Impact of operational ocean forecasting on improvement of oil spill drift modelling in Météo-France

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SYNOPSIS

Operational drift prediction of oil spills, spills of hazardous materials and floating objects for search and rescue operations are among services operated by Météo-France Marine Prevision Department. Recent significant developments in operational ocean forecasting created an opportunity to improve the quality of drift prediction by using the operational analysis and forecasts of oceanographic processes. Number of case studies in Atlantic Ocean, Bay of Biscay, Caribbean Sea and Mediterranean Sea demonstrate good results in reproducing drift of floating objects and oil spills when using ocean currents simulated by operational ocean prediction systems. Some difficulties on this way arise from differences in the spatial and time scales of processes as simulated by existing operational oceanography systems such as MERCATOR (Mercator-Ocean, France), FOAM (MetOffice, UK), TOPAZ (NERSC, Norway), MFS (INGV, Italy) or HYCOM (Univ. of Miami, USA) and these required for the accurate drift prediction. Special case of large uncertainties and errors in drift modelling could emerge also in the sea current divergence zones.

INTRODUCTION

The National Forecasting Centre at Météo-France runs an operational service to support the authorities in both the oil spill response and search and rescue operations. French operational capacity in the oil spill drift forecasting is based on the 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 operational atmospheric forcing from global meteorological models. 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 system is also operated on demands of the *Centres Régionaux Opérationnels de Surveillance et de Sauvetage* (CROSS) for support of the search and rescue operations. There was a considerable increase in the requests these last years. The essential 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 motion of oil and drifting objects on the sea surface is the net result of a number of forces, mainly ocean currents and atmospheric winds. Development of European operational oceanography and data assimilation systems during last few years made it possible to use the results of global and regional ocean analysis and forecasts in real time for improvements of existing drift prediction services. All these systems use different operational capacities, data streams and expertise. Remote sensing and in-situ data are acquired and assimilated by state-of-the-art ocean general circulation models. Models produce analyses and forecasts of the 3D state of the Global Ocean, 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 offshore oil industry. The efforts of the authors are directed on finding solution for optimal merging of best features of available prediction systems: 3D ocean circulation patterns reproduced by eddy resolving global ocean models, and high frequency surface current variations caused by corresponding wind and tidal variability that could be reproduced by existing drift models.

The present work focuses on evaluating the effects of introducing large scale currents in the MOTHY system. This effect is investigated in the Atlantic Ocean (West Indies), the Bay of Biscay, Caribbean Sea 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).

MOTHY DRIFT SIMULATION 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. Model is driven by tidal forcing specified at 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[1] (Météo-France). The MOTHY 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 following Poon and Madsen[2], 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 with significant large-scale currents, a forecaster must review the results. 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 those larger (more buoyant) droplets tend to remain in the surface layer whereas the smaller droplets are mixed downward (Elliot[3]). 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[4].

The model was calibrated on a few well-documented pollution incidents such as Torrey Canyon, Amoco Cadiz and Tanio as described by Daniel[5]. Operated since 1994 in the marine forecast section at Météo-France, it has been used extensively for the Erika[6,7] and the Prestige incidents[8]. A meteorologist on duty is able to run the model on request. About twenty interventions each month are conducted in real time.

OUTLINE OF MERCATOR, FOAM AND MFS EUROPEAN OPERATIONAL OCEANOGRAPHIC SYSTEMS

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 PSY2v1 prototype[9]. 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[10]. Model is forced with atmospheric forecast field variables from ECMWF operational products.

Other choice is the global operational PSY3 version of Mercator-Ocean system. All results are available on-line from the Mercator-Ocean OPeNDAP (DODS) server. Two weeks analysis and two weeks forecasts are generated once a week.

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 12 km grid since April 2002[11]. Operational data are also available on-line (GADS server).

The Mediterranean Forecasting System (MFS) currently produces ten-days ocean forecasts for the whole Mediterranean Sea once a week[12]. The relevant data sets (sea level anomalies from altimeters, sea surface temperature from satellite radiometers, temperature profiles from Ships of Opportunity XBTs) are assimilated 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[13]. The atmospheric forcing are the forecast fields of the ECMWF.

DRIFT CASE STUDIES

Atlantic Ocean wave buoy "Guadeloupe" drift simulation

July 3, 2005 a wave recorder, buoy "Guadeloupe", anchored East of Guadeloupe island at 16.4N and 60.9W after some accident was detached from the anchor and started to drift in Atlantic Ocean. It quickly moved to the North - North - East direction, not consistent with prevailing Eastern trade-wind. Buoy drift was tracked during more than 70 days, until September 11, 2005 using its ARGOS transmission system (Fig 1, red trajectory). This drift was simulated by MOTHY object drift prediction model with sea currents represented by Mercator-Ocean surface currents and Météo-France ARPEGE wind. Total drift time was divided in seven 10-days intervals and modelling was performed from observed buoy positions at the start of each interval. Simulated trajectories for ensemble of seventeen model objects are plotted by grey lines starting from intermediate start points marked by stars on the Fig 1. As it could be seen on the Fig 1, first, second and third simulation stages correspond rather well to observed drift with total error reaching about 100 - 200 km after 10 days of simulation. It clearly demonstrates nice quality of Mercator-Ocean sea surface current simulation results, which represent well the local eddy structure of ocean circulation. On the second stage (July 13 - July 22) total drift distance was overestimated, on the third stage (July 23 - August 1) it was underestimated when generally well reproducing the complex drift track shape. However, for the following fourth, fifth and sixth stages there are significant discrepancies between the observed drift and model results. The reason for that could be clarified analysing the Mercator-Ocean sea surface currents patterns on the Fig 2.

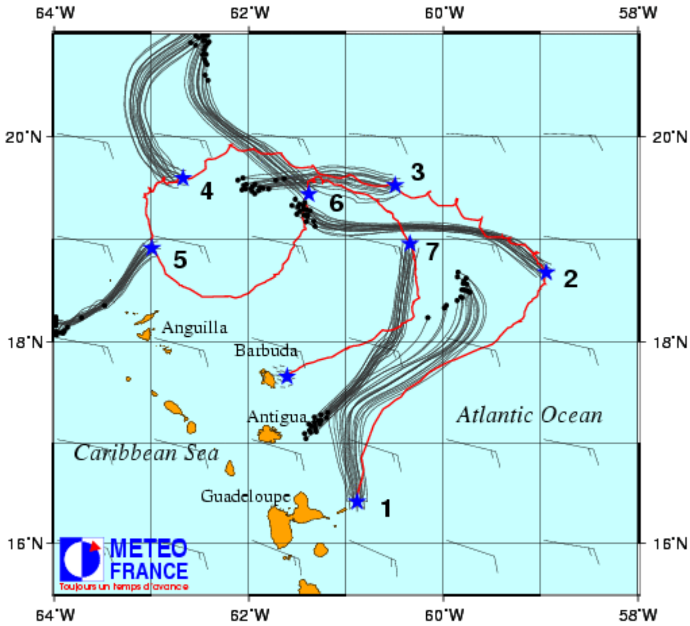

Fig 1 Observed drift of wave buoy "Guadeloupe" for July 3 - September 11, 2005 (red line) and its simulation (grey lines)

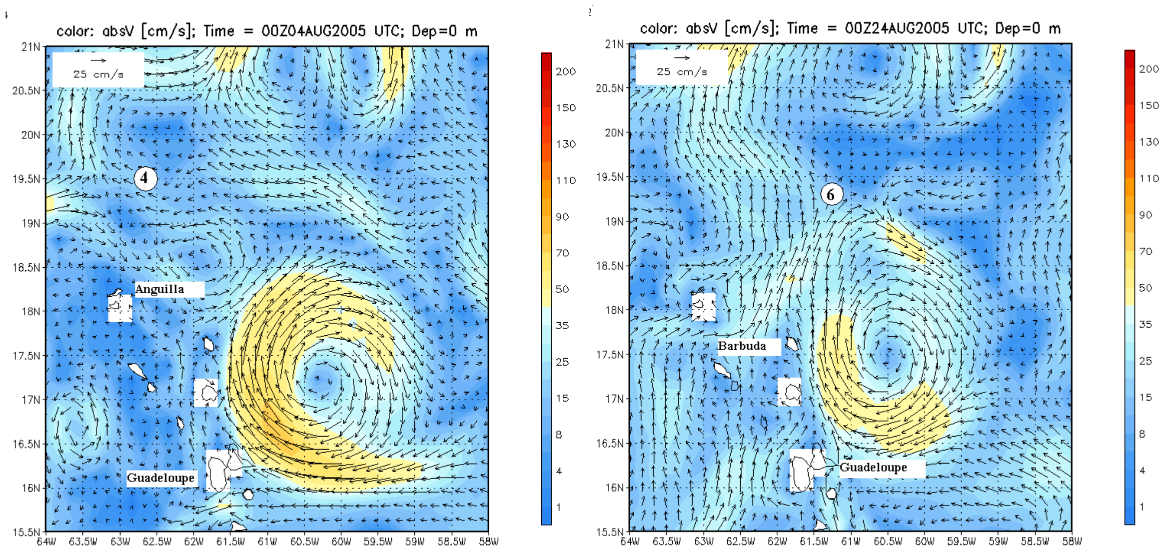

Fig 2 Mercator-Ocean surface sea current for August 4, 2005 (left panel) and August 24, 2005 (right panel)

According to the first map, August 4, 2005 drifting wave buoy was in the sea currents divergence zone between a weak cyclonic ocean eddy in the south and an anticyclonic eddy in the north. Buoy location is approximately marked by white circle with model stage number "4". Deterministic simulation in this case resulted in the northward drift in a northern anticyclonic eddy circulation, when in reality buoy drifted to the south. That could be explained by its connection to the southern cyclonic eddy circulation. Very similar situations were found for stages 5 and 6 of simulation. For example, at the start of the stage 6 wave buoy also went into the sea currents divergence zone (Fig 2, right panel) and in present simulation it was trapped by a northward sea current. According to actual observations, the buoy moved to the south-east by currents system of the south-ward anticyclonic ocean eddy. These examples demonstrate the large uncertainty in drift prediction when the drifting object enters into a current divergence zones. In addition, we have to keep in mind uncertainties that exist in modelling of mesoscale ocean eddies. A possible solution here is the estimation of drift simulation uncertainties by some kind of ensemble predictions and making use of qualified experts before delivering the final drift prediction to end-users. As an example, combining production of different operational oceanographic centres could create the ensemble of ocean forecasts. The MOTHY drift prediction model does the ensemble object drift simulation assuming some uncertainty in object initial position, buoyancy and geometrical properties. Possibly, an initial model tracers dispersion have to be the function of the ocean current spatial structure so counting for the uncertainty of ocean current presentation.

Bay of Biscay: Prestige incident

Prestige oil spill 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 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 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.

Combining MOTHY with MERCATOR

In the Prestige area, initial version of MOTHY model considers only the wind current. The Mercator-Ocean system was used here to provide background ocean currents for the drift simulation.

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[14] 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 an 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[15] but becomes useful in the Bay of Biscay for longer simulations (Fig 3). Mercator's contribution is visible for long-term simulations in waters where large-scale circulation is negligible.

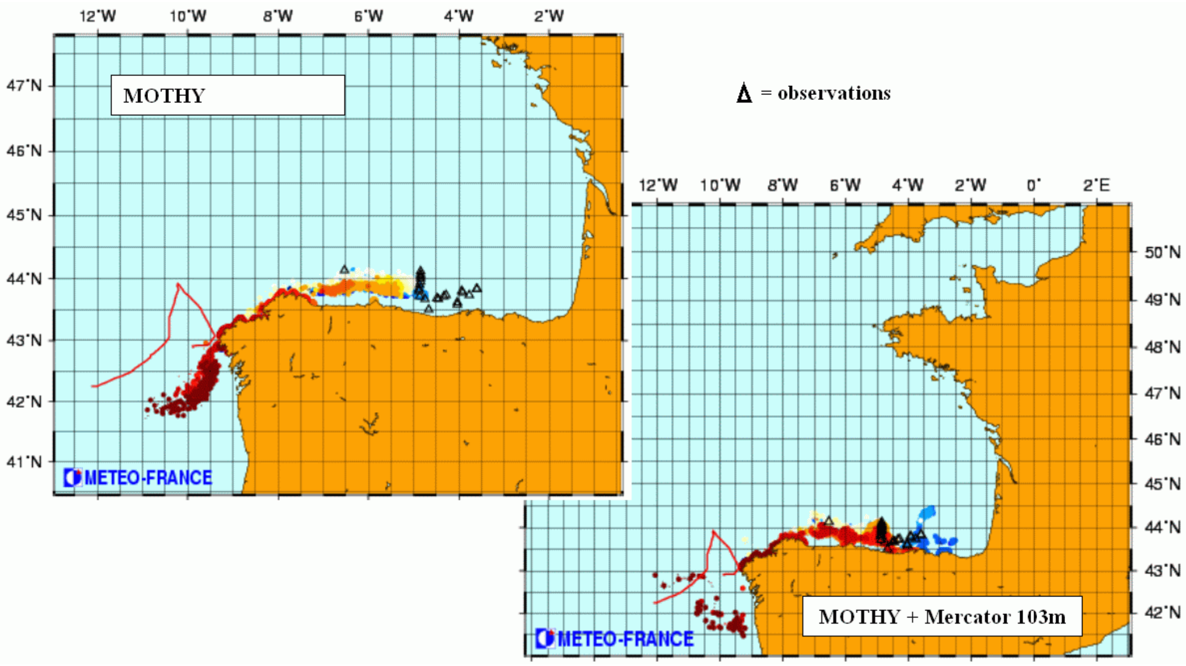

Fig 3 13 December 2002 at 12 UTC. Comparison between model and in situ observation based on a constant leakage along the tanker's trajectory (shown in red). MOTHY is behind the times. Adding a 103 m Mercator current distinctly improves its performance.

Caribbean Sea: POLMAR trial

A Polmar exercise was organized on December 8, 2003, in the North-West of Martinique. Fire protection foam was spilled into the sea by the Maïto tugboat 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 until the south of Jamaica before entering the Gulf of Mexico (Fig 4), running approximately 2 000 miles in three months. A major pollution offshore Martinique could thus be propagated in all the Caribbean zone at a mean velocity of 1.5 knots.
The potential contribution of operational oceanography products was checked[16]. Adding either the MERCATOR or the FOAM currents to the MOTHY system improve the calculation of the drift. However, significant differences exist between MERCATOR and FOAM in this area, in particular on the location of eddies downwind the Caribbean islands.

Western Mediterranean Sea

A preliminary study (Lyria incident, 1993) in the Mediterranean Sea based on monthly means from the MERCATOR prototype gave promising results[17]. Then the MOTHY system was interfaced with MFS daily snapshots. The simulations[18] showed that the space-time variability of the currents is difficult to model and has a large impact on the drift.
On December 14, 2004, a drifting buoy was released during the training exercise LIONMED'04. The buoy is supposed to drift at the same speed than an oil spill. The MOTHY system was interfaced with three operational oceanography systems (MERCATOR, FOAM and MFS) and compared with real measured data[19]. Again, the three operational models show large differences in the area of interest. None of the combinations was able to reproduce the drift of the buoy (Fig 5).

CONCLUSION

Reported results of drift simulations in different parts of the Word Ocean demonstrate that production of operational oceanographic systems is invaluable for these purposes. It helps significantly expand the areas where it is possible to make successful surface drift prediction from traditional coastal zones to the open global ocean. Same time there are still a number of problems and no single and simple solution for merging and use of operational oceanographic products and existing drift models. In some cases, like in divergence zones of oceanic currents, the uncertainties in drift prediction could be quite large and today the human expertise is still an important stage in delivering the drift prediction results to the end-users. In addition, realisation of different ensemble simulation approaches could help in future improvement of oil spill and floating objects drift prediction and in estimations of its uncertainties.

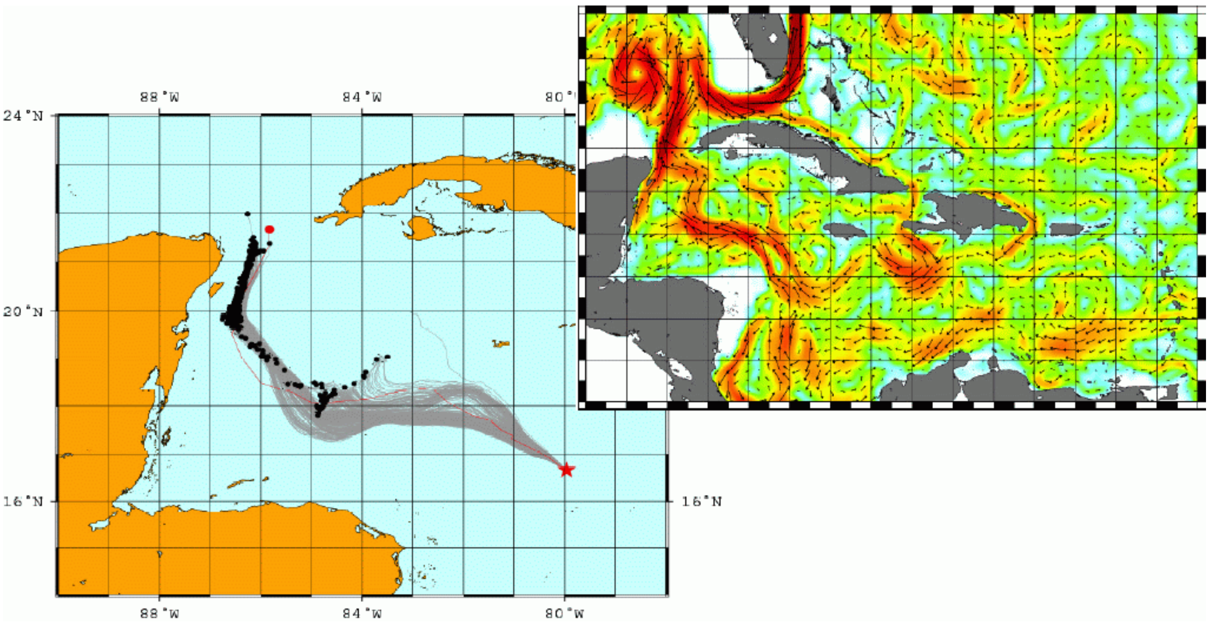

Fig 4 Oil slick drift simulation (trajectory in gray and black droplets) compared with the trajectory of a buoy (in red). Mercator current at 100 m depth.

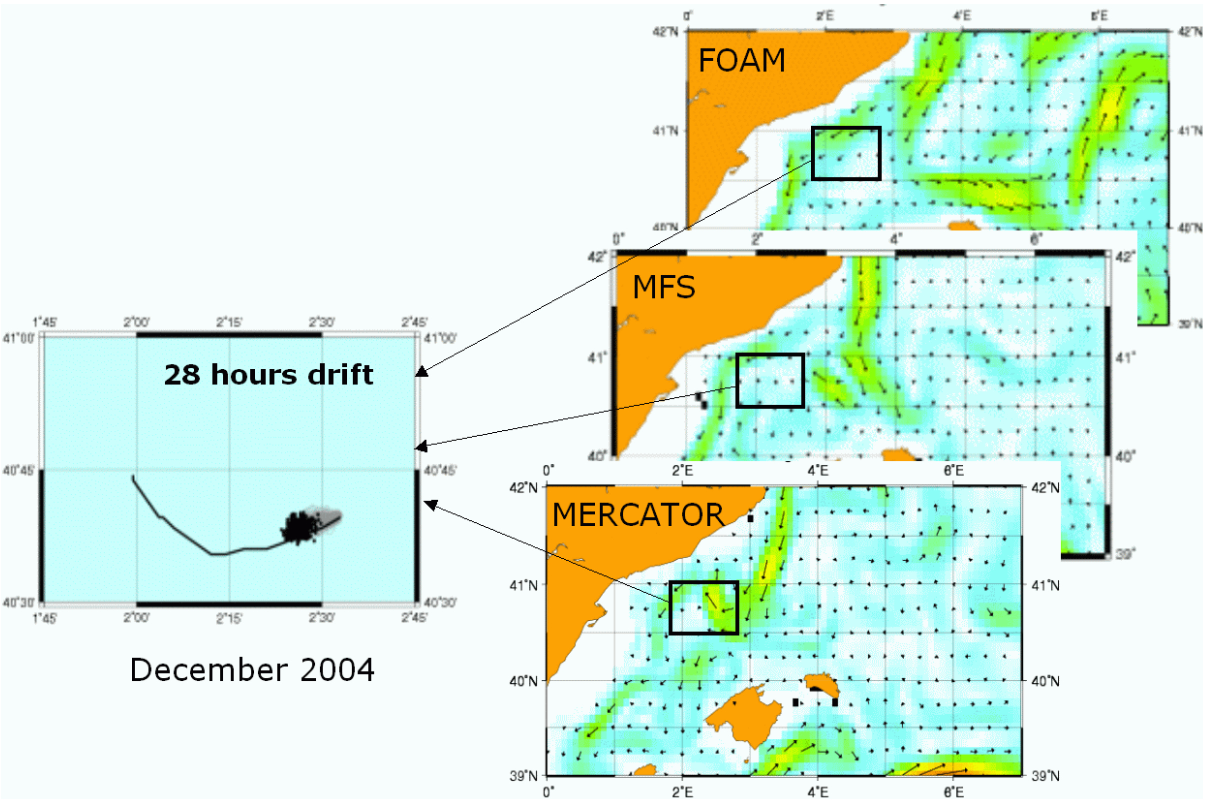

Fig 5 Left: oil slick drift simulation (trajectory in gray and black droplets) compared with the trajectory of the buoy (in black). Right: FOAM, MFS and MERCATOR current at 100 m depth.

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