Oil spill drift forecast and operational oceanography systems

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Abstract

The use of operational products delivered from operational oceanography systems to oil spill drift applications is investigated. The evaluation is conducted with the French operational oil spill drift forecast system MOTHY and three operational oceanography systems, MERCATOR (MERCATOR-OCEAN, France), FOAM (MetOffice, 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 and in the Western part of the Mediterranean Sea. Preliminary results are most encouraging.

1 Introduction

Several European operational oceanography and data assimilation systems have been implemented for 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 and 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 offshore oil industry.

French operational capacity in oil spill drift forecast is based on Météo-France and Cedre expertises. Drift forecasts rely on a pollutant drift model, named MOTHY. The system includes local area hydrodynamic coastal ocean modelling and real time atmospheric forcing from a global meteorological model. Pollutants can be oil or floating objects. MOTHY has been extensively used during Erika (December 1999) and Prestige (November 2002) crisis in the Bay of Biscay.

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 and in the Western part of the Mediterranean Sea with operational oceanography systems such as MERCATOR (MERCATOR-OCEAN, France), FOAM (MetOffice, 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 limited domain ocean model coupled to a pollutant dispersion model forced by wind and pressure fields provided by an atmosphere model. This atmosphere model 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 to forecast drift. Currents are computed using a barotrope model coupled to a 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 plate of 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 modeled as a distribution of independent droplets that move in response to currents, turbulence and buoyancy. Turbulent diffusion is modeled 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 so-called '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 it is based upon the OPA code (Madec et al, 1998). 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 35km 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 12km grid since April 2002 (Bell et al., 2000).

The Mediterranean Forecasting System (MFS) currently produces ten-days ocean forecasts for the whole Mediterranean Sea once a week (Pinardi et al, 2003). The start day of forecast is Tuesday at 12:00 of 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 it is based upon the Modular Ocean Model code (Pacanowski et al, 1990). Model is forced with atmospheric forecast field variables from ECMWF operational products.

4 Bay of Biscay: Prestige incident

4.1 Prestige incident

On Wednesday, 13th of November 2002, the single-hulled oil tanker Prestige, flying the Bahamas flag, sent a distress call offshore the region of Cape Finisterre (Galicia, Spain). The tanker was carrying 77,000 tons of heavy fuel oil loaded in St Petersburg (Russia) and Ventspils (Latvia), was heading to Singapore via Gibraltar. The vessel developed a reported 30 degrees starboard list whilst on 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 November 19th after being towed towards various directions.

The first slicks reached the coasts of Galicia in the morning on the 16th of November between La Coruña and the Cape Finisterre. Two other oil stranding flow 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 December the 4th. Afterwards, stranding of thick, viscous balls, pancakes and various size patches hit regularly the northern coast of Spain. At the beginning of January, the coast of Galicia 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 the 31st of December. The stranding, at various density hit Brittany, in May and the coast of the Channel in September. In France close to 2 500 km has been touched, the last stranding occurring in October, 11 months after the wreckage.

4.2 Improvement of drift calculation with MERCATOR

In the Prestige area, MOTHY includes only the wind current. The French MERCATOR system (MERCATOR-OCEAN, 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 last 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 have (the large-scale current) and the high-frequency information that Mercator does not have (rapid changes in the wind) into account without any overlap. 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 (Fig. 1) but becomes useful in the Bay of Biscay for longer simulations (Fig. 2). Mercator's contribution is visible for long-term simulations in waters where large-scale circulation is negligible.

Figures 1 show three simulated drift of a continuous leak of fuel oil along the trajectory taken by the Prestige from 13 November at 14 UTC: drift with Mercator current at 3 m (fig. 1a), with operational model MOTHY (fig. 1b), with operational model MOTHY + Mercator (current at 103 m) (fig. 1c). The satellite image of 17 November at 11 UTC shows the oil in black. The two branches formed because the sea broke the fuel oil up into two products of different density: the southern branch drifted along on the surface and the northern branch underneath the surface. The simulation did not take this dissociation into consideration. The colour of the simulated drift depends on the time spent in the water following the leakage. It ranges from dark blue for the spill of 13 November to white then red on 17 November. The ship's trajectory is shown by a red line with arrows on it. The areas where Mercator improved performance are circled in green. The areas where MOTHY was more accurate without Mercator are circled in red.

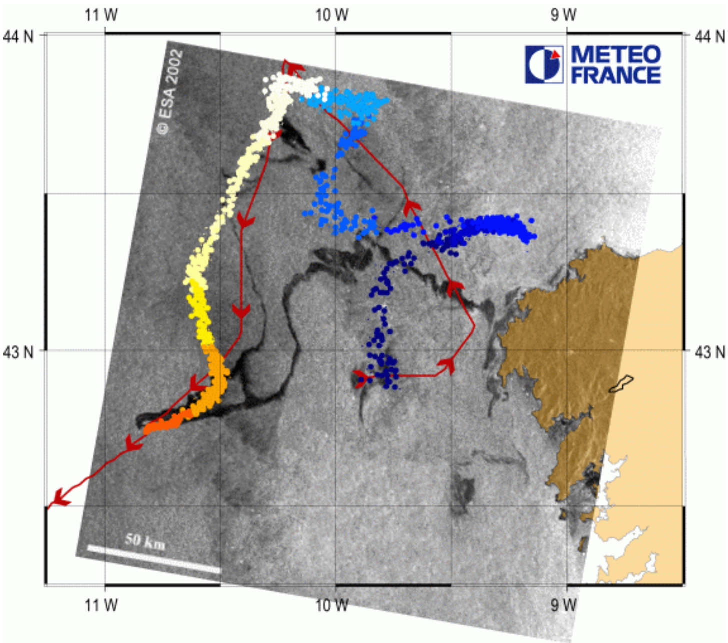

Figure 1 (a) : Drift with Mercator current at 3 m

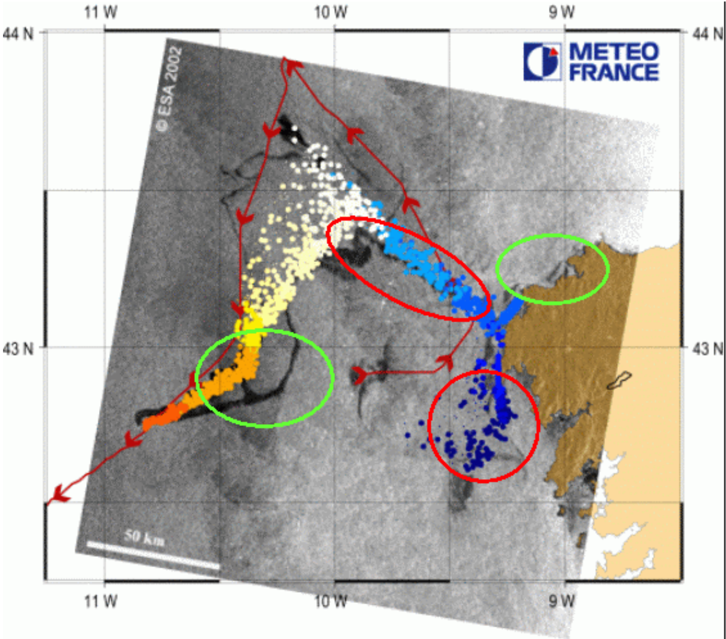

Figure 1 (b) : Drift with operational model MOTHY

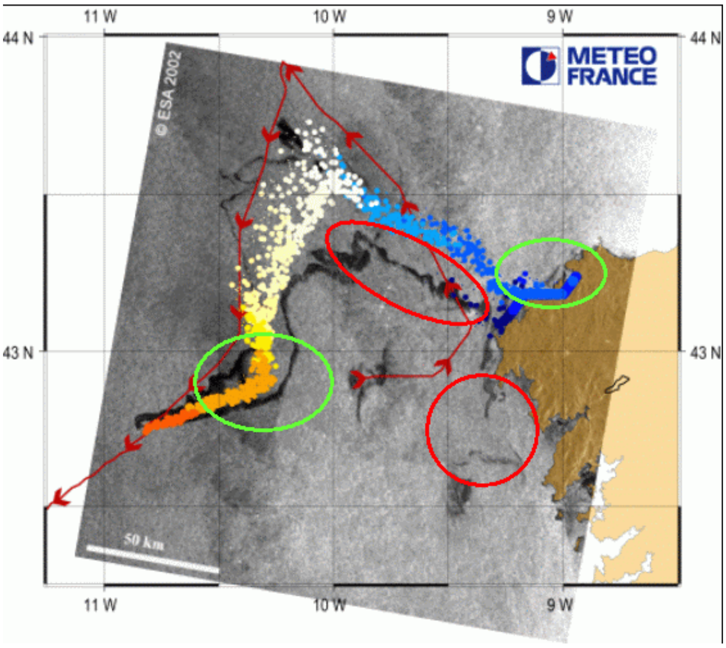

Figure 1 (c) : Drift with model MOTHY + Mercator (current at 103 m)

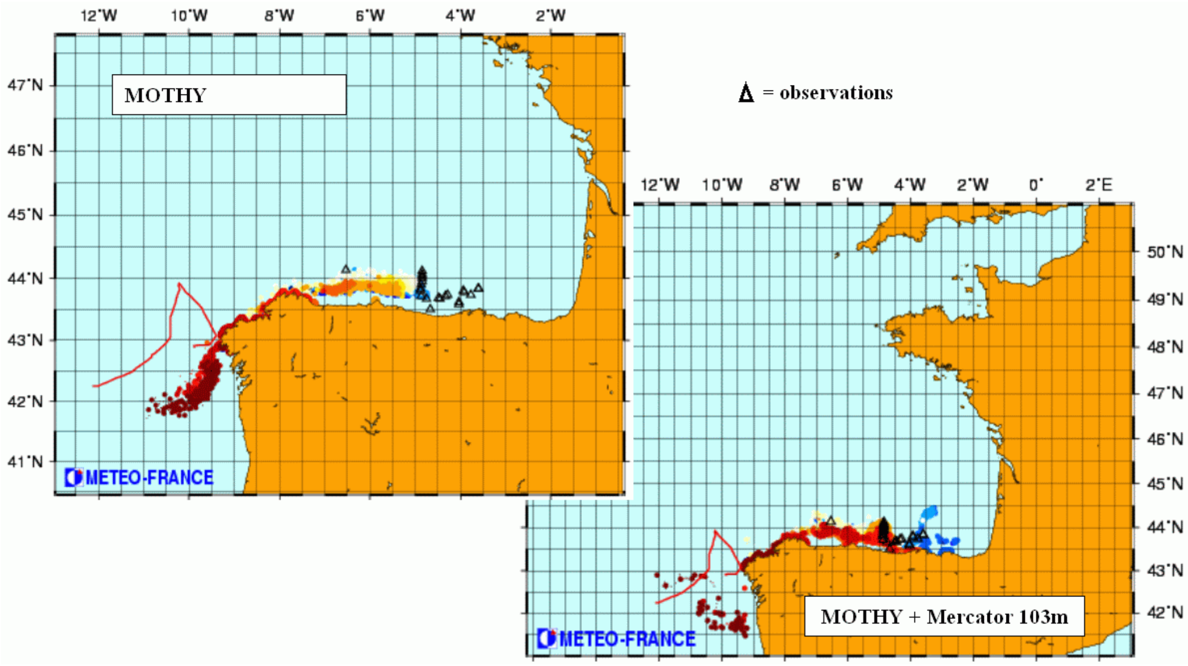

Figure 2: 13 December 2002 at 12 UTC. Comparison between a model and in situ observation based on a constant leakage along the tanker's trajectory (shown in red). MOTHY is behind the times. Adding a 103 metre Mercator current distinctly improves its performance.

4.2 MERCATOR and FOAM comparison

The FOAM system (MetOffice, UK) is used here to provide long range currents to the MOTHY system.

It was decided to use the FOAM current below the layer directly affected by the wind. The 96-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 FOAM's 96-metre current. MERCATOR and FOAM currents show large differences (figure 3). However, in terms of drift, differences are not as large (figure 4).

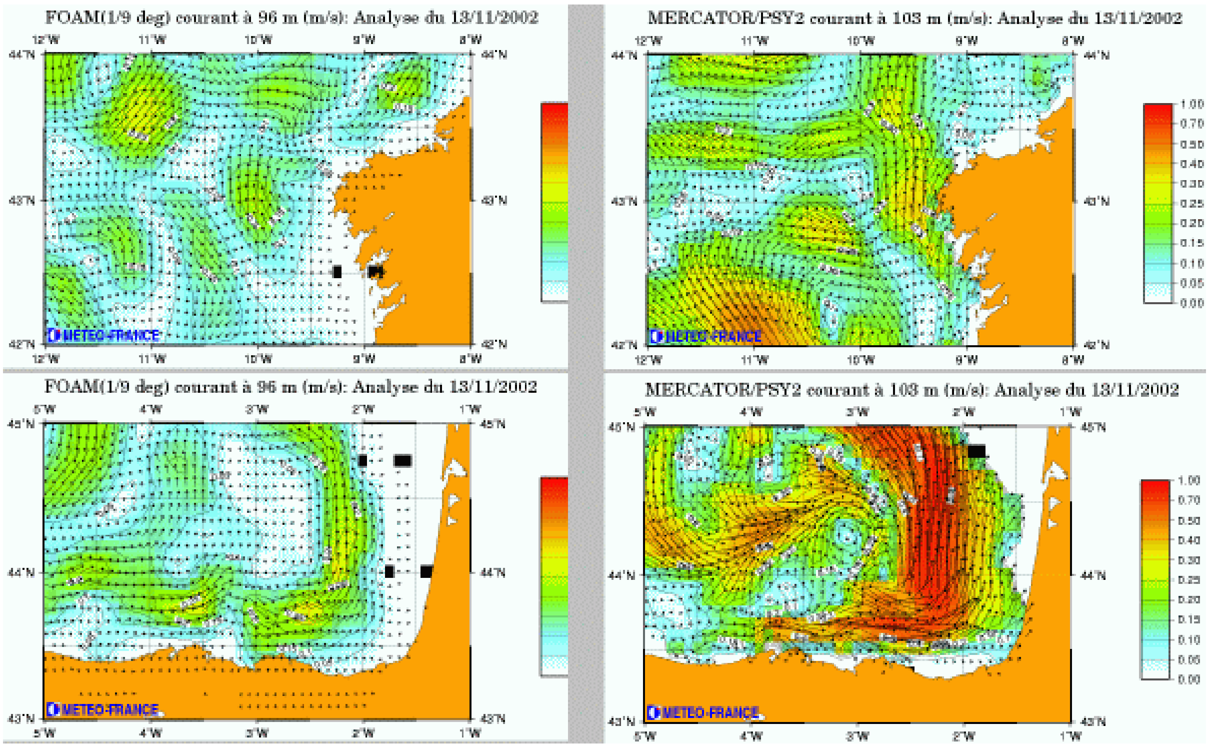

Figure 3: 13 December 2002. Comparison of FOAM current at 96 m depth and MERCATOR current at 103 m depth, in two areas: offshore Galicia and in the Bay of Biscay.

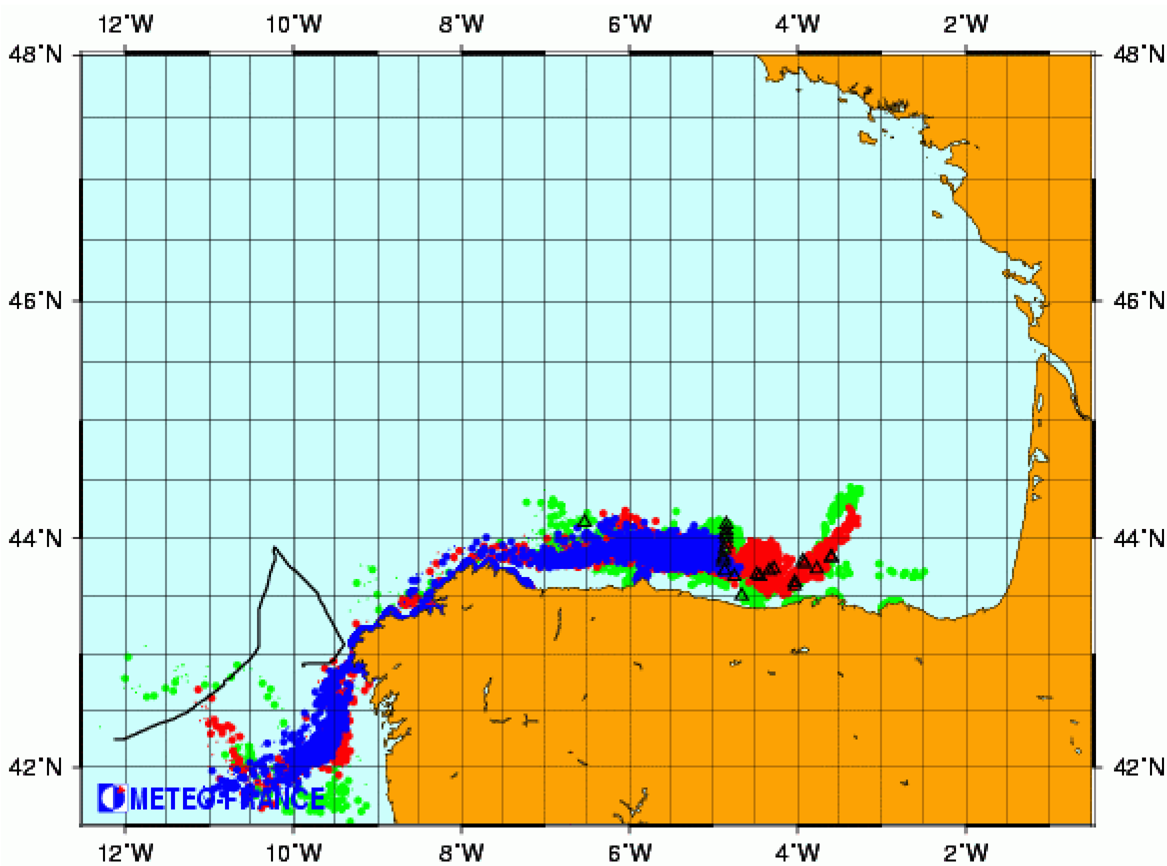

Figure 4: 13 December 2002 at 12 UTC. Comparison between models and in situ observation based on a constant leakage along the tanker's trajectory (shown in black). MOTHY is in

blue. MOTHY+Mercator in green and MOTHY+FOAM in red. Black triangles are the observed slicks.

5 Western Mediterranean Sea: Lyria incident

A preliminary study in the Mediterranean Sea based on monthly means from the Mercator prototype gave promising results (Daniel et al, 2003). Here, the MOTHY system has been interfaced with MFS daily snapshots.

On August 1993, the 2,400-ton submarine Rubis collided with the 278,000 dwt 1,115-foot long oil super-tanker Lyria some 70 miles south of Toulon, tearing a hole in the tanker and causing an oil slick. The submarine damaged its bow. The spilled oil drifted for three weeks without reaching any coast. Daily observations are available for the whole period. The main conclusion is that the addition of an information on the basin scale circulation derived from operational oceanography systems is required to simulate the behaviour of the spills. The impact of the climatology and MFS currents is similar, with better results with the climatology during the first part of the drift (Fig 5) and with MFS for the second part (Fig.6).

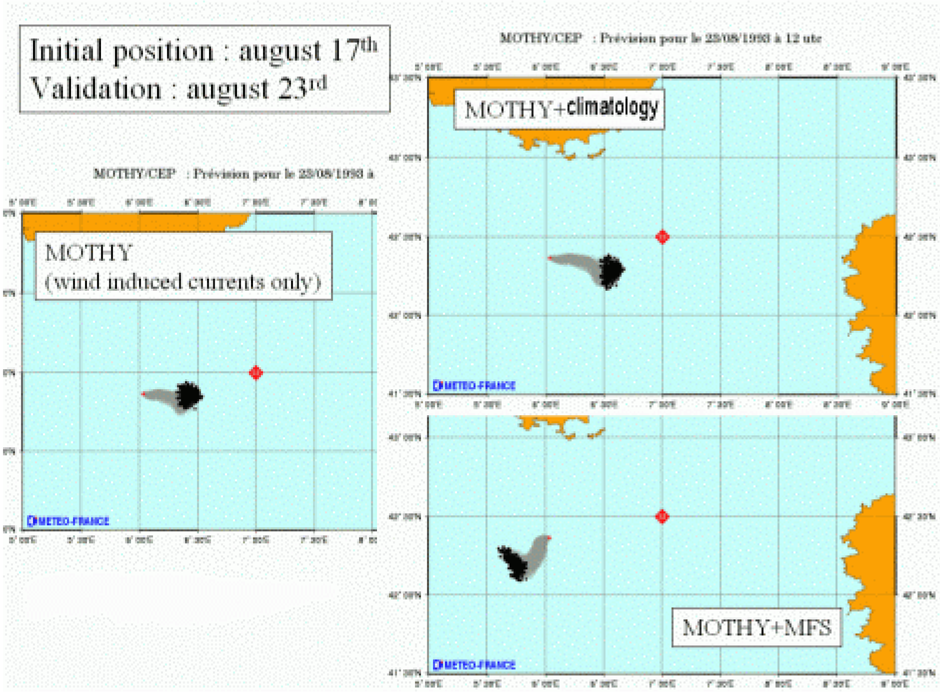

Figure 5: The red star is the starting point (August 17th), red diamond is the observation on August 23rd, black spots figure the final position of the slick for August 23rd.

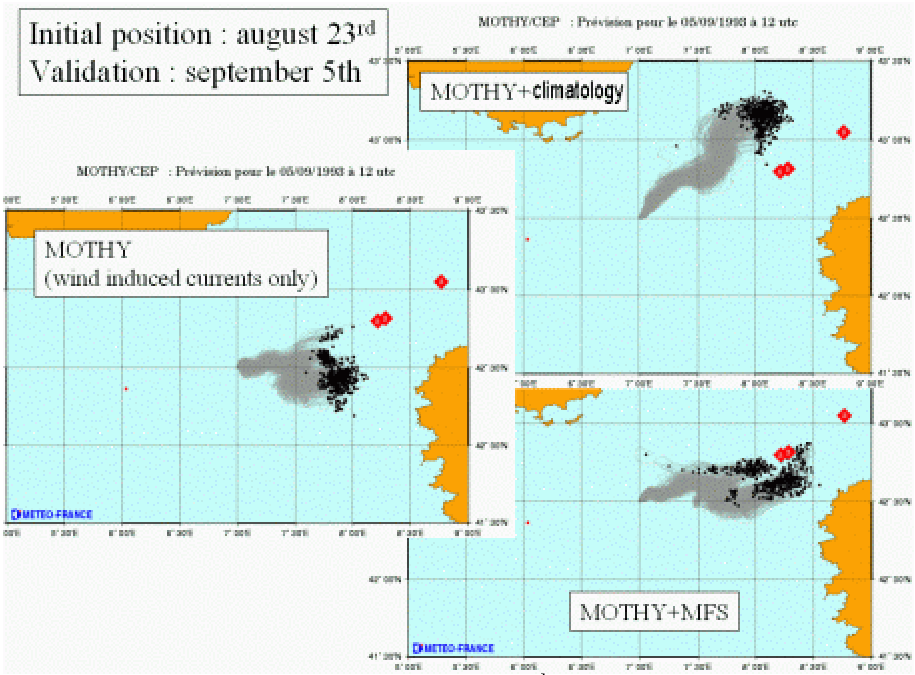

Figure 6: Simulations start on August 23rd. Red diamond is the observation on September 5th, black spots figure the final position of the slick for September 5th.

6 Conclusion

These results are most encouraging. They validate the efforts undertaken by organizations 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) Strand-1. To perfect these first attempts, it will very likely be crucial to define specific fields and processing, to compute information during the simulation of Ocean's models, and to assess different filters and combinations prior to supplying these products on an operational basis.

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