# Forecasting the Prestige oil spills

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## Abstract

On November 13th 2002 the tanker Prestige was off the coast of Galicia, Spain, when it suffered severe structural failure of the starboard cargo tanks. The ship was tugged away from the coast. On November 19th, the vessel broke into two sections at about one hundred and thirty miles from the Galicia coast. The two parts of the wreck sank at a 3500 meters depth. More than 60,000 tons of heavy fuel were released into the marine environment. At sea containment and recovery, and aerial surveillance of the oil, were hampered by the weather and the oil remained at sea for a considerable period of time. Diffuse pollution was still reaching the coastline more than six months after the break.

In France, a technical committee gathering experts of Cedre, Météo-France, IFREMER and SHOM was implemented. The drifting committee was in charge to provide daily the Préfet Maritime with coherent and relevant elements on the drift of the oil, both observations and forecasts. Thus, the oil spill drift model MOTHY has been used routinely for several months.

The paper presents the organization of the forecasts, the new implemented tools such as probabilistic forecasts and long range hindcasts, and an evaluation of the relative influence of the components of the current (wind, tide, wave, large scale).

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# Discussion

## 1. Prestige incident

### 1.1 First operations

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 and so requested the partial evacuation of the crew. Twenty-four of the twenty-seven crew members were evacuated by helicopter while the captain, the first mate and the chief mechanic stayed aboard. 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.

All night long, the tug boats Ria de Vigo, Alonso de Chaves, Charuca Silveira and Ibaizabal I from the Sociedad de Salvamento y Seguridad Maritima (SASEMAR), the Spanish organization in charge of the sea rescue and pollution control, tried to tow the oil tanker. On November 14$^{th}$, the Prestige was towed by Smit Tak. The ship sank on November 19$^{th}$ after being towed towards various directions (Fig. 1).

### 1.2 Oil combating at sea

On November 14$^{th}$, the Biscay Plan, a Franco-Spanish mutual assistance agreement in case of maritime disaster, was activated. Nautical and aerial means from the French Navy and Customs were immediately sent in Galicia under the authority of the Spanish authorities. Other European means were also called for help and a task force of 20 planes and helicopters, and 23 Spanish and 13 European recovery vessels were involved on December 10$^{th}$. By the end of December, 29 planes and helicopters, among which 26 were Spanish, were at work. The maritime operations next to the coasts of Galicia and Cantabria was composed of 36 ships : 23 Spanish and 13 European ones. Since the 23$^{rd}$ of January 2003, the Euskadi fishing fleet brought its determination and more than 200 boats/day Operated off the Euskadi coasts.

### 1.3 Shoreline pollution

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 4$^{th}$. 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.

## 2. Physico-chemical characteristics and weathering of the fuel oil spilled.

The oil transported by the Prestige was a heavy fuel, used for two kinds of applications: the industrial combustion (oil-fired power stations, furnaces, cement works) and the supplying of ships propelled by powerful slow diesel engines. The water content of the fuel aged at sea reached 60% with a viscosity of 100,000 cSt at 15°C and a measured density of 1,01. The original slicks of heavy fuel oil (hundreds of tons each) drifting at sea broke into pieces weeks after weeks and segregated into patches ( up to a few meters diameter) , pan cakes (0, 1 to 1 meter diameter, discs (up to 10 cm diameter), and finally pellets (up to a few centimeter diameter). As an illustration, in the summer (more than 8 months at sea) Brittany was hit by pellets and pan cakes and disks.

## 3. Cedre and Météo-France roles

French response capabilities in case of accidental water pollution are based on Cedre's expertise , acting as technical adviser for the administration in charge of the operations. As a non-profit association under the Ministry of the Environment, Cedre acts for national organizations (such as the French Navy or Civil Security) or for private companies (oil and chemical industries, and shipping companies). Cedre is also a member of the E.U. Task Force team, to assist European Union and foreign governments in response to accidental pollution.

Météo-France is the French national weather service, in charge of atmophere and surface ocean observation and forecast. In cases of marine pollution, Météo-France informs Cedre of the probable trajectory of the pollutants to help the authorities to organize the response as well as possible. The drift forecast is carried out by means of a numerical model, named MOTHY, describing the ocean dynamics and the physicochemical behavior of the pollutant. Forecasts strongly depend on the initial conditions, and therefore on the position of the slicks. Slicks are located at sea by aerial surveillance managed by the Préfet Maritime.

As soon as the accident was known on November the 13th, Cedre and Météo-France activated their response centers. They were mobilized by the Préfet Maritime of the Atlantic to assess the risks and to prepare drift forecast charts. The National Drift Committee (NDC) composed by representatives of the French Navy, Météo-France, IFREMER, SHOM and Cedre) was activated the 25th of November after a decision of the French Secretariat of the Sea, depending directly from the prime Minister, and operated in Cedre facilities. The NDC gathered every day during four months and produced daily situation reports dispatched to the authorities (Fig. 2).

On the 3rd of December, the maritime Préfet of the Atlantic activated the Plan Polmar mer in order to gather all the means from various administrations and from the private sector to organize and put in action the fighting operation at sea.

## 4. **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 (1999) incident (Daniel et al, 2001, 2002). A meteorologist on duty is able to run the model on request. Five to ten interventions each month are conducted in real time.

## 5. Prestige slick drift forecast

### 5.1 Short range predictions

Accurate slick drift information is essential to help to the pollution recovery at sea and to prepare the response on the coastline. From November the 13th, Cedre and Météo-France started producing drift forecast charts for the Préfet Maritime of the Atlantic. At the request of SASEMAR, Cedre was also preparing a daily position chart of the hydrocarbons observed at sea. On November the 18th, a SASEMAR engineer joined the map-making unit situated in Brest for an urgent technology transfer. From this date, SASEMAR produced daily a position chart of the observed pollution.

### 5.2 Long range analysis and predictions

Our experience with the Erika incident lead to the development of new tools. At the time of the Erika incident, diffuse pollution reached the coastline 2 days before the main slicks, about 200 km east of the main beaching. At the time of the beaching, it was difficult to explain the original location of that oil. Now, we know that a part of the fuel was not observed under very bad weather conditions and it is also probable that part of the cargo leaked from the wrecks and perhaps even before the break up of the ship. This reflects a major difficulty in observation and analysis, and highlights the need for reconsidering and organizing these aspects. This is why we set up two specific analysis. The first is a continuous release from the initial one on November 13th to the sinking on November 19th. The second assumption is a continuous release from the wreck, starting on November 19th.

These simulations in hindcast mode where very useful to keep in mind where the oil might be found. An example is shown here (Fig. 3). On January 8th, the simulation of a continuous release from the wreck shown a possible important concentration of oil in an area where there was not any fly over. The drift expert team proposed an overflight to the observers onboard the observation aircrafts. This overflight was successful: observers found large amount of oil in this particular area. This example illustrates the type of difficulties that such crises can generate, requiring an extreme vigilance of the actors implied in the fight.

### 5.3 Probabilistic forecast

The quality of slick drift forecasts depends primarily on the reliability of weather forecasting. The traditional method of making a weather forecast is to take the best model available and run it until it loses it's skill due to the growth of small errors in the initial conditions. Skill is typically lost after 5 days or so, depending on the season. An alternate method that produces forecasts with skill up to 10 days after the initial forecast uses what is called "ensemble forecasting". Instead of using just one model run, many runs with slightly different initial conditions are made. An average, or "ensemble mean", of the different forecasts is created. This ensemble mean will likely have more skill because it averages over the many possible initial states and essentially smoothes the chaotic nature of climate. In addition, it is now possible to forecast probabilities of different conditions because of the large ensemble of forecasts available.

The ECMWF Ensemble Prediction System (EPS) simulates possible initial uncertainties by adding, to the unperturbed analysis, small perturbations within the limits of uncertainty of the analysis. 50 perturbations are computed independently and forms the basis for 50 alternative forecasts up to 10 days. The different initial states are a priori assumed to be equally likely.

Every day, MOTHY was run with these 50 alternative scenarios and provide 50 forecasts. One of the challenge was to summarize this huge amount of information. It was undertaken by counting the number of oil droplets in small boxes. And then, the oil droplet density is represented as risk areas. (Fig. 4)

## 6. Improvement of drift calculation

### 6.1 Components of the drift

In the Prestige area, MOTHY includes only the wind current. The influence of large scale current, wave current and tide current is investigated below.

### 6.2 Large scale currents

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. The French MERCATOR system (MERCATOR-OCEAN, France) is used here to provide long range currents to the MOTHY system.

A preliminary study in the Mediterranean Sea based on monthly means from the Mercator prototype gave promising results (Daniel et al., 2003). 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. 5) but becomes useful in the Bay of Biscay for longer simulations (Fig. 6). Mercator's contribution is visible for long-term simulations in waters where large-scale circulation is negligible.

These results are most encouraging. They validate the efforts undertaken by the Mercator Ocean public interest grouping and other organizations investing in the construction of a French operational oceanography system. 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. Other operational oceanography projects such as FOAM and MFS will also be assessed during this project. To perfect these first attempts, it will very likely be crucial to define specific fields and processing, to compute information during the simulation of Mercator Ocean's models, and to assess different filters and combinations prior to supplying these products on an operational basis.

### 6.3 Wave current

The impact of wave (or swell) current, which is usually neglected in such models, is investigated. Wind waves are implicitly included in wind current in MOTHY hydrodynamic model. Current from swell is not included.

The current produced by a monochromatic wave is well known. According to Stokes theory (Stokes, 1847), it is:

$$u_s = \frac{2p^3}{g}\frac{H^2}{T^3}\exp(2kz)$$

where $H$ is the wave height, $T$ the period, $g$ the gravity and $k$ the wave number.

Actual swell is a superposition of monochromatic waves. Statistical consideration lead to a Stokes averaged current:

$$\langle u_s \rangle = \frac{p^3}{g}\frac{H_{1/3}^2}{T^3}\exp\left(\frac{8p^2}{gT^2}z\right)$$

In practice, only primarily swell is considered.

VAG model is a global wave model developed by METEOFRANCE (Guillaume, 1987; Fradon et al, 2000; Lefevre et al, 2003) forced by ARPEGE atmospheric model. The wave model that is used for ocean wave forecasting at ECMWF is the WAM model, developed during the 1980's (WAMDI Group, 1988) and driven by IFS winds. Both models assimilate altimeter data.

Three simulations were conducted starting from the sinking of the ship: one without swell and two with swell from VAG and WAM models (Fig. 7). The model without swell does not forecast a beaching in Galice. Simulations with swell are faster. Model WAM is closer to the observation with a forecast of beaching near cape Corrubedo in the night of December 5th.

### 6.4 Tide current

Tides produce strong currents in many parts of the ocean. Tidal currents can have speeds of up to 5 m/s in coastal waters. However, at a distance from the coast, tide currents are small compare to wind current. Tide currents are periodic, they generate a residual circulation that can be important in some areas such as the Channel. The effect of tide currents is investigated in the Bay of Biscay. The effect is significant on long range simulations (Fig. 8).

## Conclusion

The MOTHY model was an important tool to predict the drift of the Prestige spills. It improved the monitoring of the spills and included in the operational choices a more scientific weather concern. In a similar long drift case, with the knowledge that the observation is very difficult, long range analyses were particularly useful for the strategy of observation and management of fight.

The study on the drift components illustrates the potential benefits of ocean forecasting and are encouraging efforts to develop a French operational oceanography system.

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# Figures

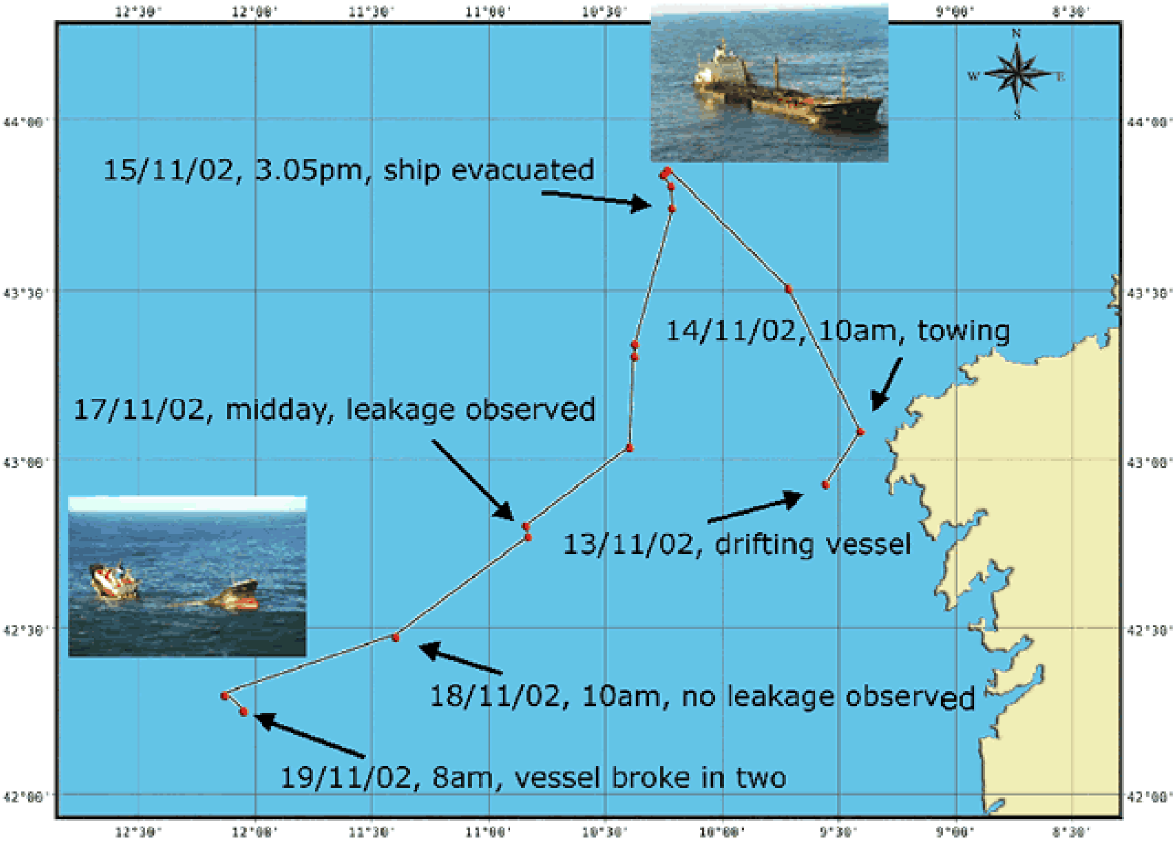



**Figure 1** : trajectory of the Prestige

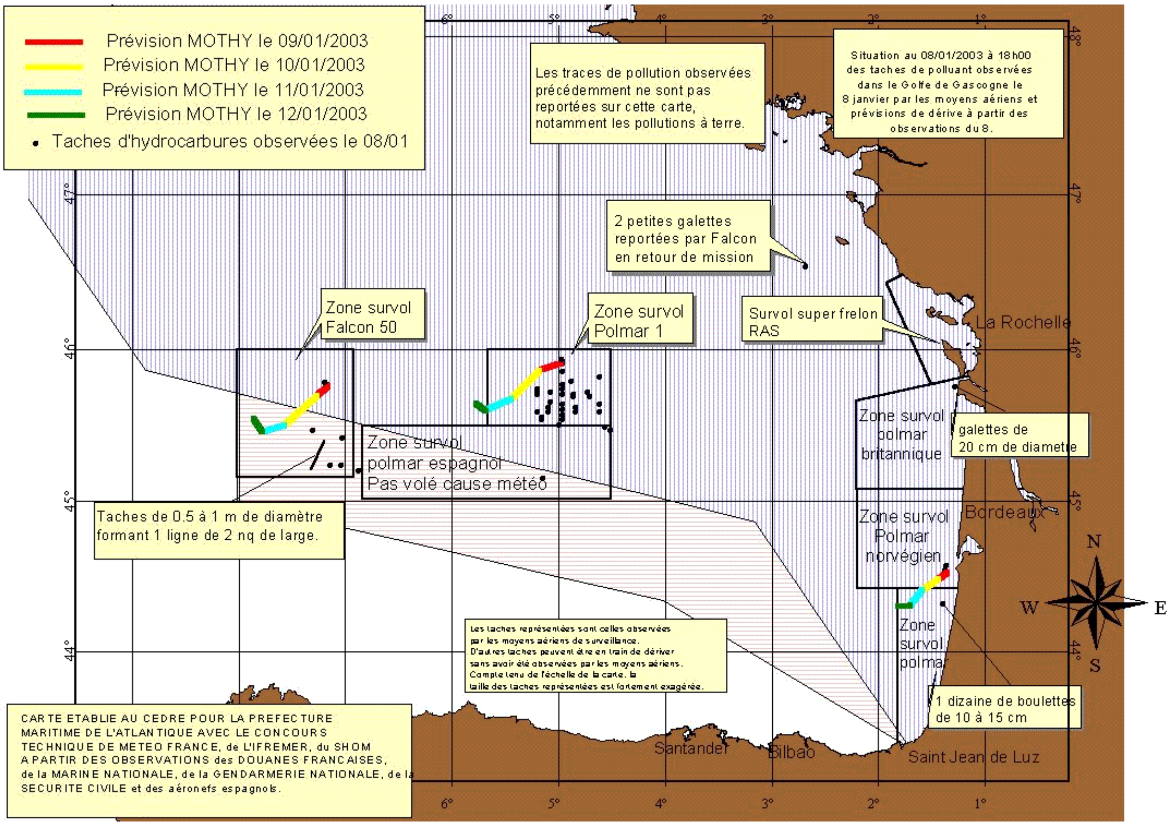



**Figure 2** : example of situation report produced by the National Drift Committee

January 8th, 2003.

Left: Simulation based on the assumption of a continuous release from November 13th to the sinking on November 19th.

Right: Simulation based on the assumption of a continuous release the wreck, starting on November 19th.

The area where oil was missing is circled in red.

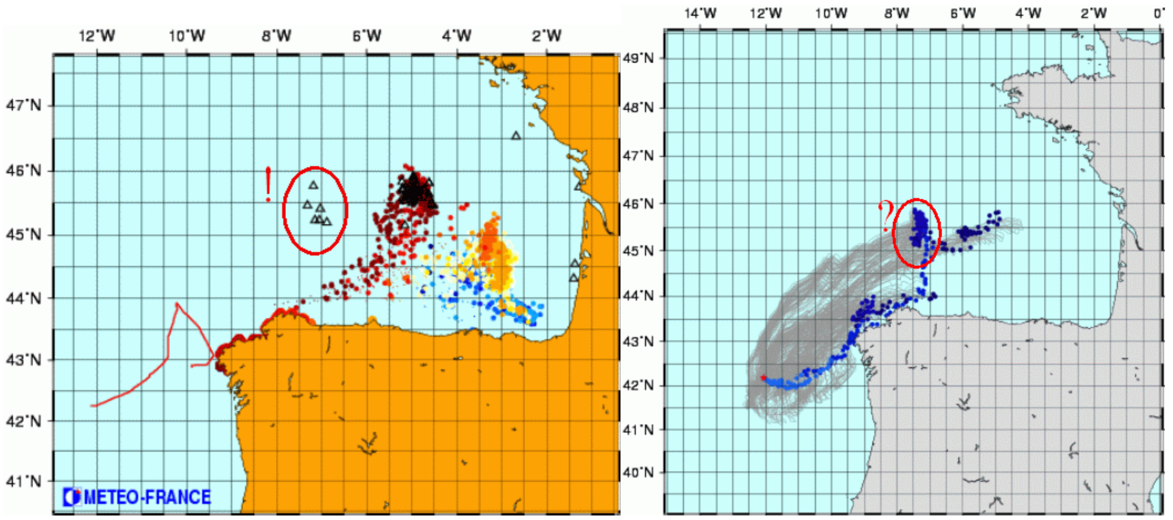



**Figure 3:** Long range analysis and predictions

Example of probabilistic forecast .

Blue: risk almost zero. White: weak but considerable risk. Orange: significant risk. Red-brown: risk very marked.

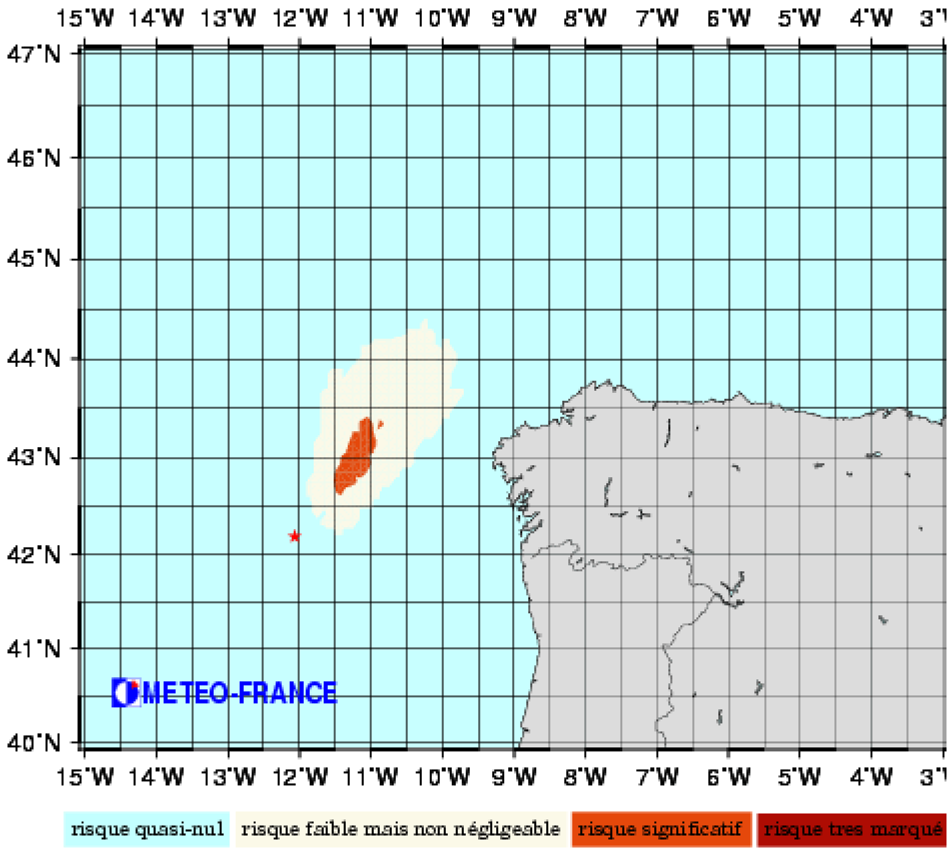
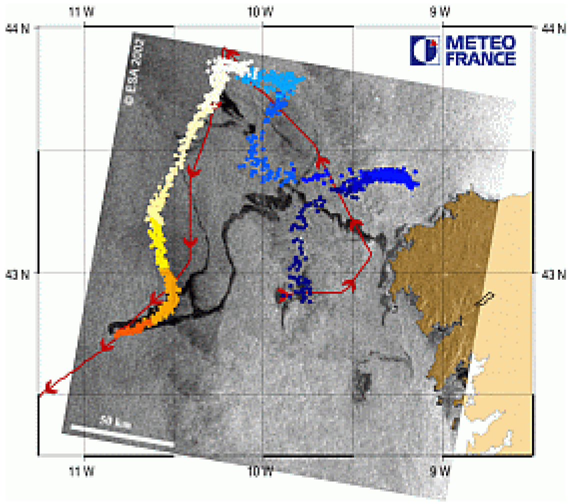
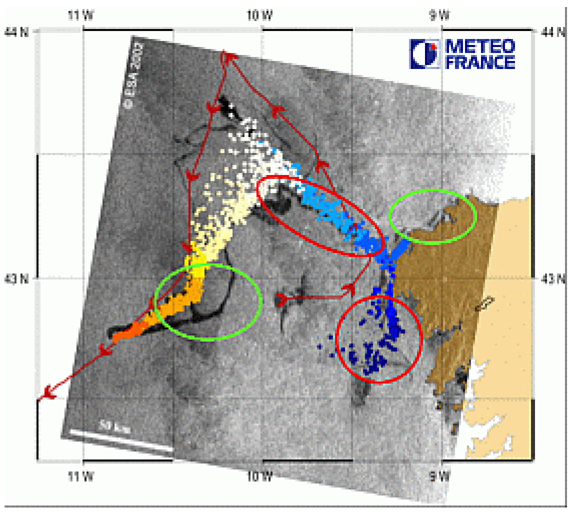



**Figure 4 :** Probabilistic forecast

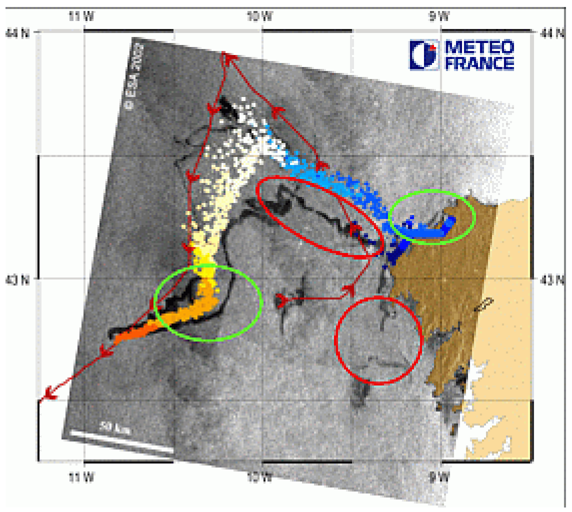
Simulated drift of a continuous leak of fuel oil along the trajectory taken by the Prestige from 13 November at 14 UTC. The satellite image of 17 November at 11 UTC shows the oil in black. The two branches formed because the sea broke the fuel oil up into two products of different density: the southern 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.




Drift with Mercator current at 3 m




Drift with operational model MOTHY




Drift with operational model MOTHY + Mercator (current at 103 m)

**Figure 5:** Large scale currents

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.

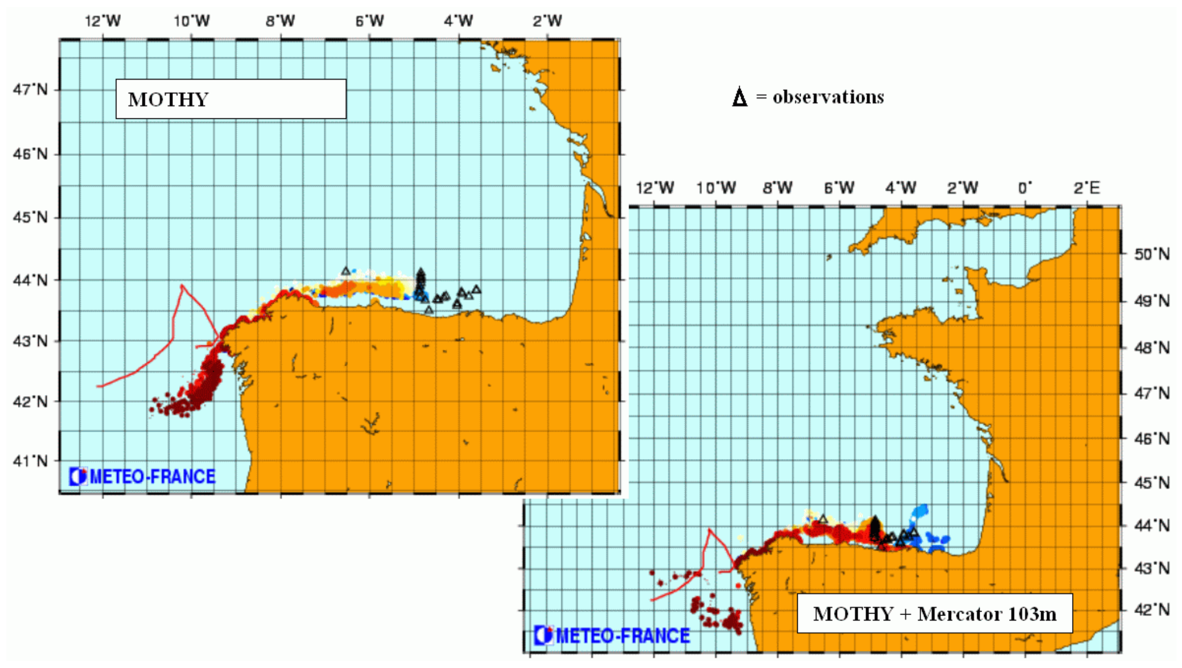



**Figure 6:** Large scale currents

December 6th, 2003.

Drift of one droplet. Gray line: operational (without swell drift). Blue line: with swell from VAG model. Red line: with swell from WAM model.

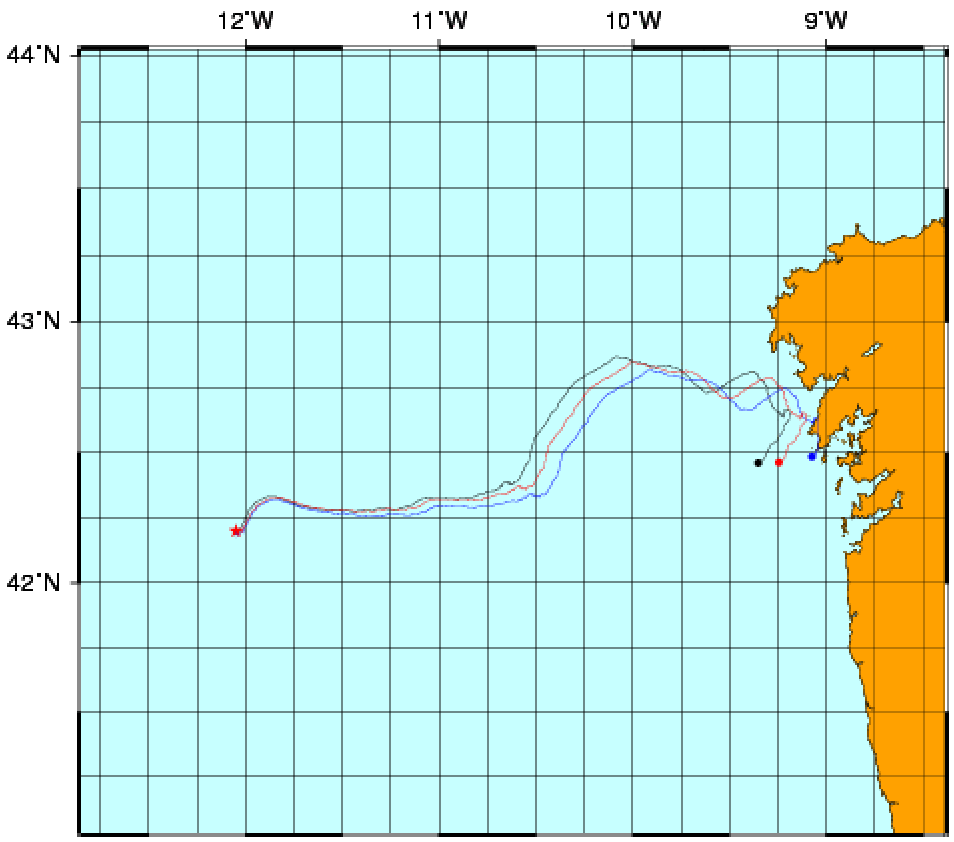



**Figure 7:** Swell current

January 5th, 2003.

Drift comparison with tide current (right ) and without tide current (left) at the time where some oil reached the French coastline. The simulation including tide current is closer to the observation.

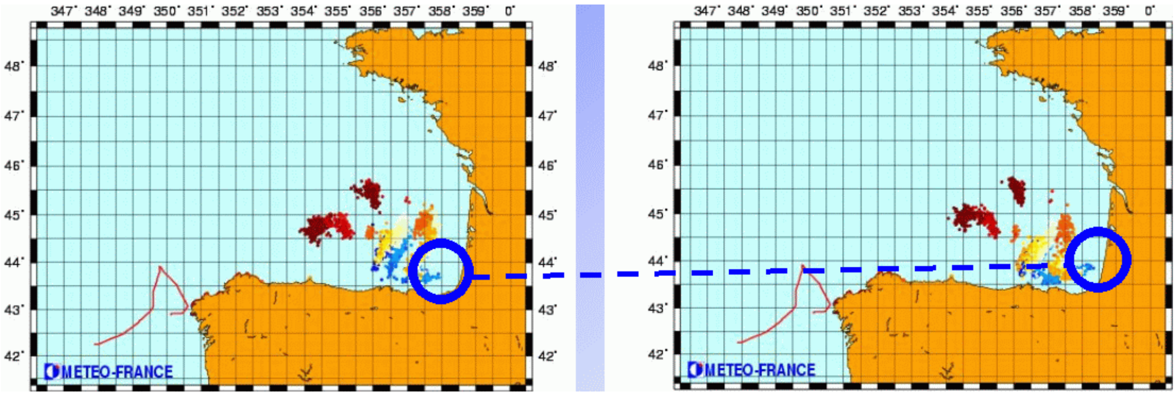



**Figure 8:** Tide currents