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Needs for operational marine services: drift and waves

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Abstract

There is currently an increasing demand for integrated marine meteorological and oceanographic data and services. Operational oceanography products can help improve the behaviour and quality of existing marine meteorological systems: marine pollution drift forecasts, search and rescue operations and sea states forecasts.

The use of products delivered from operational oceanography systems to oil spill and object drift applications is investigated. The evaluation is conducted with the French operational drift forecast system MOTHY and three operational oceanography systems, MERCATOR (Mercator-Océan, France), FOAM (Met Office, UK) and MFS (INGV, Italy).

The present work focuses on evaluating the effects of introducing large scale currents in the MOTHY system. This effect is investigated in the Bay of Biscay, the Caribbean Sea and in the Western part of the Mediterranean Sea. Preliminary results are very encouraging. Operational oceanography products do significantly improve the response capability in two different cases.

1. Introduction

Several European operational oceanography and data assimilation systems have been implemented over the last few years. All these systems use different operational capacities, data streams and expertise. Remote sensing and *in situ* data are acquired and assimilated in state-of-the-art ocean general circulation models to analyse and forecast the 3D state of the North Atlantic, adjacent European Shelf Seas, and the Mediterranean Sea. They aim to support a wide range of scientific and operational services and applications including oil spill monitoring, marine safety as well as the offshore oil industry.

The National Forecasting Centre, at Météo-France, runs an operational service to support the authorities in both oil spill response and search and rescue operations. French operational capacity in oil spill drift forecast is based on Météo-France and Cedre expertise. The core of the service is a trajectory model MOTHY. The system includes local area hydrodynamic coastal ocean models with tidal and real time atmospheric forcing from global meteorological models. Pollutants can be oil or floating objects. MOTHY has been extensively used during the Erika (December 1999) and Prestige (November 2002) crisis in the Bay of Biscay.

The system is also operated for search and rescue operations on demand from the Centres Régionaux Opérationnels de Surveillance et de Sauvetage (CROSS). The motion

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of a drifting object on the sea surface is the net result of a number of forces acting upon its surface (mainly water currents and atmospheric wind). There was a considerable increase in the requests these last years. The key issue in such a service is the rapidity of the response and the ability to use the drift system in any region of the world ocean.

The present work focuses on evaluating the effects of introducing large scale currents in the MOTHY system. This effect is investigated in the Bay of Biscay, the Caribbean Sea and in the Western part of the Mediterranean Sea with operational oceanography systems such as MERCATOR (Mercator-Océan, France), FOAM (Met Office, UK) and MFS (INGV, Italy).

2. Key features of the MOTHY model

The MOTHY model developed by Météo-France is used on an operational basis to predict the drift of pollutants on the ocean surface. It is based on a hierarchy of nested limited domain ocean models coupled to a pollutant dispersion model. The model is driven by tidal forcing specified at the open boundaries and by wind and pressure fields provided by atmosphere models. These atmosphere models can be the IFS model (European Centre for Medium-Range Weather Forecasts) or the ARPEGE model (Météo-France) (Courtier *et al.*, 1991). The system was designed specifically for drift forecasting. Currents are computed using a shallow water model coupled to an analytical turbulent viscosity model with a bilinear eddy viscosity profile (Poon and Madsen, 1991), so as to represent vertical current shear. This approach is particularly well-suited to areas where large-scale currents are negligible (such as in the English Channel or on the continental shelf in the Bay of Biscay). In seas affected by large-scale currents, the results must be reviewed by a forecaster. This is always the case in the Mediterranean Sea, for example, and sometimes necessary for the Spanish coastline in the Bay of Biscay, depending on the place, time, season and year.

The oil slick is modelled as a distribution of independent droplets that move in response to currents, turbulence and buoyancy. Turbulent diffusion is modelled with a three-dimensional random walk technique. The buoyancy force depends on the density and size of the oil droplets so that larger (more buoyant) droplets tend to remain in the surface layer whereas the smaller droplets are mixed downwards (Elliot, 1986). In general, about 65 to 70% of the droplets remain on the sea surface. If a droplet is moved on to land, then that droplet is considered beached and takes no further part in the simulation. A weathering module is also included (Comerma *et al.*, 2002).

The model was calibrated on a few well-documented pollution incidents such as Torrey Canyon, Amoco Cadiz and Tanio (Daniel, 1996). Operated since 1994 in the marine forecast section at Météo-France, it has been used extensively for the Erika (Daniel *et al.*, 2001, 2002) and the Prestige incidents (Daniel *et al.*, 2004). A meteorologist on duty is able to run the model on request. An average of ten interventions each month are conducted in real time.

3. Key features of MERCATOR, FOAM and MFS models

The MERCATOR formulation is based on the primitive equations for the temporal evolution of ocean speed, temperature and salinity in its three horizontal and vertical dimensions. The version used here is the PSY2 prototype (Bahurel *et al.*, 2001). It marks the start of high resolution MERCATOR forecasting for European seas assimilating altimeter and *in situ* data, and then on the basis of this data, generates analyses and forecasts of the three-dimensional state of the ocean in these regions. The model resolution is 1/15 degree with 43 levels unevenly spaced in the vertical and is based on the OPA code (Madec *et al.*, 1998). The model is forced with atmospheric forecast field variables from ECMWF operational products.

FOAM is an ocean and sea-ice model and assimilation system that produces real-time daily analyses and forecasts of temperature, salinity, currents and sea-ice in the deep ocean, for up to five days ahead. A global version of FOAM on a latitude-longitude grid with 1° spacing and 20 levels has produced 5-day forecasts daily in the Met Office operational suite since 1997. A nested model covering the Atlantic and Arctic with a grid spacing of 35 km and 20 levels was introduced into the operational suite in January 2001. Five-day forecasts have been made daily by a nested model covering the North Atlantic with a 12 km grid since April 2002 (Bell *et al.*, 2000).

The Mediterranean Forecasting System (MFS) currently produces ten-day ocean forecasts for the whole Mediterranean Sea once a week (Pinardi *et al.*, 2003). The start day of the forecast is Tuesday at 12:00 each week. The relevant data sets — Sea Level Anomalies (SLA) from altimeters, Sea Surface Temperature (SST) from satellite radiometers, temperature profiles from Ship of Opportunity XBTs — are currently assimilated every week into the model with an intermittent Optimal Interpolation scheme. The model resolution is 1/8 degree with 31 levels unevenly spaced in the vertical and is based upon the Modular Ocean Model code (Pacanowski *et al.*, 1990). The model is forced with atmospheric forecast field variables from ECMWF operational products. Recently, the MOM code has been replaced by the OPA code (Madec *et al.*, 1998).

4. Bay of Biscay: Prestige incident

4.1 Prestige incident

On Wednesday, 13 November 2002, the single-hulled oil tanker Prestige, flying the Bahamas flag, sent a distress call offshore of the region of Cape Finisterre (Galicia, Spain). The tanker was carrying 77000 tons of heavy fuel oil loaded in St. Petersburg (Russia) and Ventspils (Latvia), and was heading to Singapore via Gibraltar. The vessel developed a reported 30 degrees starboard list during passage in heavy seas and strong wind. As the engine was damaged, the ship became out of control and drifted according to the weather conditions. An aerial observation revealed a fuel leak at sea. The ship sank on 19 November after being towed in various directions.

The first slicks reached the coasts of Galicia in the morning of 16 November between La Coruña and Cape Finisterre. Two other oil stranding flows followed in late November and in early December. During December, the northern coast of Spain was touched from Asturias to the Spanish Basque Country. The first slicks impacted the Gijon area (Asturias) on 4 December. Afterwards, stranding of thick, viscous balls, pancakes and various sized patches regularly hit the northern coast of Spain. At the beginning of January, the coast of Galicia was faced with a fourth massive pollutant flow whereas in

Asturias, Cantabria and Euskadi (the Spanish Basque country) these phenomena remained relatively moderate. The French coast was hit near St. Jean de Luz on 31 December. The stranding, at various densities hit Brittany in May and the coast of the Channel in September. In France roughly 2500 km has been affected, the last stranding occurring in October, 11 months after the wreckage.

4.2 Combining MOTHY with MERCATOR

In the Prestige area, MOTHY includes only the wind current. The French MERCATOR system (Mercator-Océan, France) is used here to provide long range currents to the MOTHY system.

For the Prestige shipwreck, we used daily current data from Mercator's high-resolution model. Coupling Mercator surface currents directly to the MOTHY module simulating the oil slick does not represent surface drift properly for two reasons. One is that the current in the model's upper level (3 metres) is much weaker than surface drift. A joint study by Ifremer and Météo-France (Jouan *et al.*, 2001) after the Erika oil spill showed that to use the current in the last level of a 3D model, it is necessary to refine the vertical grid size in the first few metres directly below the surface. The second reason is an operational one. The coupled model must be able to take into consideration rapid changes in the wind and keep constantly up to date. The chosen approach aims to extract from Mercator the information that MOTHY needs and feed it into the current system. It is necessary to take the low-frequency information that MOTHY does not resolve (the large-scale current) and the high-frequency information that Mercator does not reproduce properly (rapid changes in the wind) into account without any overlap.

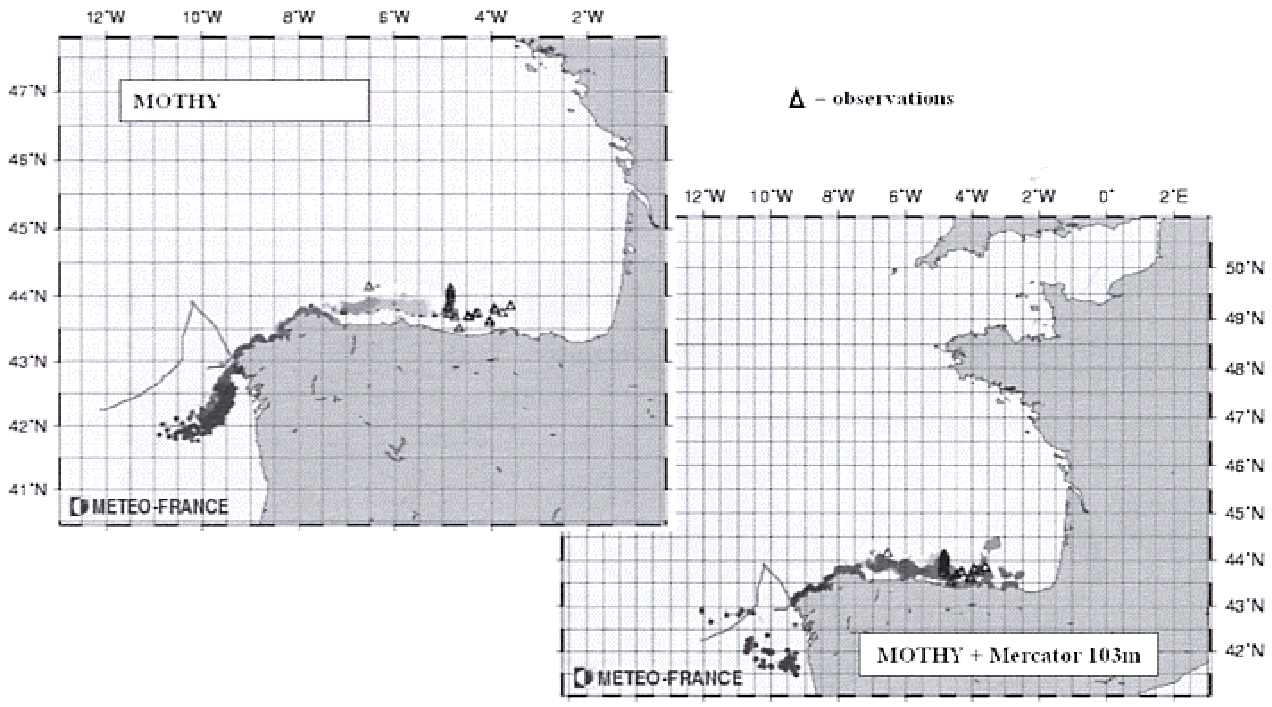

Figure 1 13 December 2002 at 12 UTC. Comparison between a model and *in situ* observation based on a constant leakage along the tanker's trajectory. The MOTHY simulation shows a drift which lags behind the observations. Adding a 103 m Mercator current distinctly improves its performance.

It was decided to use the Mercator current below the layer directly affected by the wind. The 103-metre current appears the most suitable for representing the missing information while remaining unaffected by surface effects. The drift current is thus the sum of the current computed by MOTHY and Mercator's 103-metre current. This first attempt at integrating Mercator currents in MOTHY was carried out during the Prestige disaster and will be enhanced in the future. It is nonetheless a solution that makes the most of national operational means and was used as such by French authorities.

The impact of adding the Mercator high-resolution model's 103 metre current to represent the large-scale current missing from MOTHY is unclear during the first few days of the spill (Daniel *et al.*, 2005) but becomes useful in the Bay of Biscay for longer simulations (Figure 1). Mercator's contribution is visible for long-term simulations in waters where large-scale circulation is negligible. This result is a major progress for oil spill planning since it allows the authorities to be provided with a more accurate view of the possible consequences for the coastline.

5. Caribbean Sea: Polmar trial

An antipollution Polmar exercise was organised on December 8, 2003, in the North-West of Martinique. Fire protection foam was spilled into the sea by the Maïto tug boat of the French Navy. Two drifting buoys provided by Cedre were dropped and the MOTHY model was activated. The two buoys drifted towards the west as far as the south of Jamaica before entering into the Gulf of Mexico (Figure 2), running approximately 2000 miles in three months. A major pollution offshore Martinique could thus be propagated into the entire Caribbean zone at a mean velocity of 1.5 knots.

The potential contribution of operational oceanography products was checked (Chatenet and Giroux, 2004). Adding either the MERCATOR or the FOAM currents to the MOTHY system improves the calculation of the drift, but significant differences exist between MERCATOR and FOAM in this area, in particular on the location of the eddies downwind of the Caribbean islands.

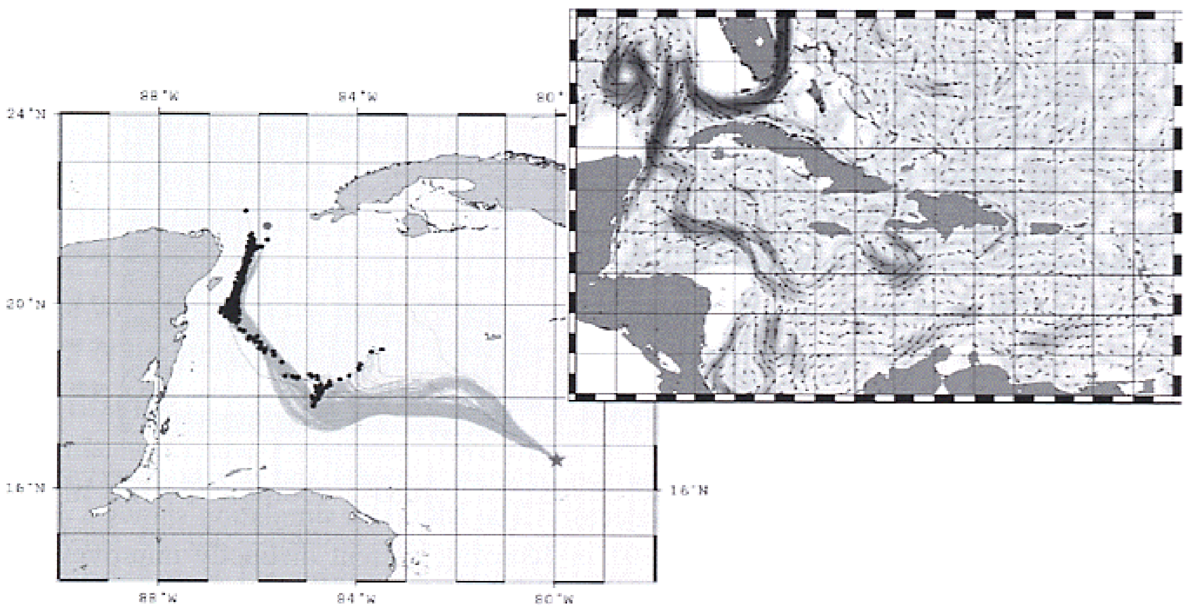

Figure 2 Oil slick drift simulation (trajectory in gray and black droplets) compared with the trajectory of a buoy. Mercator current at 100 m depth.

6. Western Mediterranean Sea

A preliminary study (Lyria incident, 1993) in the Mediterranean Sea based on monthly means from the MERCATOR prototype gave promising results (Daniel *et al.*, 2003). The MOTHY system was interfaced with MFS daily snapshots. The simulations (Daniel *et al.*, 2005) showed that the space-time variability of the currents is difficult to model and has a large impact on the drift.

On 14 December, 2004, a drifting buoy was released during the training exercise LIONMED'04. The buoy is supposed to drift at the same speed as an oil spill. The MOTHY system was interfaced with three operational oceanography systems (MERCATOR, FOAM and MFS) and compared with real measured data (Belleguic, 2005). Again, the three operational models show large differences in the area of interest. None of the combinations is able to reproduce the drift of the buoy (Figure 3).

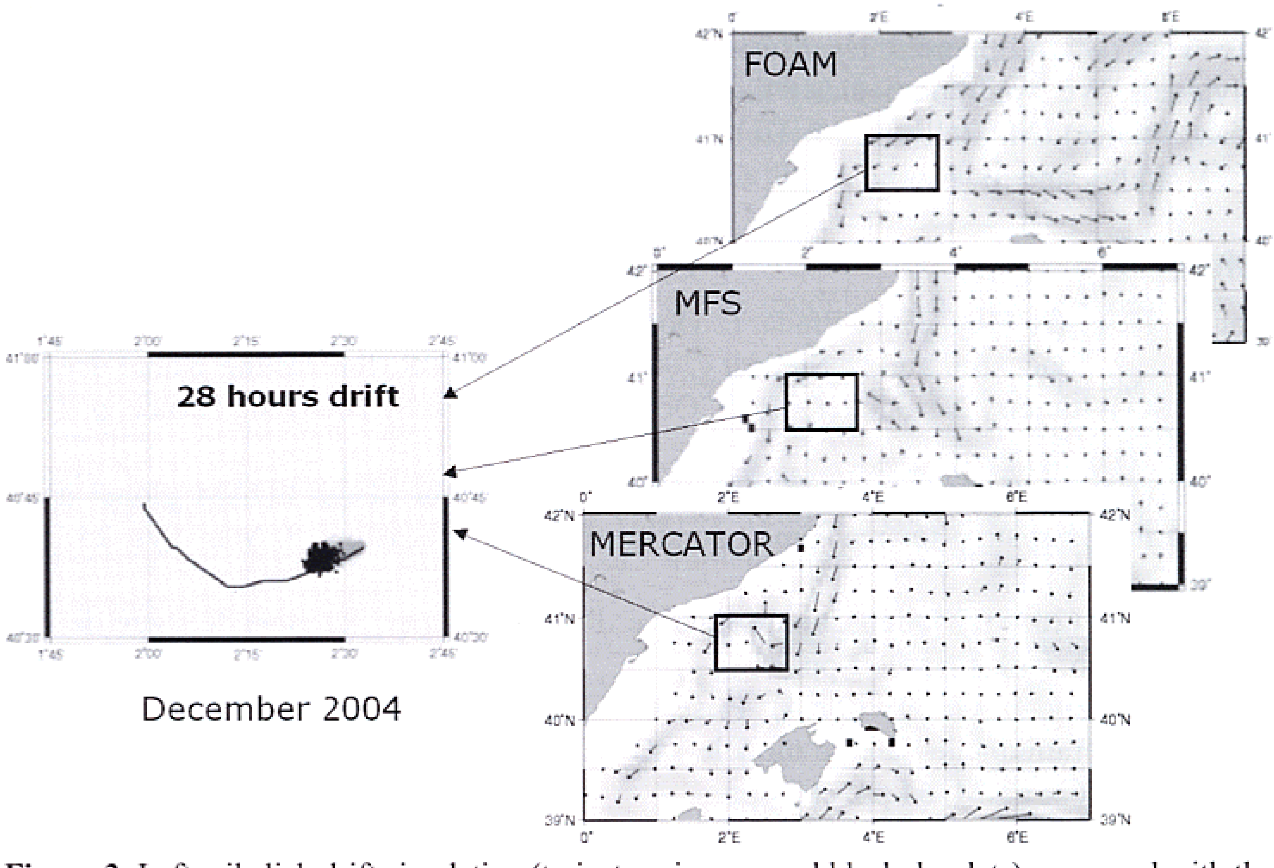

Figure 3 Left: oil slick drift simulation (trajectory in gray and black droplets) compared with the trajectory of the buoy (in black). Right: FOAM, MFS and MERCATOR current at 100 m depth.

7. Waves

Operational oceanography systems may improve wave forecasting through wave/current interaction.

The model system will be interfaced to the real time global and regional MERSEA forecast products, and used to demonstrate the benefit of using forecast products for wave forecasting. In a specific application to the European Seas, areas of discrepancy between observed and predicted waves, as provided by satellite altimeters and sea-state models respectively will be identified. Results will be correlated with surface currents from MERSEA estimates. In a further step, the evaluation of the impact of currents on the sea-state will be performed for a few cases and will be based on sea-state model hindcasts.

8. Conclusion

The reported results are very encouraging. They validate the efforts undertaken by organisations investing in the construction of oceanography systems. This work will be continued as part of the French contribution to Europe's operational oceanography project, MERSEA (Marine EnviRonment and Security for the European Area). It will very likely be crucial to defining specific fields and processing, computing information during the simulation of ocean models, and assessing different filters and combinations prior to supplying these products on an operational basis.

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