FORECASTING THE *ERIKA* OIL SPILLS

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ABSTRACT: *On December 12, 1999, the Erika tanker broke in two sections at about 30 miles from the Brittany coast in the Bay of Biscay, France. The two parts of the wreck sank a few hours after the break. Some 15,000 tons of heavy fuel were released into the marine environment. It is the most serious discharge that has occurred in France since 1980 (Tanio, 6,000 tons). The nature of the incident, the kind and quantity of oil spilled, and the prevailing weather conditions posed considerable response problems. The spilled oil drifted for 2 weeks before reaching the coast. Three different models were implemented by CEntre de Documentation de Recherche et d'Expérimentations sur les pollutions accidentelles des eaux (CEDRE) within a couple of hours of the Erika sinking. On December 14, it appeared that the forecast of the MOTHY model was closer to reality.*

The MOTHY model was developed by Météo-France (the French national weather service) to simulate the movement of pollutants in three dimensions. MOTHY is an integrated system that includes hydrodynamic coastal ocean modeling and real-time atmospheric forcing from a global model. Pollutants can be oil or floating objects. CEDRE contributes to the improvement and validation of the model using both experiments and interventions during actual pollution events. New developments, exercises, and training are jointly conducted. In the event of marine pollution, Météo-France sends meteorological forecasts and pollutant drift forecasts to CEDRE. This response system has been operational since February 1994.

The MOTHY model was used routinely for several weeks after the ship broke up. The model predicted that the coastline was at risk and that the beaching of the main slick would occur after 2 weeks. Diffuse pollution reached the coastline 1 or 2 days before the main slicks, about 200 km west of the main beaching. Hindcast runs and backward integration of the model explained this unexpected arrival of oil. Some pollution was still arriving onshore several weeks after the initial release. This longer-term pollution came from the wrecks, but also of older pollution by the coastal detachment and deposit tides. Using the model in conjunction with remote sensing information allowed operators to develop and then execute a response strategy rather than react only to observed information.

The *Erika* incident

On December 12, 1999, the Maltese tanker *Erika*, loaded with 30,000 tons of Fuel Oil No. 6, was sailing from Dunkerque (France) to Livorno (Italy), when it began to list, broke in two sections at 8:15 A.M. (local time), and sunk in international waters off the Brittany coast (point of Penmarc'h, South Finistere) in rough weather conditions (wind force 8 to 9, 6-meter high waves) (Figure 1). The French Navy, assisted by the British Royal Navy, rescued the crew.

When the vessel broke in two parts, approximately 5,000 to 7,000 tons of fuel oil were released at sea. The front part sank close to the location of breaking at a depth of 120 m during the night of December 12 to 13. The aft part was taken undertow by the deepsea tug *Abeille Flandre* towards the southwest. They succeeded in moving her only 10 km offshore. The stern finally sank at 2:50 p.m. on December 13 at the same depth of 120 m.

The first aerial observations (French Navy and Customs) revealed several slicks, including one a 15 km long estimated at 3,000 tons that drifted to the east at a speed of 1.2 knots. During the following days, other aerial observations undertaken in cooperation with International Tanker Owners Pollution Federation (ITOPF) showed two stringy slicks elongated by the set of the wind and located eastward of the wreck probably resulting from the first release of oil when the hull was broken. Two other slicks were lying above each part of the wreck, the front part one being very diffuse and very thin. The thick patches (5 to 8 cm) of stringy slicks drifted along the coast and then broke up into smaller ones. On December 16, small slicks 100 meters in diameter gathered in a 25 × 5 km area. From December 17, these patches and slicks began to sink a few centimeters under the sea surface.

The first oil on the shore was observed in South Finistere on December 23, 11 days after the accident. Further oil came ashore during the following days reaching Belle-Ile and Groix islands (Morbihan) on December 25 and the northern coast of Noirmoutier (Vendee) on the December 26. Because of very rough weather conditions (wind > 100 km/h blowing perpendicular to the coast) and the very high tides, the oil was

Figure 1. Trajectory of the *Erika*.

thrown to the upper part of the shore, reaching the top of 10-meter high cliffs.

On December 26 (14 days after the accident), Groix Island was also severely impacted as well as the Loire Atlantique coast between Piriac sur mer and Saint-Nazaire and also the coast further south down to Saint Brevin. A very viscous slick, 5 to 30 cm thick and several meters large, covered the shoreline; the fuel oil stuck on the rocks and some slicks were remobilized by the waves towards other sites. Drifting slicks were still threatening the Bay of Bourgneuf. The rough weather conditions (wind > 100 km/h) off the Loire Atlantique coast prevented any sea-based control operations.

Physico-chemical characteristics and weathering of the fuel oil spilled

The Fuel Oil No. 2 (Fuel No. 6 or Bunker C) is a heavy product with a specific gravity quite similar to seawater; this product is heated for transport, its viscosity at ambient temperature is very high (20,000 cSt at 10°C). Chemical dispersants are ineffective on this type of product, which eliminated the option of spraying at sea.

Some tests conducted in the CEntre de Documentation de Recherche et d'Expérimentations sur les pollutions accidentelles des eaux (CEDRE) hydraulic test canal (Polludrome) showed that after 1 day, the fuel oil was still floating despite its density; the slick began to break up and to form a water-in-oil emulsion with 30% of water, very viscous (70,000 cSt). One day later, the emulsion contained 50% water. A sample taken at sea 4 days after the accident showed an emulsion with less water than in the CEDRE canal and more sticky. Containment and recovery at sea were assessed as difficult, but possible.

CEDRE and Météo-France roles

French response capabilities in case of accidental water pollution are based on CEDRE's expertise in mitigation of both oil and chemical spills in marine and inland waters. As a nonprofit 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 European Union (E.U.) Task Force team to assist E.U. and foreign governments in response to accidental pollution.

Météo-France is the French national weather service. 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 maritime Prefect.

Key features of the MOTHY model

The oil slick is modeled as a distribution of independent droplets that move in response to currents, turbulence, and buoyancy. A coupling between a 2-D hydrodynamic, limited area, ocean model and a 1-D eddy viscosity model provides currents (Daniel, 1996; Daniel *et al.*, 1998). The objective of this approach is to ensure a realistic representation of near-surface current velocity structure. The 2-D model is driven by tide components and by winds and sea level pressure forecasts from a global atmospheric model. This atmospheric model can be the IFS model (European Centre for Medium-Range Weather Forecasts) or the ARPEGE model (Météo-France) (Courtier *et al.*, 1991). The 1-D model assumes a bilinear eddy viscosity profile (Poon and Madsen, 1991).

Turbulent diffusion is modeled with a 3-D 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.

The model was calibrated on a few well-documented pollution incidents such as *Torrey Canyon* (1967), *Amoco Cadiz* (1978), and *Tanio* (1980). A meteorologist on duty at the marine service in Toulouse is able to run the model on request. Since 1997, about 10 interventions per year have been conducted in real time.

Erika slick drift forecast

First predictions. The first modeling of the slick drift was made on December 12: MOTHY (Météo-France), OSIS (BMT), and OILMAP (ASA) gave a drift towards the east-southeast without any onshore impact within the next 5 days (Figure 2). The OILMAP American model gave a slick leading edge near Yeu Island (Vendee) on December 17. The British OSIS model gave the same direction of drifting 1 or 2 days later (December 19). The French MOTHY model was closest to reality, giving a drift parallel to the coast with the slick leading edge at 60 nautical miles west of Yeu Island around December 18.

The differences between model MOTHY and the two other models can be explained by nature of the environmental data (winds, currents) and their processing within the model. Thus, the environmental data and the calculation of drift are controlled from beginning to the end by a marine forecaster. The forecaster knows the quality of the data input. According to the weather situation, the forecaster is able to say which model will be better than the other. The calculation of the currents by a hydrodynamic model allows a precision much better than that of currents resulting from databases or calculated by a percentage the wind speed.

Long-range predictions. Météo-France confirmed that oil would move towards the coast based on climatological analysis. On December 14th, long-term forecasts, up to 10 days, were carried out with IFS ensemble atmospheric predictions. According to the results of the tubing (classification of the 51 forecasts) of this day, six atmospheric predictions were chosen: the most likely and one representative of each alternative scenario. The corresponding surface fields were used to force the drift model MOTHY (Figure 3). In spite of different behaviors, no one simulation indicated oil coming ashore for at least 10 days (December 23). This information that the pollutant would remain, a long time at sea proved to be essential for the authorities in charge of the organization of the means of fight.

Forecasting the arrival on the shore. From the December 12 to December 25, Météo-France simulated the drift with position fixes obtained by aerial observation and relayed by CEDRE. The forecasts of drift were updated regularly according to the most recent observations. The locations at sea confirmed, with a remarkable precision, the drift forecasts of the previous day. On December 18, Météo-France dropped a drifting buoy, equipped with a wind recorder, in the main slicks. According to the forecast, a reverse of the drifting towards the west on December 20 and then to the north was observed. On December 21, the observation at sea revealed the presence of 13 slicks at 105 km of Belle-Ile and 72 km from the island of Yeu. The slick leading edge arrived near Belle-Ile (38 km) on December 23 where impact was forecast for the night of December 24 to 25. The impact of the shore impact in Le Croisic and the mouth of the Loire River was forecast for December 25 and 26 and was actually observed (Figure 4).

Slick observations were transmitted to Météo-France in the following way. CEDRE defined a zone surrounding the slicks and transmitted to Météo-France some extreme points of this polygon (Figure 5). These points were used as starting position for the drift calculation. The person who activated the model had a partial vision of the observation at sea.

Diffuse pollution reached the coastline of Finistère and Morbihan, 1 or 2 days before the main slicks, about 200 km east of the main beaching (Figure 6). At the time of the beaching, it was difficult to explain the original location of that oil. 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

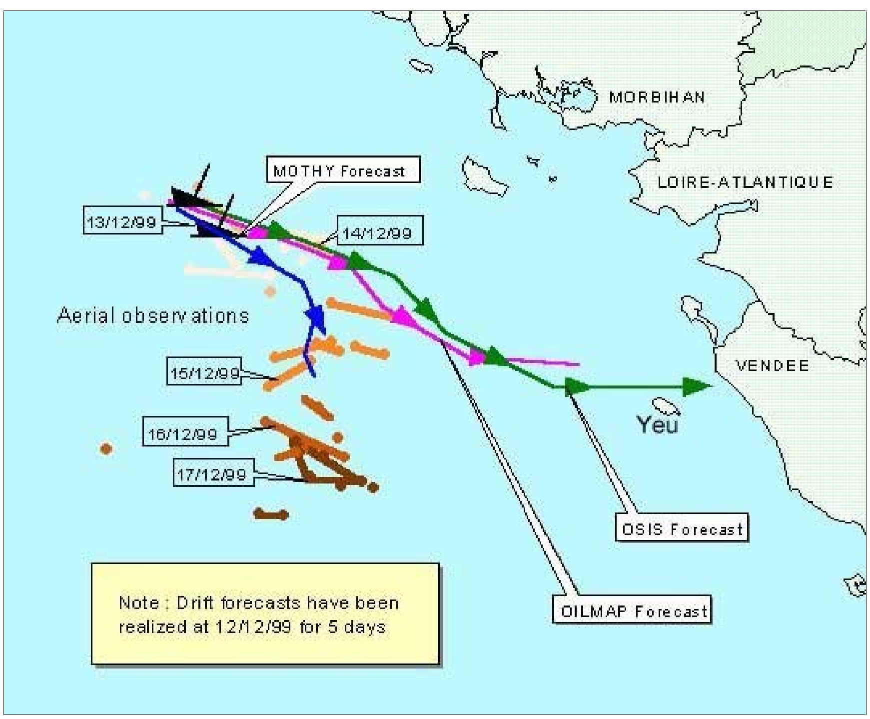

Figure 2. Forecast drift model comparison.

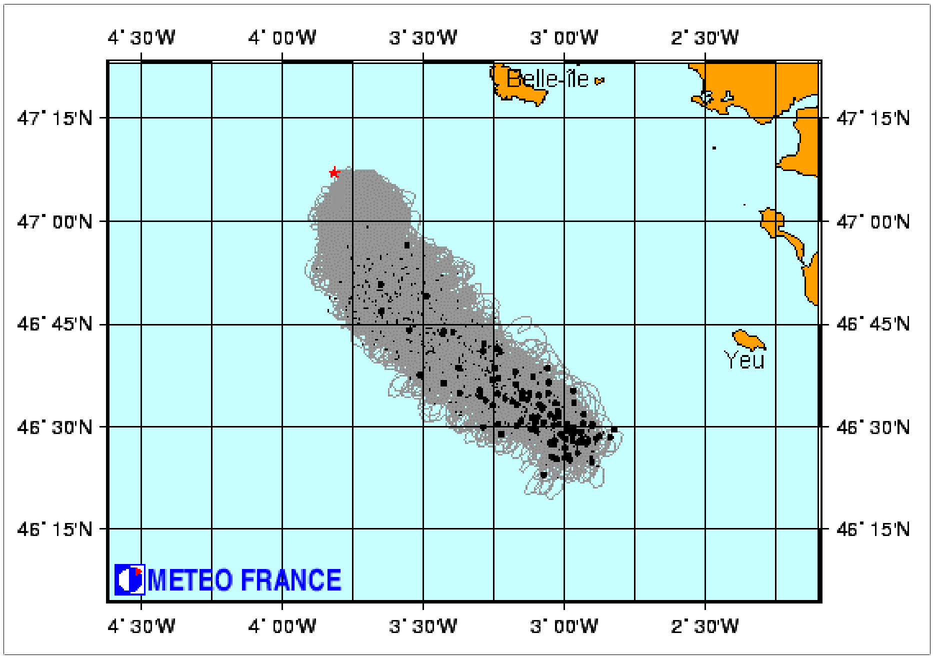

Figure 3. Ten days forecast (the most likely scenario) from an observed slick position on December 13, 16 UTC. A red star figures the position of the spill. Black disks figure the final position of the slick modeled by MOTHY. The trajectories of the droplets are in gray.

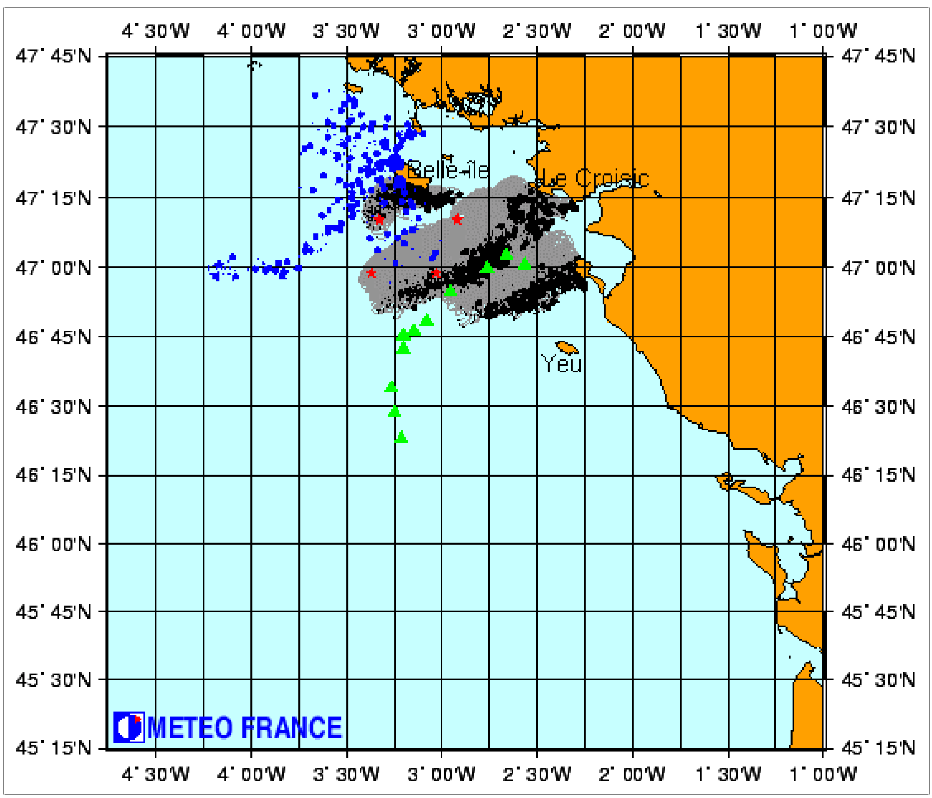

Figure 4. Forty-eight hours operational forecasts for December 26, 00 UTC. Red stars figure the initial position of the spills. Black disks figure the final position of the slicks modeled by MOTHY. The trajectories of the droplets are in gray. Blue disks figure the position of the oil released from the wreck. Green triangles are positions of a drifting buoy.

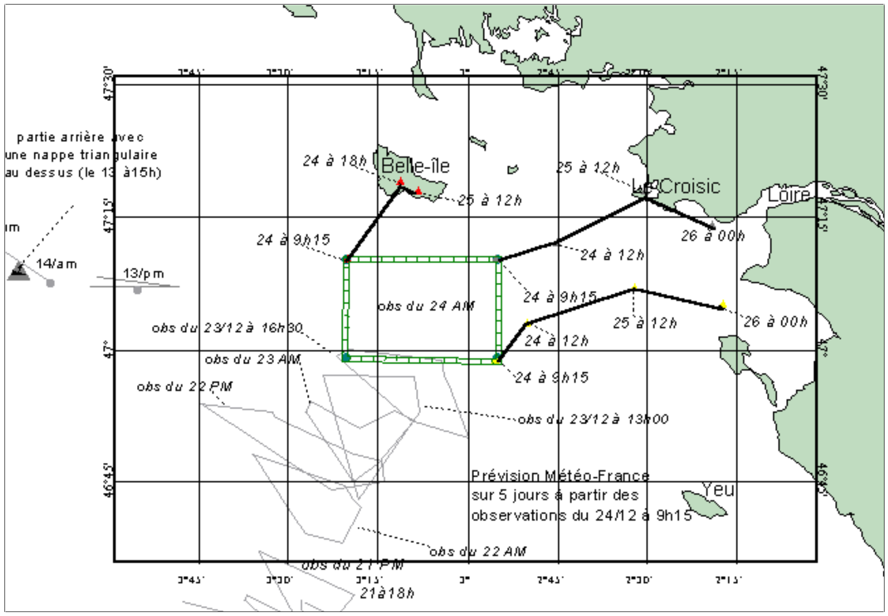

Figure 5. Forty-eight hours operational forecasts for December 26, 00 UTC. Green square figures the initial position of the spills. The trajectories of the corners are in black.

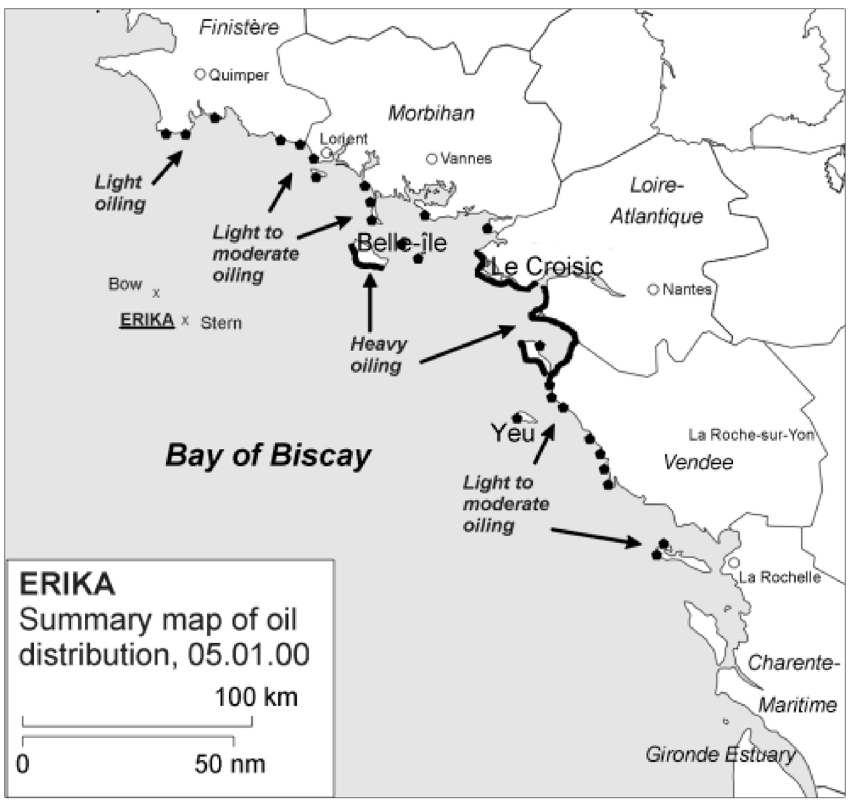

Figure 6. Summary map of oil distribution (source: ITOPF).

need for reconsidering and organizing these aspects of the Polmar fight in a more rational way. It seems desirable to find the means to better coordinate the observation of the spills at sea, their detection, and their follow-up. All those involved in marine pollution control must think of it collectively.

The quantity of fuel oil spilled is estimated at 10,000 tons. The very rough weather conditions on December 12 and during the following weeks did not relent except during a very short lull (a few days) to allow the containment and recovery operations at sea. That is why it was impossible to prevent the arrival of oil slick on shore (11 days after the accident). The length of shoreline impacted between December 23 and February is estimated at 400 km; among the arrivals, some are probably resulting from the movement of oil deposited on shore or on sea bottom. In spite of the relatively high emulsification of Fuel Oil No. 6, the great quantities of oil stranded onshore are difficult to explain by the quantities observed at the sea surface. One possibility is the existence of slicks deposited on the sea bottom or drifting in the water mass below the sea surface.

Slicks survey and data transmission. Satellite images (in particular SAR images) were useless because of the nature of the pollutant. Fuel oil does not behave like an oil film and does not destroy the capillary waves on the sea surface.

Information on the accident transmitted by the authorities in charge of the control to the experts in charge of risk assessment studies (French Navy and C.R.O.S.S. to CEDRE) needs a validation by overflights to get accurate values for running the model. Collection of relevant information right from the few hours following the accident and until the end of the spill is, therefore, capital for having a good prediction. One can start with simple evidence: incorrect input data (slick location, wind, currents) gives incorrect slick predictions. There are cases where prediction maps that have been produced by CEDRE could be made available too late to be used by the Navy authorities to plan the observation flights the following day because of excessive delays in the transmission of the information needed to activate the model on the one hand, and no less excessive delays of transmission of the results on the other hand. Such deficiencies in a communication system may lead to an incomplete information problem: the absence of oil slick in a given area may not necessarily indicate the absence of pollution in a particular area, but only the mere fact that the area was not included in the air survey plans. Would that fundamental difference happen to remain unnoticed by slick drift prevision users, the results may be dramatic. Thus, the flow of information must be accelerated without any loss in accuracy.

***Erika* slick drift hindcast.** To explain the oil arrivals in the west of the main stranding area, simulations of drift in hindcast mode were carried out starting from the following assumptions. The first assumption is a continuous fuel flow on the way of the ship before the accident (Figure 7). The second is a continuous release from the wrecks (Figure 8). In both cases, fuel reached or passed near the coasts of Finistère and Morbihan where the impact was observed (Figure 6).

Conclusions

The MOTHY model correctly predicted the main impact of the shore 2 days in advance, but some pollution came ashore and was not forecasted because it was not observed. It will be necessary in the future to improve the monitoring of the spills and to include in the operational choices a more scientific weather concern. The use of forecasting must be reconsidered to draw the trajectory of the pollutants, but also strategy of observation and management of fight, evaluation of risks, etc. In a similar long drift case, with the knowledge that the observation is very difficult, it would be useful to systematically check each day at the location forecasts the previous days, if traces of pollutant are there or not.

Biography

Pierre Daniel has been an R&D engineer in coastal ocean modeling since 1991. He is in charge of oil spill drift modeling at Météo-France. He is rapporteur on Marine Pollution Emergency Response Support System within the World Meteorological Organisation.

Patrick Josse has a Ph.D. in Physical Oceanography and is deputy director in charge of R&D activities at the Marine Forecast Section of Météo-France.

Philippe Dandin, Ph.D. in Physical Oceanography, is head of the Marine Forecast section of Météo-France.

Vincent Gouriou, Member of the CEDRE Emergency Response Team since 1997, in charge of the management and development of oil spill computerized models (fate and drift of oil slicks at sea) and of GIS. V. Gouriou has a Ph.D. in data processing and communication.

Dr. Michel Marchand, Doctor in Chemistry, IFREMER (French Institute for the Exploitation of the Sea) Researcher, moved to CEDRE in 1996 to take in charge the Emergency Response Team for 4 years (until June 30, 2000).

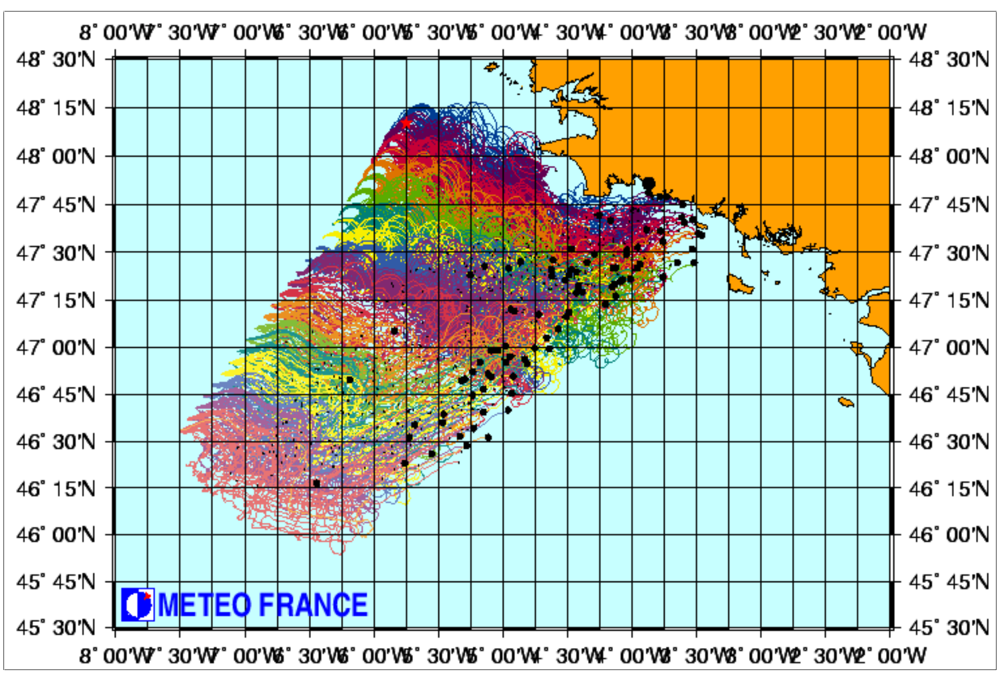

Figure 7. Continuous release on the ship course up to December 25 at 12 UTC.

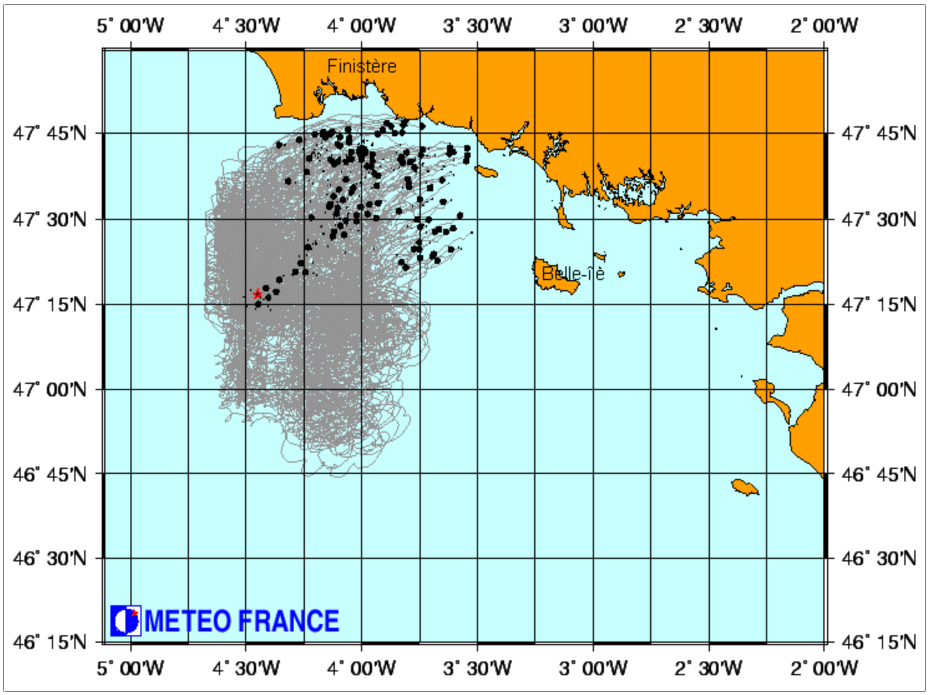

Figure 8. Continuous release from the wreck up to December 25 at 00 UTC.

Dr. Claudine Tiercelin, Member of the CEDRE Emergency Response Team since 1989, in charge of oil spill contingency planning and studies on the fate of oil spilt at the sea surface. Dr. Tiercelin is Doctor in Marine Geology and Engineer in Petroleum Geology. She was an exploration engineer during 7 years (1981–1988) in Elf Aquitaine Petroleum Company.

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