spills is still an area of active research. It includes the problems of hydrodynamics and trajectories and weathering of the oil. Each of these 3 has particular difficulties in different environments (nearshore, offshore, inside an estuary, etc).

As technology evolves, the modelling techniques will be used more and more to support decisions in emergency situations. The present emergency systems concepts will surely develop to include new knowledge. This will lead to faster and more accurate forecasts of meteorological and oceanographic conditions and of oil spill trajectories and fates. This improvement in the modelling techniques must be supported by better field measurements, which will also improve in the future.

The group of people working together in this area (Hidromod, IST & MeteoGalicia) believes modelling and measurements may be included in emergency systems with three perspectives:

- During the phase of developing a DSS;
- To update existing DSS's;
- During the occurrence of an emergency situation.

3 Emergency systems general concepts

DSS based on GIS, databases and Oil Spill models are in place, or being adopted, in several countries. The ways these systems are implemented depend on the type and intensity of use of the marine environment. The solution that is in place in Australia is different from the Japanese, which in turn is different from the French, the North American or the Brazilian.

Also, each country, state, local authority or oil company, who needs to be prepared for a marine pollution emergency, must set up its own DSS depending on factors like international protocols, national legislation, geographic areas of responsibility, equipments and human resources, etc.

In all DSSs there are two phases of work: planning and emergency response. The first is done previous to the emergency; the second is done during the emergency.

In all these DSSs, the forecast of oil spill trajectories and compromised coastlines is crucial for the planning of the oil recovering and protection of sensitive sites. The

forecast of those oil spills is done with two purposes and in two different time contexts:
Simulation of different scenarios of oil spills in terms of spilled volume, oil characteristics, location and meteo-oceanographic conditions. This is done in the context of emergency planning studies;
Operational modelling of a specific oil spill. This is done after the oil spill and needs a high degree of preparedness.

4 Decision support systems

The mathematical modelling tool behind a DSS for marine pollution emergencies is a very important part once it is the support for the definition of strategies of contention, protection and recovery of the spilled product. The combination of all the available information, whether it is about environment, human activities, geographic references, available equipment, etc, must be done with a GIS accessed database. Also the modelling results must be accessed through the GIS.
When an operational model exists, it needs also to be linked to the DSS, which should be prepared to set up good initial conditions for the model and to analyze the results of the model with the GIS.

5 Planning

In the planning phase of the emergency, along with all the information that is gathered to set up the DSS, a risk analysis is done to define oil spill scenarios that should be studied with a mathematical model. Also the meteo-oceanographic (MO) conditions for the site are analysed and a number of MO scenarios are defined as relevant to simulate in the model.
The result of this modelling study is usually a large number of simulations of hydrodynamics and oil spill trajectories and fate that are used to set up strategies for the immediate actions in the first hours after the oil spill event.
This modelling study is more important for nearshore areas and inside estuaries, reservoirs or rivers, due to the short time the oil may take to reach land.
Although the modelling study is done by specialists, the results will be used by technicians that may not be very familiar with modelling techniques. All this information will be used by the people who will be running the emergency plan and interacting with the field taskforces.

6 Emergency response

After an accident has occurred, an operational centre may be activated to start forecasts of the specific oil spill, introducing in the modelling tools the characteristics of the spill and the MO conditions. A response from such a centre is not possible in the time frame of the previous section, that is, a few hours after the accident.
An operational centre should always have the model for the relevant MO conditions running in order to be prepared to make good forecasts of the location of the spill. This imply the existence of monitoring equipment, large scale boundary and forcing conditions (oceanic and atmospheric) for the local model, detection of the location and evolution of spill (remote detection either with airplanes or helicopters), deployment of measuring equipment, efficient communications for data acquisition, sampling of the spilled oil, etc.
This centre should supply to the On Scene Commander (OSC) the best forecasts of the real location of the spill, based on the acquired field data and on the mathematical model results.

7 Changes in technology

The foreseen changes in technology should be mainly due to:
Increasing computing power;
Better hydrodynamic and meteorological modelling, including operational modelling;
Better measuring equipments and communications;
Faster, safer and more reliable Internet;
Better GIS and Database tools.
All these enhancements will undoubtedly change, in a few years time, the way DSS's will be looked at. More importance will be given to operational modelling and monitoring systems and its publication in Internet in a friendly way.

8 The Prestige Experience

On the November 13, 2002, the *Prestige* tanker caused an oil spill off the coast of Galicia (northwest Spain) during a severe storm. The ship traveled first to the north and later southward, while the fuel continued to leak out. The amount of spilled oil at this point was estimated to be about 10.000 tons. The ship split in half and sunk on November 19 at the southern edge of the Galician Bank, 133 nautical miles from the Galician coast in an area with depths of about 3500 m. In this process the ship spilled roughly 11.000 tons of fuel oil. The oil spill caused extensive damage along the coast of Galicia and the Bay of Biscay. An Office of Nearshore Surveillance was created by the Fisheries Department of the Galician Government. This office managed the contribution of several Institutions. One of these contributions was given by MeteoGalicia together with MARETEC/HIDROMOD. During the crisis these institutions made daily predictions of the trajectories of several patches identified by visual observation made from ships and helicopters. MeteoGalicia was responsible for the wind forecasts while MARETEC/HIDROMOD was responsible for the hydrodynamic and oil spill trajectories' forecasts. The results were validated with remote sensing and visual observations. The results were published on the internet using animated pictures and WEB/GIS tools. Basically, these institutions were able to implement, in a very short time (3 days), a forecast system of oil slick trajectories for the Galicia coast named at the time MeteoMohid. This system consists on a one-way coupling of the meteorological model ARPS with the hydrodynamic module of the MOHID water modeling system (http://www.mohid.com). In order to obtain oil tracks, the lagrangian oil spill module of the MOHID system was used.

8.1 Wind forecasting

MeteoGalicia runs since 1999 a weather prediction center for the Galician region. This center is responsible for daily weather forecasts that are disseminated via internet (http://meteo.usc.es), television, radio and phone services. A very important component of this forecast system is the numerical models. The MM5 and ARPS are run and validated in a daily base for the Galician region by MeteoGalicia.

During the Prestige crisis the ARPS model was used to make wind field forecasts for the affected area. The governing equations of the ARPS include conservation equations for momentum, heat, mass, water substance (water vapour, liquid and ice), subgrid scale (SGS) turbulent kinetic energy (TKE) and the equation of state of moist air. More details on the model formulation can be found in Xue et al. (2000) and Souto et al. (2003).

For this application, the nesting was set up to allow the resolution of flows at two scales: the influence of local terrain features in the 10-km fine grid, and the mesoscale circulations (particularly those concerning the passage of cold fronts from the Atlantic Ocean) by the 50-km coarser grid. Every day, the ARPS model starts from an enhanced 12-hour forecast of the NCEP AVN model and uses the boundary conditions also obtained from the NCEP AVN model at a three-hour interval on coarse grid covering an area of 3000x3000 km^2. A fine grid, covering an area of 430x430 km^2, is nested within the coarse-grid domain. There are 30 sigma-z levels in the vertical, extending to 18 km. The fine grid uses its own higher-resolution terrain with a gradual transition to the coarser-grid terrain in a boundary zone to improve the match between solutions.

8.2 Hydrodynamic forecasting

For the hydrodynamic forecasting MARETEC/HIDROMOD use the MOHID water system (http://www.mohid.com). This numerical tool is under development since 1985 and aims to simulate the main hydrodynamic and water quality processes in aquatic systems. The main area of application so far has been the coastal and estuarine systems. MARETEC is a research a center from the Technical University of Lisbon. HIDROMOD is a private company formed by former PhD students of MARETEC. These two institutions have developed MOHID together, with significant contributions of people from the Algarve University and Santiago de Compostela University.

This model has shown its ability to simulate complex coastal and estuarine flows (Coelho et al., 2002, Martins et al., 2001). Among its applications some previous work in Galician Rias hydrodynamics has successfully reproduced the main observed features of the circulation in some of these rias (Taboada et al., 1998, Montero et al. 1999, Gómez-Gesteira et al., 1999, Ruiz-Villareal et al., 2002).

The governing equations of the hydrodynamic module include: conservation equations for momentum, heat, mass. These equations are solved considering the hydrostatic hypothesis and Boussinesq approximation. In time a semi-implicit discretization is used and in space a finite volume approach is used (Martins et al., 2001).

Two types of hydrodynamic simulations were made one aimed to forecast the hydrodynamic field in the area where the ship sunk. The other type had a smaller domain aimed at simulating the trajectory of oil slicks observed near shore. In both types of simulations the GOTM model was used to compute the vertical turbulence.

A November climatologic profile offshore (11Wº, 42ºN) was considered for the initial density field. The vertical discretization was done with 20 cartesian layers. The surface layer had the minimum thickness (10 cm). The only forcing mechanism used was the wind field forecasts produced by MeteoGalicia. The horizontal domain of the larger scale simulations was 39º-44º N and 13º-7º W. In this case a 10 Km spatial step was used (Figure 1).

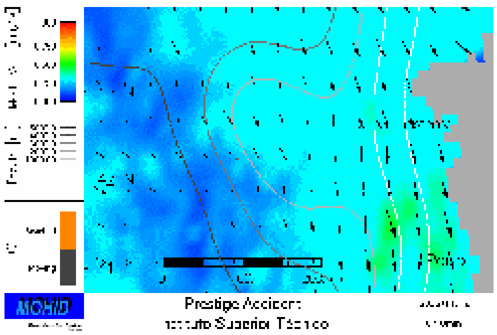

Figure 1 – Hydrodynamic field using a large spatial step.

For the near shore simulations a variable spatial step was used with a minimum value of 2 km near the coast. The horizontal domain of the smaller scale simulations was 41.5º-43.5º N and 10º-7º W (Figure 2Figure 1).

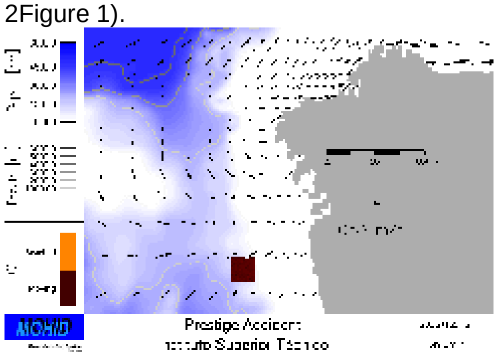

Figure 2 – Hydrodynamic field using a smaller spatial step.

In both simulations a radiation boundary condition was assumed. Tests were made to understand the sensitivity of the solution to large scale processes like the slope current. A flow field forced by November climatologic density gradients (Levitus and Boyer, 1994) was added linearly to both hydrodynamic solution forced by the wind forecasts. These large-scale flow fields were produced in the framework of European project OMEX. This project aimed to estimate the carbon fluxes between coastal areas and the deep ocean (Coelho et al., 2002). The oil track forecasts improved when the slope current was added.

8.3 Oil trajectories

The oil spill lagrangian module of the MOHID system is able to predict fate and weathering of oil spills. Oil trajectory is calculated assuming that oil can be idealized as a large number of particles that independently move in water, due to advection induced by wind or tides (advection velocity is determined with hydrodynamic module), turbulent diffusion and oil specific spreading forced by thickness gradients. A 3D lagrangian transport module is used to that effect. Several oil properties and weathering processes are also simulated.

The smaller scale hydrodynamic simulations were used in a first stage to simulate the trajectory of the oil leak out along the ship trajectory (Figure 3).

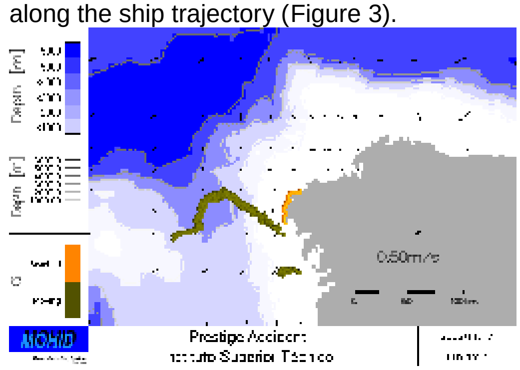

Figure 3 – Forecast of the oil slick position emitted along the ship trajectory in 17 of February of 2002.

These results were validated with an ESA (European Spatial Agency) satellite image that shows the affected areas in 17 of February of 2002 (Figure 4). The model results (Figure 3) reproduce very well the observed data (Figure 4). It's possible to see three main slicks in the model results, the larger slick has a format similar to the ship trajectory but deformed by SE transport. Near the coast it is possible to observe one slick beaching and another moving south maybe due to the intensification of the current over the platform. The satellite image show also these three slicks reproduced by the model. However, there is a fourth slick also with a format similar to the ship trajectory but with a much weaker SE transport. These four slicks could be explain by the emission of an oil with different characteristics of the fuel. One of the differences could be the ability to mix with water in a more homogenous way. In this case the direct action of wind over the slick would be less intense, explaining the weaker SE transport.

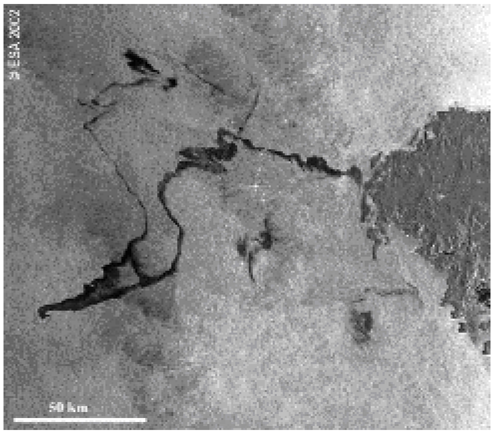

Figure 4 - Satellite image that shows the affected areas in 17 of February of 2002 (ESA).

In a second stage these hydrodynamic simulations were used to simulate trajectories of several slicks observed visually near the coast.

The large scale simulation aimed to simulate the trajectory of 11.000 tons of oil emitted where the ship sunk (Figure 5).

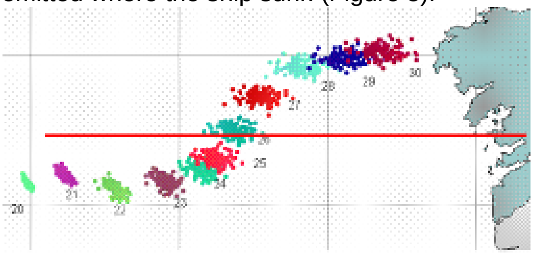

Figure 5 – Oil slick trajectory emitted in the sinking process. Each patch represents the oil slick position for a specific day in February (from 20 to 30 of February).

These results were validated based on visual information gathered and published in a WebGis by the Office of Nearshore Surveillance. This office was able to filter down all the date to reproduce the slick core trajectory (Figure 6). It is possible to verify that the model results (Figure 5) and the observed ones are very similar (Figure 6).

Figure 6 – Schematic trajectory of the oil slick emitted when the Prestige sunk. This data was published by Office of Nearshore Surveillance.

In a second stage, these simulations were made using a continuous emission of oil with the aim of defining areas of possible contamination due to leaks from the sunken ship.

8.4 Publishing data in the internet

One interesting feature of this experience was the fact that internet enabled the atmospheric forecast to be made in Santiago de Compostela, the hydrodynamic and oil trajectories' forecasts to be made in Lisboa and the final result to be used by the Office of Nearshore Surveillance located in La Corunha. At the same time the entire world had access to the oil trajectories' forecasts published in the MOHID internet page (Figure 7). In the crisis hottest moments, the number of accesses per day was greater than 1000. This is very large number for a site of technical and scientifical issues.

To help end users cross model data with observed data, a WebGis tool, made using MapServer, was published in the MOHID site (Figure 8).

Figure 7 – Internet site where the oil trajectory forecasts were published (www.mohid.com/Prestige/index.htm).

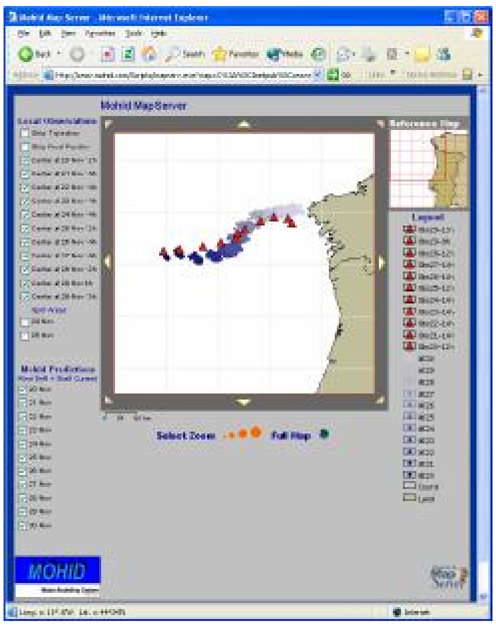

Figure 8 – WebGis published in the MOHID site to help end users cross observed data with model results.

9 Discussion and conclusions

The Prestige is an excellent case to illustrate the potential of an operational system able to forecast weather plus sea conditions. The Spanish authorities realised with this experience that in a crisis situation in open sea, reliable real time data and forecasts are necessary. To access information with the above characteristics, the decision maker needs the support of an operational system, due to the highly variable nature of the atmospheric and ocean systems.

MARETEC/HIDROMOD, together with MeteoGalicia are partners in a Spanish project name SEOMET that aims the implementation of an operational system for supporting emergency situations related with accidents in open sea.

From the Prestige experience it is possible also to conclude that there are two interfaces with an operational system that must be predefined in a crisis situation. These interfaces are with the decision maker and with the public opinion. On one hand, the decision maker needs to act rapidly and to take into account a large number of factors, including operational data (e.g. social, economic and environmental). In this case, the operational system must give to the decision maker reliable information, in a comprehensive format. On the other hand, public opinion (represented by the media) has a large appetite for news, mostly during crisis.

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