TOWARDS BETTER FORECASTING OF OIL SLICK MOVEMENT AT SEA BASED ON INFORMATION FROM THE *ERIKA*

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SUMMARY

The Erika sank on December 12, 1999 of the coast of Brittany. Fuel oil slicks drifted for two weeks before polluting roughly 400 km of coastline. Movement forecasts were made by Météo-France (French National Weather Service) in close collaboration with the Cedre. The Erika accident showed that a working tool existed for forecasting oil slick movements, providing cleanup authorities with essential decision-making support. The crisis also showed that this was not enough and that correct forecasting requires appropriate observation capabilities. Forecasting models must be supplied with initial conditions that represent the actual situation. Moreover, the accident demonstrated that making use of the full potential of forecasting requires the ability to integrate important information, including methods and tools. Current projects such as CEP&M or Lit'eau are collaborations between Météo-France, the CEDRE and IFREMER, and should produce significant improvements in forecasting tools.

DISCUSSION

The Erika accident

On December 12, 1999 the Maltese oil tanker Erika, loaded with 30,000 tons of heavy fuel oil, broke in two at 8:15 AM local time and sank roughly 70 km from Penmarch Point to the south of Brittany (figure 1). In very rough weather conditions (force 8 to 9 winds and 6-meter waves), the crew was rescued by the French Navy with the help of the British Royal Navy. When the accident occurred, 5,000 to 7,000 tons of fuel oil were disgorged into the sea. The bow sank near the accident site in 120 m of water during the night of December 12 to 13. The stern was towed to the southwest by the ocean tug "Abeille Flandre" over a dozen km. It finally sank at roughly 2:50 AM (GMT) on December 13.

Number two heating oil (bunker C) is a heavy hydrocarbon that is transported hot and has a density close to that of seawater. Its viscosity at ambient temperature is very high (20,000 cSt at 10°C). Dispersants are not effective on this type of product. Tests conducted by Cedre in the hydraulic test canal (polludrome) showed that the product’s viscosity increases very quickly.

Initial forecasts on the movement of slicks from the Erika

On December 12, the Atlantic Maritime Prefect started a daily schedule of surveillance flights by specialized planes from the Customs Authority (Polmar I and II) and from the French Navy. Initial aerial observations noted oil slicks drifting to the east at a speed of 1.2 knots. One of the slicks was estimated at 3,000 tons and spread over 15 km. During the following days, other aerial observations performed in collaboration with ITOPF (International Tanker Owners Pollution Federation) showed slicks lengthening into the wind's path and located to the east of the wrecks resulting from the initial accident. Two other slicks were located above the wrecks.

The CEDRE started movement modeling via three different models: the British OSIS model, developed from a project financed by the European Community; the American OILMAP model, the commercial model that is widely distributed throughout the world (the oil spill management federation Oil Spill Response Ltd. has a license to use this model, and TotalFina is a member of this federation); and the MOTHY model from Météo-France.

Forecasts from these different models on the day of the accident (figure 2) were worrying. The slick leading edges would arrive at Yeu Island on December 17 according to the American model. They neared Yeu Island on the same day according to the British model. They stayed far out to sea in the Météo-France model.

Difficult observation at sea

Satellites had little chance of seeing the Erika slicks. Those that "see" by day and night (e.g. Radarsat and ERS) have radar that can distinguish a difference in water surface roughness caused by an oil slick, and lose this ability when the sea is too calm or too rough (as it was in this case). Those that "see" in the visible and infrared spectrum (e.g. SPOT) are blind at night and in cloudy weather. They had only rare moments of clear sky and were disturbed by swells that broke over the slicks. All were in polar orbit and only passed over the zone one out of every ten days. In fact, not a single useful satellite image could be obtained, in contrast with the situation in 1996 during the Sea Empress oil slick. Thus, all observation work had to be performed by planes in weather conditions that were difficult for both men and equipment. Plane crews worked on the position of slicks, sea conditions and pollutant characteristics in conditions so difficult that the positions of some slicks were lost, found, and lost again as they drifted and broke up.

Choosing a drift forecasting model

As early as December 14, it was clear from these observations that the forecast from Météo-France was by far the best. An emergency unit was formed at the Météo-France maritime forecasting center in Toulouse to update the forecasts. This was done immediately after receiving data from aerial observations - at first once a day, then later twice a day. During the updating, forecasts were systematically verified, confidence increased, other models were discarded and Météo-France forecasts, communicated to ground authorities by the Maritime Prefect and Cedre, gradually became the information used for reference.

The roles of Cedre and Météo-France

The Maritime Prefect is responsible for coordinating pollution control and managing the POLMAR-MER plan. Cedre makes use of its marine pollution expertise to assist in the effort. One of the Cedre's missions is to inform authorities about oil slick drifting in the ocean. Pollutant drift forecasts are made by Météo-France in the framework of a Cedre / Météo-France partnership. Pooling of interests between Cedre and Météo-France took place under the auspices of the Maritime General Secretariat, resulting in a joint effort agreement in effect since 1996. Operational procedures that have been set up and implemented with Cedre for several years now allow this service to be provided 24 hours a day, 365 days a year with optimal effectiveness. Cedre works with the Crisis Response Team of the Maritime Prefect to place forecasts within the context of the situation observed at sea, providing the Maritime Prefect with recommendations based on different aspects of the problem (volumes involved, type of pollutant, level of risk, etc.). The Maritime Prefect can then decide on the control strategy to be used. Note that forecasts made by other organizations can also add to the information used by Cedre and the Maritime Prefect to assess the situation.

MOTHY system

The service set up by Météo-France includes weather assistance and pollutant drift forecasts. This public service mission is performed within the framework of life and property safety. In cases of marine pollution, Météo-France provides support at both the national and international level to emergency operations. A dozen interventions have taken place each year in actual cases of pollution. The oil slick drift forecast is performed using a specific model called MOTHY, developed within the oceanographic and maritime forecasting division of Météo-France. MOTHY is an ocean model that calculates tidal currents and currents produced by winds (the winds used are those forecast by quantitative forecasting weather models). These currents are used to make the pollutant drift, taking into account all information available on the product. The model is described in detail in Daniel

(1996). MOTHY can be used 24 hours a day by a marine forecaster based on information furnished by Cedre. The forecaster evaluates output from the model and produces a marine weather forecast (wind, waves and swells, surface temperature as necessary, etc.).

Long-term forecasting

Initial results from the long-term slick forecasts indicated that the pollutant would remain at sea for a long time. 10-day simulations are performed by using forecasts from the entire IFS atmospheric model. These are multiple forecasts in which dispersion is quantified in order to deduce how "predictable" the situation is. None of these simulations predicted oil arriving on the coast for at least 10 days (figure 3). The authorities were notified of this essential fact, enabling better planning of control procedures (e.g. the use of foreign ships that would have enough time to arrive in the zone).

Two weeks of ocean drift forecasts

From December 12 to 25, Météo-France made drift forecasts based on aerial positions transmitted by Cedre. The forecasts were regularly updated each time a new observation was made. Observations at sea confirmed the drift forecasts of previous days. Day after day, thick slicks (5 to 8 cm) broke up into small slicks that were 100 meters in diameter. On December 16, the slicks covered a 25 km by 5 km zone. Starting on December 17, the slicks started to sink a few centimeters under the surface. On December 18, Météo-France decided to place two buoys in the water within the slick zone. A Marisonde buoy was equipped with a wind gauge to measure winds and surface current. It drifted with the slicks and ran aground on Noirmoutier Island. An SVP buoy that measures current under the surface was also released with an anchor floating at 15 meters. It was left to drift with tidal currents in the accident zone (by turning in a circle), and drifted very slightly over several days. This very slight drifting proved something: large oceanic currents (called "permanent currents") were not important in the zone, where wind effects and tidal currents dominated.

In line with forecasts, the drift reversed direction to the west on December 20, then to the north. On December 21, observation at sea revealed 13 slicks positioned 105 km to the south of Belle-Ile and 72 km to the southwest of Yeu Island. Some simulations performed during the night of December 20 to 21 indicated a risk that they would reach Yeu Island 5 days later. Differing predictions appeared between the IFS and ARPEGE atmospheric models (Courtier et al., 1991). The ARPEGE model indicated a faster moving slick that was further north than in the IFS model. A simulation performed from a position on 21/12 1600TU showed contact in the Noirmoutier / Yeu / Saint-Gilles triangle 5 days later. Another initial position chosen by Cedre led to trajectories and impacts further to the north and targeted the Loire estuary and Noirmoutier. A third targeted the north of Yeu Island. The triangle would certainly be hit. The slick leading edge arrived near Belle-Ile (38 km) on December 23. The bulletin sent to the Executive Assistant to the Minister on 23/12 at 7:31 AM read: "Oil slick impact points should be located between Noirmoutier and Le Croisic during the day of Sunday December 26. Wind rotation in the Western sector should then drive part of the slick toward Yeu Island and the Vendean coast during the day of December 27". High-resolution models were then implemented (resolution 25 times greater than the resolution of the version used up to then).

How are drift scenarios chosen?

According to observations performed at sea (by planes that are specialized in the remote detection of pollution (Customs Authority: Polmar planes), by planes from the French Navy Maritime Patrol or by any other available means, including boats in the zone), coordinates are chosen by Cedre and furnished to the marine forecasting service of Météo-France as initial conditions for forecasting from these points.

For example, we took the four initial points chosen for the simulation and placed them on the situation summary map published by Cedre on the night of December 24 (figure 4). In this summary, the initial points for trajectory forecasting calculations are shown in red surrounded by gray. The situation in the zone is shown in red. As soon as we received the points chosen by Cedre and the Polmar Response Team of the Maritime Prefect, the MOTHY model was started by the department's marine forecasting engineer.

Arrival on the coast

The scenario for oil slicks coming ashore starting on December 25 on the coasts between Belle Ile, the coast to the north of the Loire estuary (Le Croisic), Bourgneuf Bay, Noirmoutier, Yeu, Saint-Gilles-Croix-de-Vie, Les Sables d'Olonnes, etc. was correctly predicted by forecasts (location and chronology).(figure 5). Most of the pollution did come ashore from December 24 to 27 in the zone indicated by this forecast. But smaller slicks that came ashore on the Morbihan coast to the west of Belle-Ile were not forecast: they were not observed and thus were not included in slick forecasts.

In fact, diffuse pollution reached the coast of Finistère on December 23 before the major slicks came ashore, roughly 200 km to the west of the main accident zone (figure 6). The December 23 arrivals on the southern coast of Finistère again raised the question: was this sludge or fuel from the ERIKA? On December 24, analyses showed that the fuel that came ashore the day before on the coast of Finistère did come from the ERIKA. Part of the pollution had therefore not been observed, either leaking from the ship prior to its breaking up or coming from the wrecks.

Due to very difficult weather conditions (winds greater than 100 km/h) and strong tides, the fuel was sprayed onto the tops of cliffs all along the coast. The coast was covered by a very viscous slick that was 5 to 30 cm thick and several meters wide. The poor weather conditions prevented further intervention at sea.

Swells caused by the storm finally calmed on December 30, and only then could the Maritime Prefect use four planes simultaneously to fully monitor the situation along the affected coasts. These observations showed a slick that was twenty meters long, several hundred smaller slicks (1 to 5 m), discs (less than 1 m) and many trailing droplets. What was previously at sea was now washing ashore, not sinking or disappearing but breaking up into many smaller units that were invisible in rough seas. At the start of January, slicks once again came ashore, originating from remobilization of the fuel already on the coast or on sediments at the sea bottom.

Verifying the leak hypothesis

Backward simulations were performed from the following two hypotheses. In the first hypothesis, the ship was leaking prior to the accident (figure 6). The second hypothesis assumed continuous leaking from the wrecks (figure 7). In both cases, the fuel reached the coasts of Finistère and Morbihan on the dates on which it was actually observed. Fuel was later found to be missing when the wrecks were being pumped, confirming that leaks were present before or after the accident.

How can we do better?

This accident was a catastrophe at several levels. Permanent monitoring of the slicks was undertaken to aid the Maritime Prefect in deciding on the best control strategy (which does not mean that everything was irrevocably decided from then on), and this was a completely new idea in pollution control.

Overall, forecasts were in keeping with what was actually observed, including some differences that were corrected via human expertise combined with the simulations. This being said, we must be aware of the uncertainties associated with the physics of weather and sea environments, conditions that are sometimes exceptionally difficult and hypotheses which impart advantages and disadvantages to all models, in addition to defining their operating conditions. We must also remember that Météo-France only forecasts from initial positions provided to it and observation at sea was difficult in this case. Finally, forecasts derived from all models must be analyzed with an overall perspective of the situation in the field (i.e. other sources of information, observations, operating constraints and even choices that must sometimes be made).

The main areas where progress can be made include improving modeling techniques and organizational processes.

Improving modeling techniques

Currents produced by winds and tides are included in the MOTHY model used by Météo-France. Current variables that are not included may be insignificant (e.g. in the Erika oil slick zone), but studies have shown that these large-scale currents may also have a considerable impact. This is true for strong neighboring currents like the Gulf Stream, but also in the Mediterranean Sea.

Work on these dynamics is a large project far upstream of the MOTHY model. We must verify the possible contribution of oceanic models (Mercator project) for both the global ocean (global prototype 1/3°) and higher resolution basin models (Atlantic-Mediterranean prototype 1/12°), or even coastal and near-coastal models (IFREMER models).

Large improvements can also be made to the physical-chemical section of the model (pollutant aging, diffusion, etc.). CEDRE will play a central role in this area. The Erika situation showed that density alone cannot correctly describe the physical-chemical behavior of a pollutant. In fact, the compact character of the Erika type fuel and its ability to break up into small fragments must be included in MOTHY.

The influence of time resolution for the climate forcing used was tested in order to verify (theoretically and via quantitative experiment) whether the forcing frequencies that are currently used and available produce energy losses, and thus drift bias. We found that in very strong wind conditions with quite a bit of rotation, drift can be underestimated by 10% (Skandrani and Daniel, 2001).

Other aspects were identified and will be studied by Météo-France development teams in collaboration with other French oceanography organizations where appropriate. In addition, the effect of waves on surface current may be evaluated and, if necessary, included in the drift model thanks to the expertise of Météo-France in modeling sea conditions. Work already started to improve bathymetry (higher resolution and better description of coastal characteristics) will be continued in cooperation with the Coastal Oceanography scientific community (CNRS and IFREMER). Finally, more work could be done on the description of slicks: Currently, the model only includes one point of origin and cannot treat a broad slick. On this point, information can be gleaned from work done on atmospheric modeling for the transport of radionucleides in the atmosphere. Currently, using several initial points requires repeating the same calculations over and over, which wastes valuable time when slicks are approaching coasts.

Improving organizational processes

Various steps must be distinguished in the process leading to useful information for forecasting the behavior of pollutant slicks at sea. The process naturally starts with observation at sea or by plane. This raw information (e.g. the positions of many small slicks) must then be analyzed in order to be used as an initial condition for forecasting per se (note that by forecast we mean output from the MOTHY model assessed by a meteorologist). These forecasts must then be placed in their context, which means another assessment. This operation cannot be separated from the analysis, since there is mutual feedback between the two. Finally, for monitoring a drift of long duration, forecasts must be one of the items used to update the observation strategy for the coming days.

Two improvements may be made to the current organization: save time and minimize signal loss.

Saving even a little time during each of the steps described above would make forecasts available sooner and thus more useful, e.g. for moving control equipment at sea or on the ground. The use of real-time transmission techniques for observation/analysis/forecasting would enable plane or on-site observations to be used more effectively. This is even mores crucial for slicks approaching coastlines.

Sequential transmission of information between the various workers runs the risk of losing information. New procedures will be implemented for better information sharing before and after the different assessments. For example, new ideas have come out of the Erika crisis: analysis briefing ability between the Customs Authority, POLMAR Crisis Response, Cedre and Météo-France; the use of geographic information systems and information cross-analysis; summary presentation of forecasting information in cases where several forecasts are made on the same initial situation.

CONCLUSIONS

The Erika accident showed that a working tool existed for forecasting oil slick movements, providing cleanup authorities with essential decision-making support. The crisis also showed that this was not enough and that correct forecasting requires appropriate observation capacities. Forecasting models must be supplied with initial conditions that represent the actual situation. Moreover, the accident demonstrated that making use of the full potential of forecasting requires the ability to integrate important information, including methods and tools. The Erika accident showed us once again how important it is to work on these areas, including technical issues to constantly refine forecasting, as well as organizational issues to control how these tools are used and establish a control strategy that is as effective as possible.

This catastrophe included several characteristics that were "new" compared to other marine pollution incidents. First, the physical-chemical properties of the Erika fuel (particularly its compact character and propensity to fragment into many small slicks) resulted in special constraints on the number of "slicks" that must be observed and monitored for change. In addition, the position of the wreck was far from the coasts and required long-term monitoring, making forecast updating by new observations at sea even more critical.

The time duration meant that the slick involved several uncertainties. In spite of regular updating based on observations, the forecasts were highly dependent on correct atmospheric forecasts (climate forcing input data for the model) and of course, correct description of ambient ocean conditions.

This information adds to the experience accumulated over several years by Météo-France and Cedre and has allowed us to identify several improvements that can be made to the model and to organizational processes in cases of accidental marine pollution. Areas have been identified where improvements could be made, supported by long-term analysis. The recent Erika crisis has brought some of these areas to the forefront. The Erika tragedy also taught us quite a bit about how to organize the forecasting process and showed how important it is to optimize this process. On this point, tools are essential: new information technologies (communication and telecommunications) allow us to foresee overlaying solutions on the current system (which operated correctly) to make it more effective.

Current work included in the CEP&M or Lit'eau competitive bidding projects represents a collaboration between Météo-France, CEDRE and IFREMER, and has already produced significant improvements in forecasting tools.

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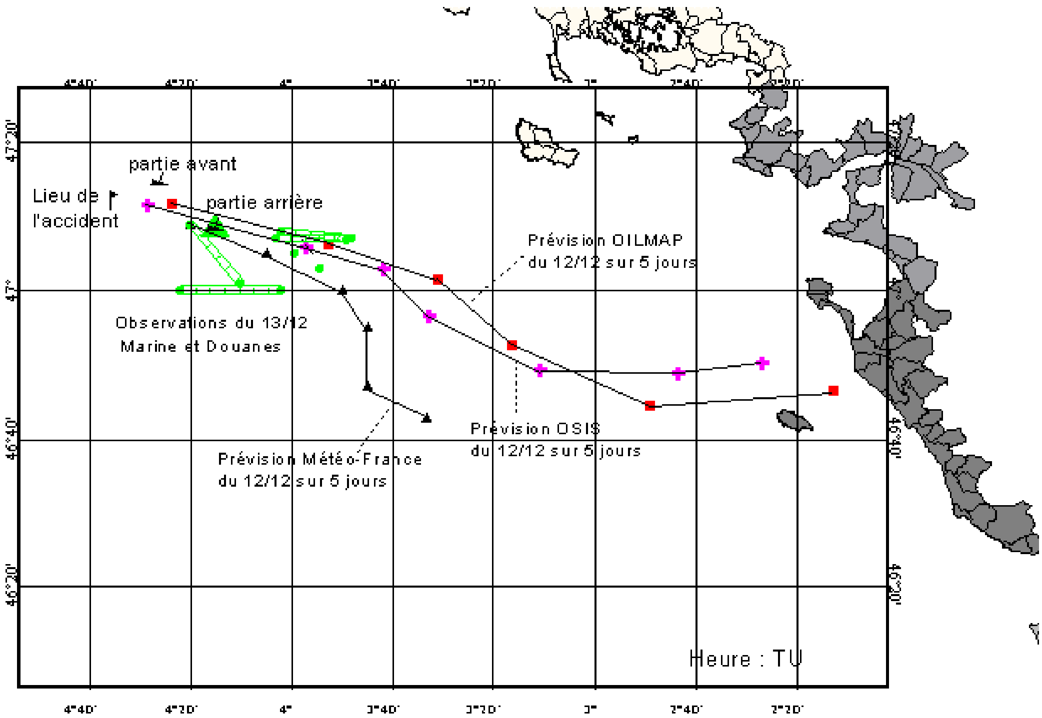
Daniel P., 1996: Operational forecasting of oil spill drift at Météo-France, Spill Science & Technology Bulletin. Vol. 3, No. 1/2, pp. 53-64.

Skandrani C. and P. Daniel, 2001: Atmospheric forcing impact study in MOTHY oil drift model, Coastal Engineering V, Computer modeling of seas and coastal regions, WIT Press, pp. 265-274.

Figure 1: Route followed by the Erika



Situation des observations et premières prévisions de dérives, le 12 décembre

Figure 2

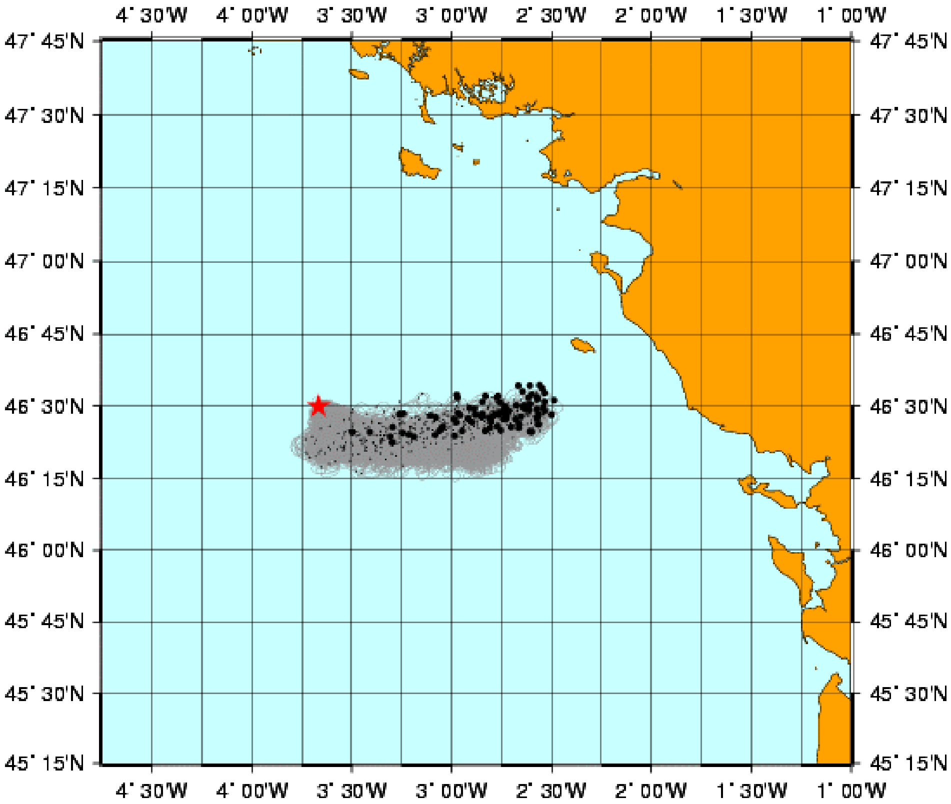


Figure 3: 10-day forecast (worst-case scenario) made by the MOTHY model from a position observed on December 13 at 16UTC. The red star shows the initial observed position of the slick, and black circles indicate the forecast pollutant positions ten days later. Trajectories are shown in gray.

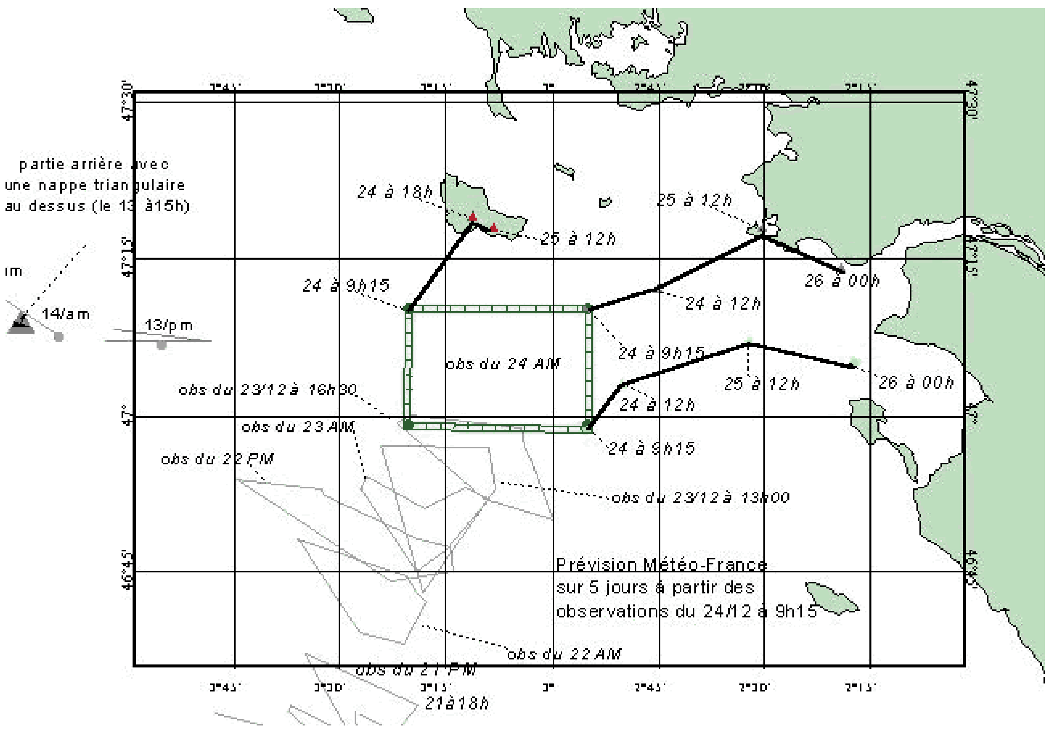


Figure 4: Polygons representing the distribution of slicks observed by planes from the Customs Authority and French Navy and use of drift forecasts provided by Météo-France in the Cedre summary given to authorities on December 24. (Source: Cedre)

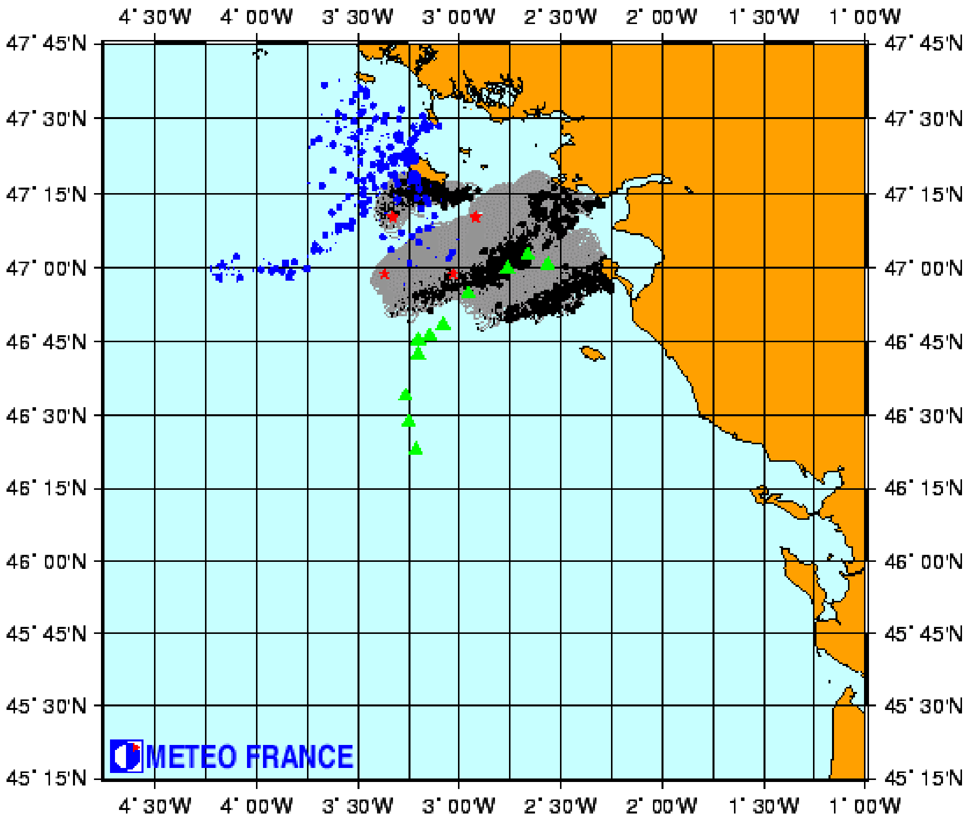


Figure 5: 48-hour forecast for December 26 at 00 UTC. Red stars show the initial observed positions of slicks, and black circles indicate the forecast pollutant positions two days later. Trajectories are shown in gray. Blue circles indicate the forecast positions of fuel spilled from the wrecks. Green triangles show positions of the Marisonde buoy.

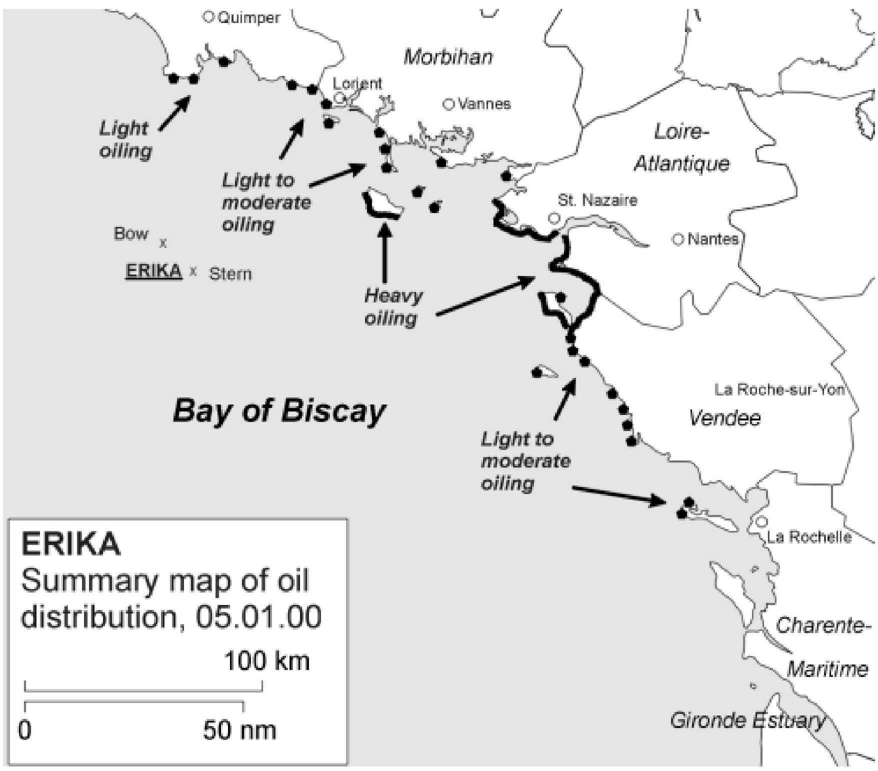


Figure 6: Coastline affected by the pollution (Source: ITOPF)

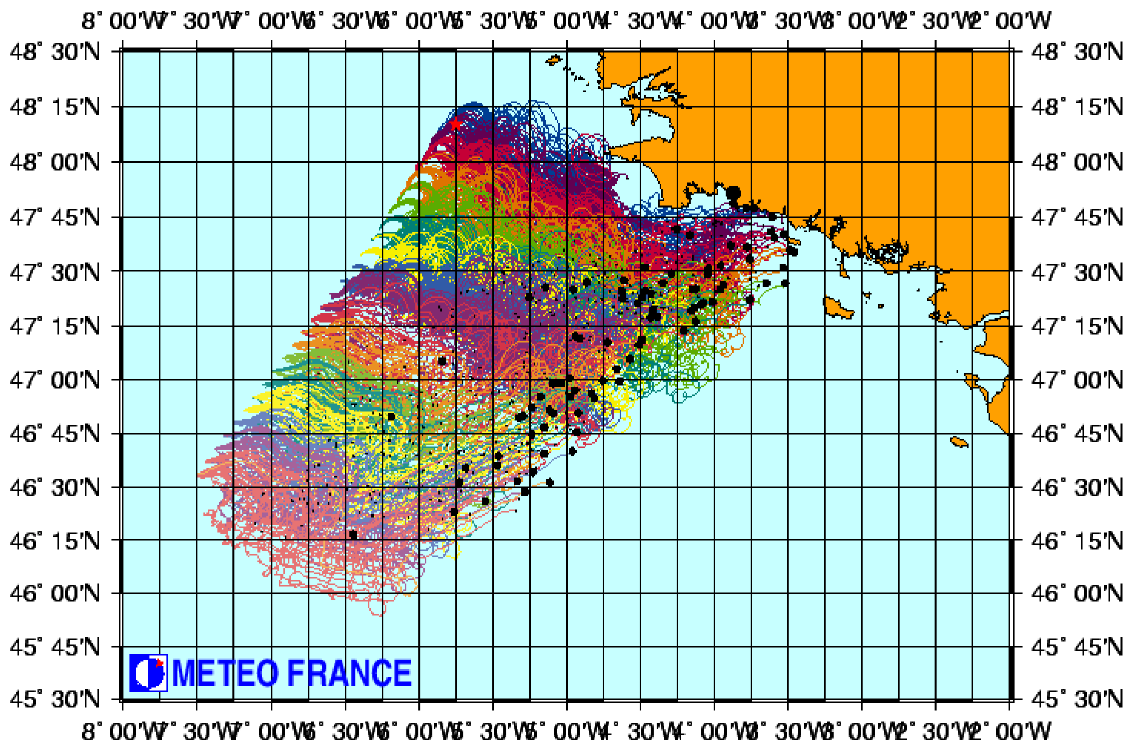


Figure 7: Continuous spilling on the ship's route. Forecast for December 25 at 12 UTC.

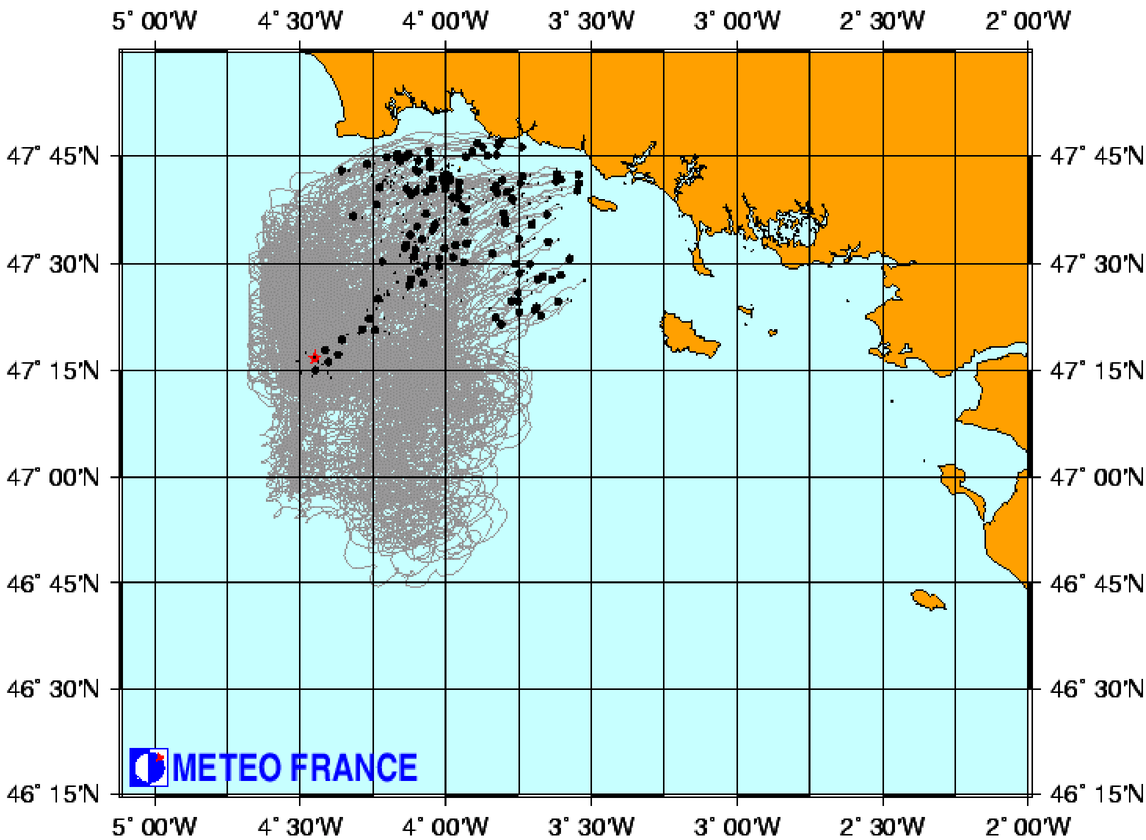


Figure 8: Continuous spilling from the wreck. Forecast for December 25 at 00 UTC.