Pergamon

Spill Science & Technology Bulletin, Vol. 3, No. 1/2, pp. 53–64, 1996

1353–2561/96 $15.00+0.00

PII: S1353–2561(96)00030–8

TECHNICAL NOTE

Operational Forecasting of Oil Spill Drift at Météo-France

PIERRE DANIEL
Météo-France, SCEM/PREVI/MAR, 42 avenue Coriolis, 31057 Toulouse Cedex, France
(Tel: 05 61 07 82 92; Fax: 05 61 07 82 32; E-mail: pierre.daniel@meteo.fr)

Météo-France has national and international responsibilities concerning marine oil pollution fighting:

- **In case of a threat of marine pollution by oil along the French coastline, the Préfet Maritime may request the services of Météo-France.**
- **Météo-France is engaged within the World Meteorological Organization (WMO) Marine Pollution Emergency Response Support System (MPERSS).**

Because of these engagements, Météo-France developed an oil spill response system. This system is designed to simulate the transport of oil in three dimensions. It consists of a hydrodynamic ocean model linked to an oil spill model including current shear, vertical movements and fate of the oil. The atmospheric forcing is provided by the wind and sea level pressure forecasts from a global atmospheric model. In the English Channel and the Bay of Biscay, a tide forcing is also included.

This oil spill response system is applicable anywhere in the world (with a coarser resolution far from the French coastline) and is available round the clock.

New developments, exercises and training are conducted jointly with the collaboration of CeDRE (Centre de Documentation de Recherche et d'Expérimentation sur les pollutions accidentelles des eaux).

Keywords: **Oil spill model, Torrey Canyon, Sea Empress.**

Observing the sea surface of the ocean and forecasting its evolutions is one of the missions of Météo-France. In case of marine pollution by oil, Météo-France provides assistance to the marine pollution emergency response operations authorities. Météo-France can intervene at a national level within the spill response plan POLMAR-MER in case of a threat for the French coastline, and at an international level within the Marine Pollution Emergency Response Support System (MPERSS) for the high seas. The MPERSS is a World Meteorological Organization (WMO) system implemented on an experimental basis since 1 January 1994. The purpose of this system is to provide a meteorological support to marine pollution emergency response operations on the high seas. The oceans and seas are divided into areas of responsibility where a national meteorological service is designated as area coordinator. Météo-France is the coordinator in area II and a supporting service in areas I, III and VII(B) (Fig. 1). The support to emergency operations may include a variety of elements such as: basic meteorological forecasts and warning for the area concerned, observation, analysis and forecasting of the values of specific meteorological and oceanographic variables required as input to marine pollution models, operation of such models and access to national and international telecommunication facilities.

Because of these engagements, Météo-France developed an oil spill response system, designed to simulate the fate and transport of oil in three dimensions. It consists of a two dimensional ocean model linked to an oil spill model including shear current, vertical movements and fate of the oil.

This oil spill response system is applicable for any location in the world and is available round the clock.

This paper summarizes the key features of the model and presents three examples of model applications:

- an application in hindcast mode for the *Torrey Canyon*;

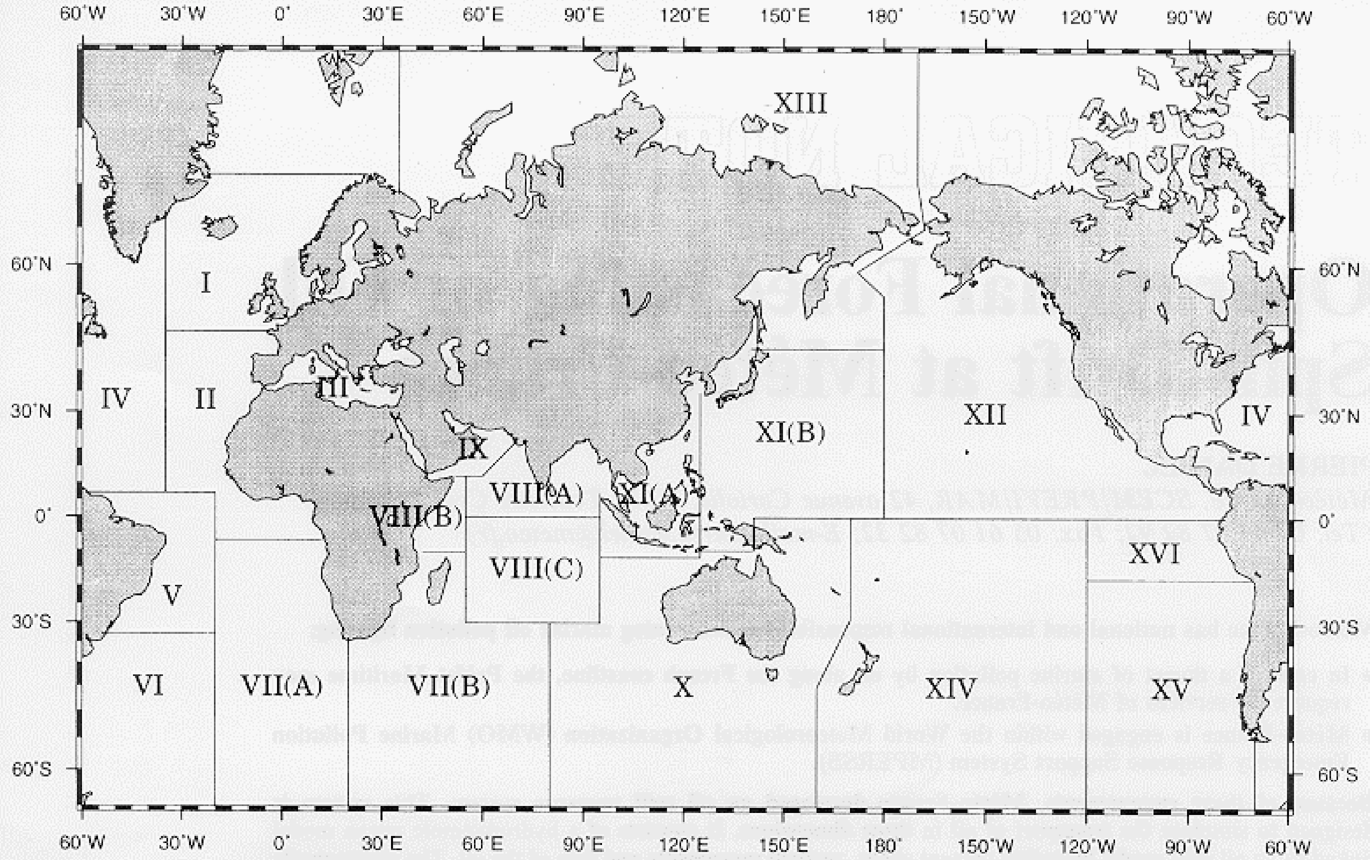

Fig. 1 MPERSS areas.

- an application in real-time mode for the Sea Empress accident;
- and an example of an exercise (Antipol 95).

Ocean Model

This part is designed to simulate the wind currents and tide currents.

The model is depth-integrated and solves the non-linear shallow water equations on a 5′ grid mesh:

$$\frac{\partial q}{\partial t} + q\nabla q + fk\wedge q = -g\nabla\eta - \frac{1}{\rho}\nabla P_a + \frac{1}{\rho H}(\tau_s - \tau_b) + A\nabla^2 q$$

$$\frac{\partial \eta}{\partial t} + \nabla(Hq) = 0$$

where t denotes time, q the depth-integrated current, the sea surface elevation, H the total water depth, f the Coriolis parameter, k a unit vector in the vertical, the atmospheric surface pressure, τ_s the surface wind stress, τ_b the bottom frictional stress, ρ the density of water, g the gravitational acceleration, A the horizontal diffusion coefficient (2000 $m^2\ s^{-1}$). These equations, written in spherical polar co-ordinates, are integrated forward in time on an Arakawa C-grid using a split-explicit finite difference scheme. The surface wind and bottom stresses are computed using a quadratic relationship. A gravity wave radiation condition is used at open boundaries.

The atmospheric forcing is provided by the winds and sea level pressure forecasts from a global atmospheric model. This model can be the model of the European Centre for Medium-Range Weather Forecasts (ECMWF) or the Météo-France model (ARPEGE).

In the English Channel and the Bay of Biscay, a tide forcing by 16 waves is included.

The bathymetry is extracted from marine charts for areas near the French coastline and from a global data base (Etopo5) for elsewhere.

Oil Spill Model

The oil slick is modelled as a distribution of independent droplets which move in response to shear current, turbulence and buoyancy. This approach to follow the movement of individual oil droplets has already been used in a number of oil spill models (Elliot, 1986; Venkatesh, 1990; Proctor *et al.*,

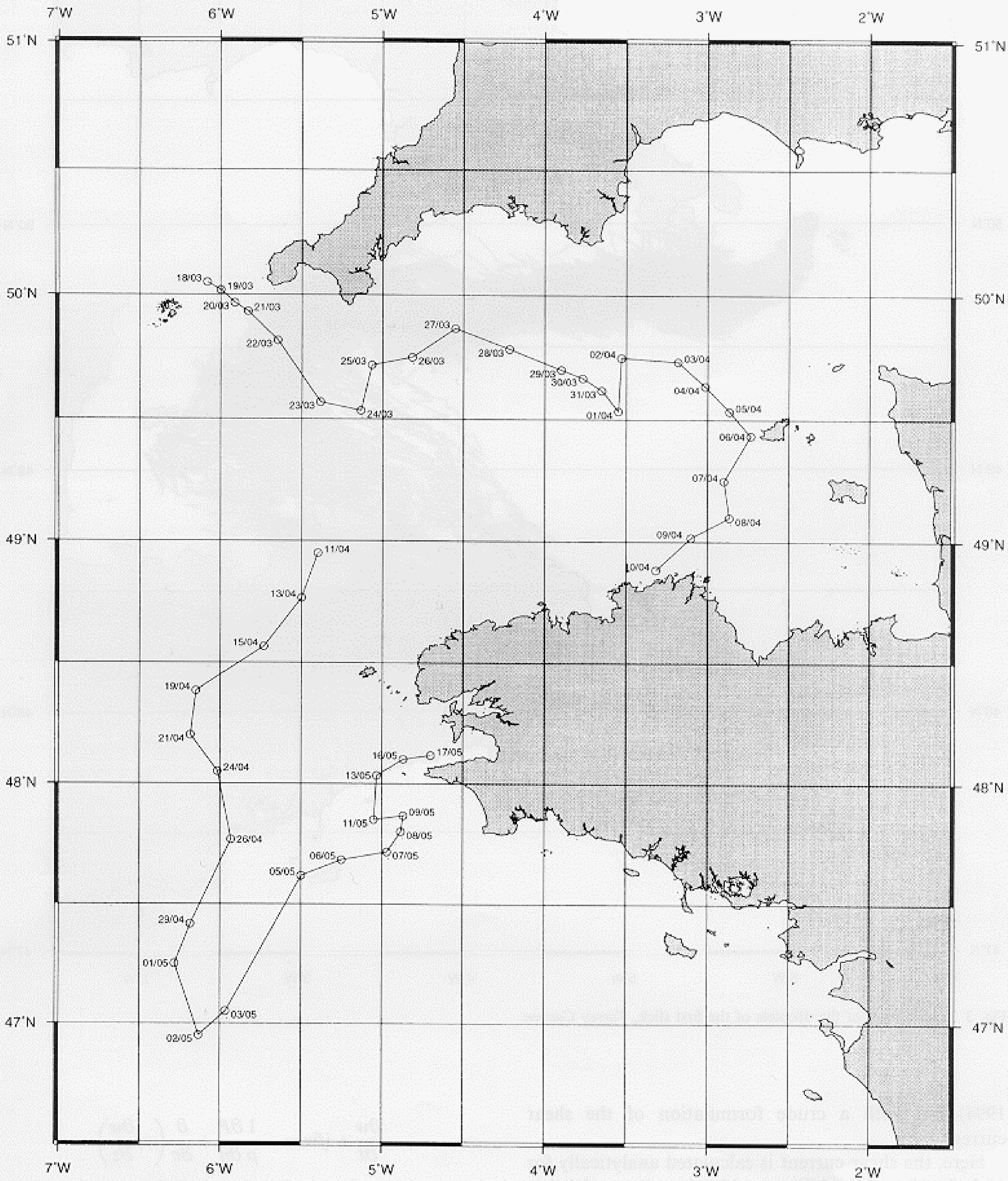

Fig. 2 Actual trajectory of the leading edge of the slicks, *Torrey Canyon* 1967.

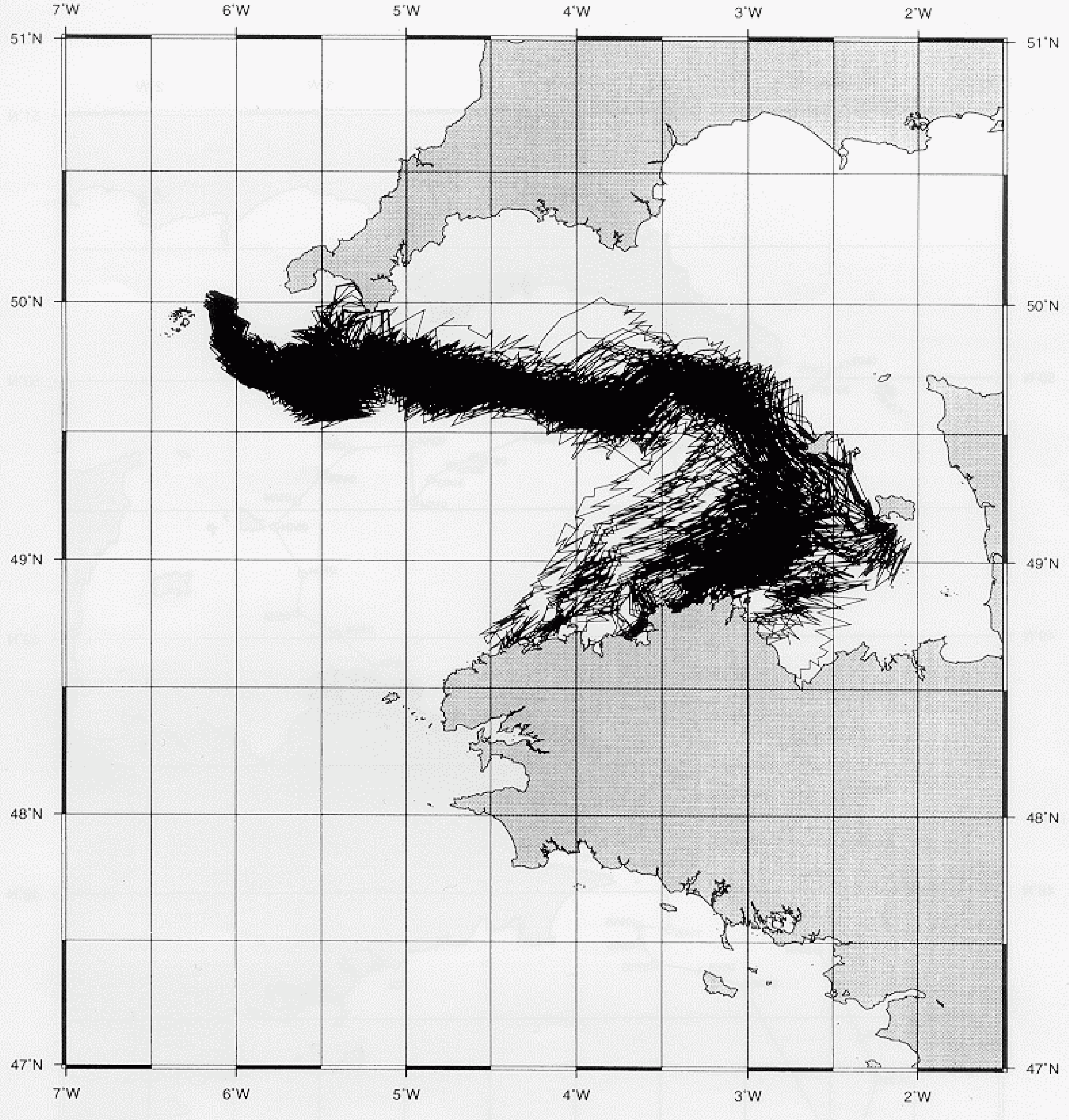

Fig. 3 Trajectories of the droplets of the first slick, *Torrey Canyon*.

1994) but with a crude formulation of the shear current.

Here, the shear current is calculated analytically for each droplet with a bilinear eddy viscosity model that assumes the vertical eddy viscosity to increase linearly with the distance from both the water surface and the bottom boundary (Poon and Madsen, 1991). The governing equation is:

$$\frac{\partial w}{\partial t} + \mathrm{i}fw = -\frac{1}{\rho}\frac{\partial P}{\partial n} + \frac{\partial}{\partial z}\left(\nu_t \frac{\partial w}{\partial z}\right)$$

in which $w = u + \mathrm{i}v$ is the horizontal velocity (u and v are the components of current), is an eddy viscosity and:

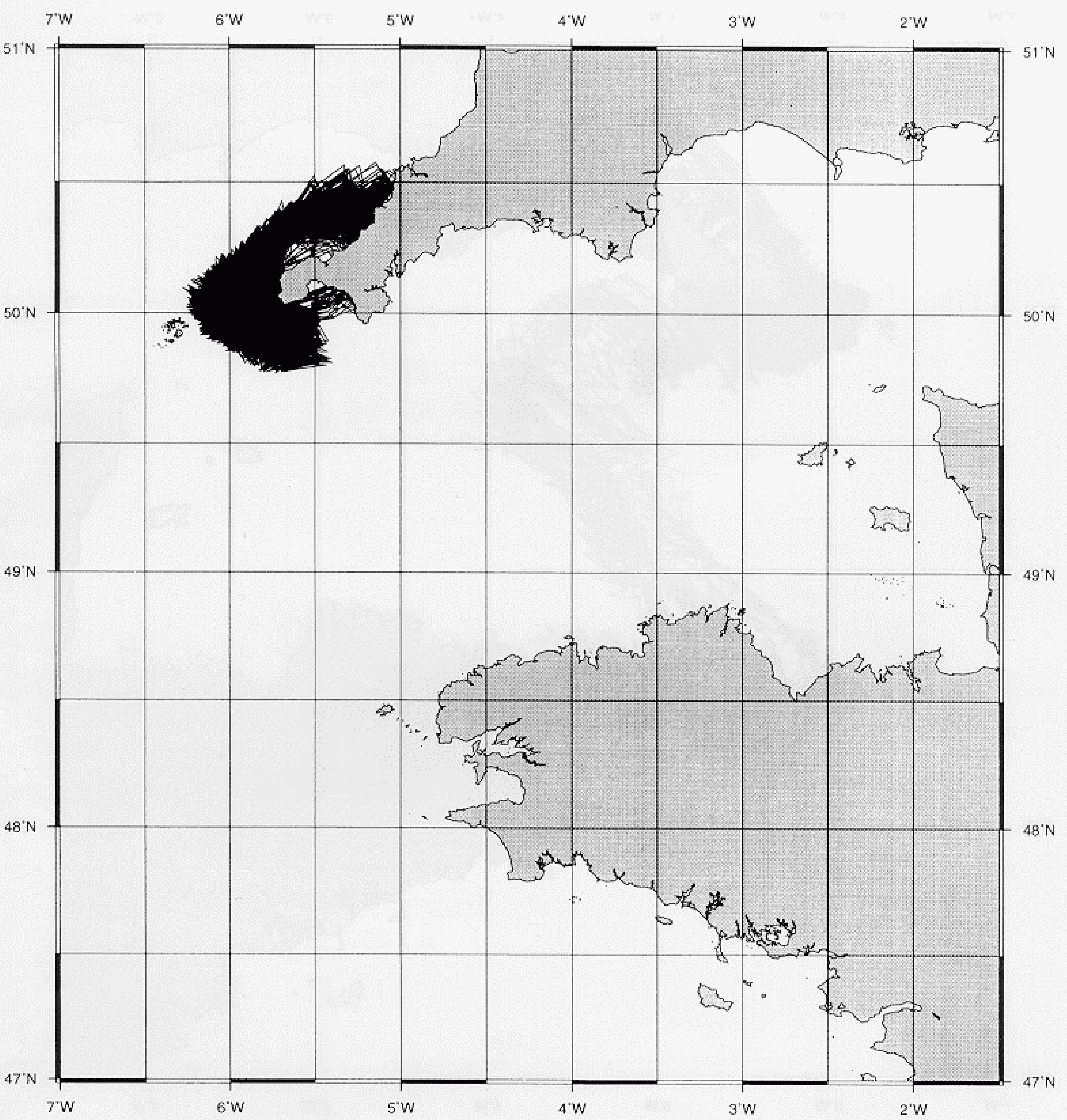

Fig. 4 Trajectories of the droplets of the second slick, *Torrey Canyon.*

$$\frac{\partial}{\partial n} = \frac{\partial}{\partial x} + i\frac{\partial}{\partial y}$$

The model is coupled to the ocean model by:

$$q = \frac{1}{H}\int_0^H w\mathrm{d}z$$

The turbulence (diffusion) is represented by a three-dimensional random walk technique.

In the horizontal, for a time step Δt, the motion is given by:

$$D_\mathrm{h} = R\sqrt{2K_\mathrm{h}\Delta t}$$

in the direction $\theta = 2\pi R$, where K_v is the horizontal diffusion coefficient and R a random number between

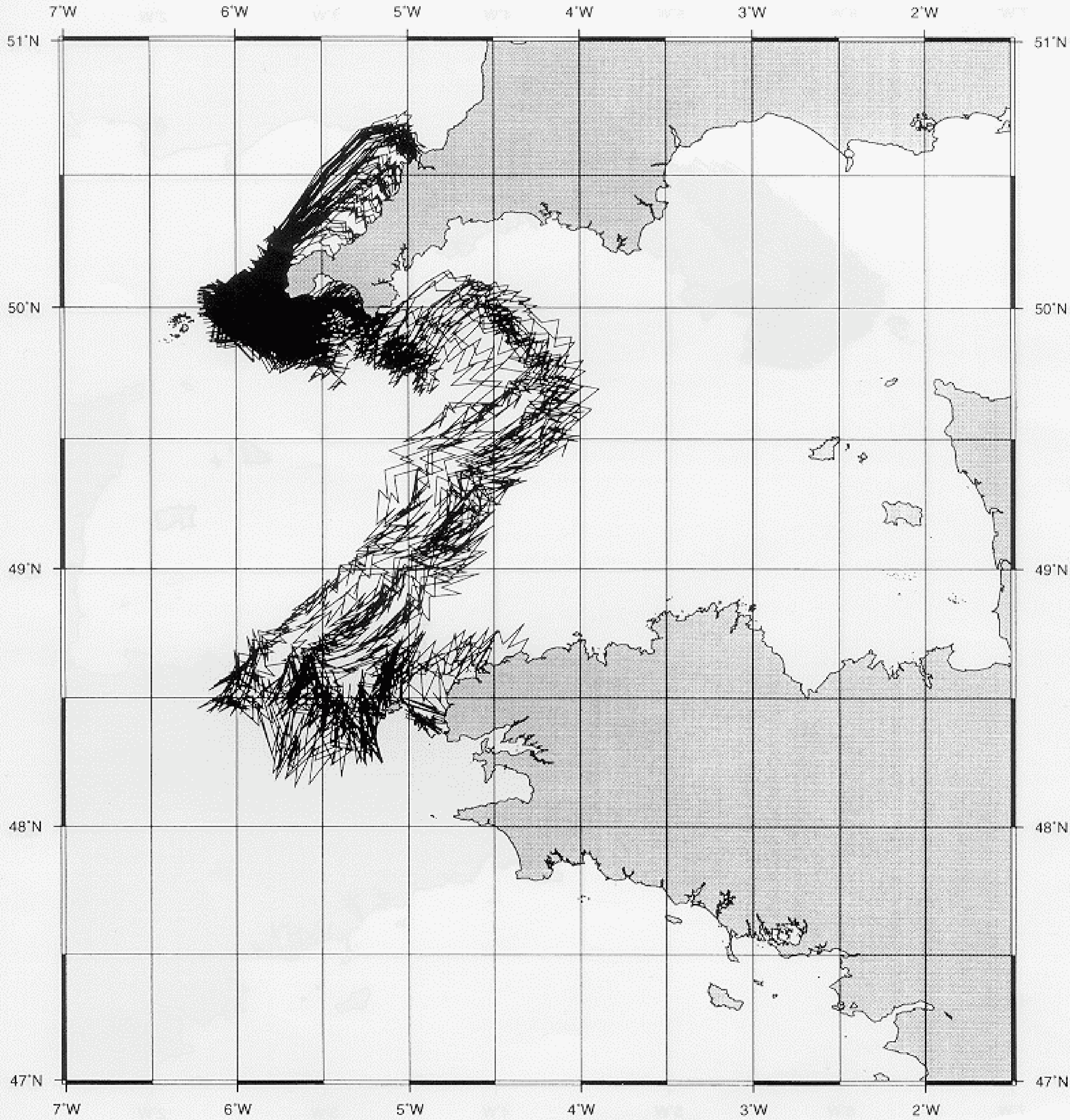

Fig. 5 Trajectories of the droplets of the third slick, *Torrey Canyon.*

0 and 1. In the vertical, the motion is:

$$D_v = (2R - 1)\sqrt{2K_v\,\Delta t}$$

where K_v is the vertical diffusion coefficient. The buoyancy force depends on the density and size of the oil droplets so that larger, more buoyant, ones tend to remain in the surface layer whereas the smaller droplets are mixed downwards.

The vertical speed U_f is (Elliott, 1986):

$$U_f = \frac{gd^2(1-\rho_0/\rho)}{18\nu}$$

for the small droplets $d \leqslant d_c$

$$U_f = \sqrt{\frac{8}{3}gd(1-\frac{\rho_0}{\rho})}$$

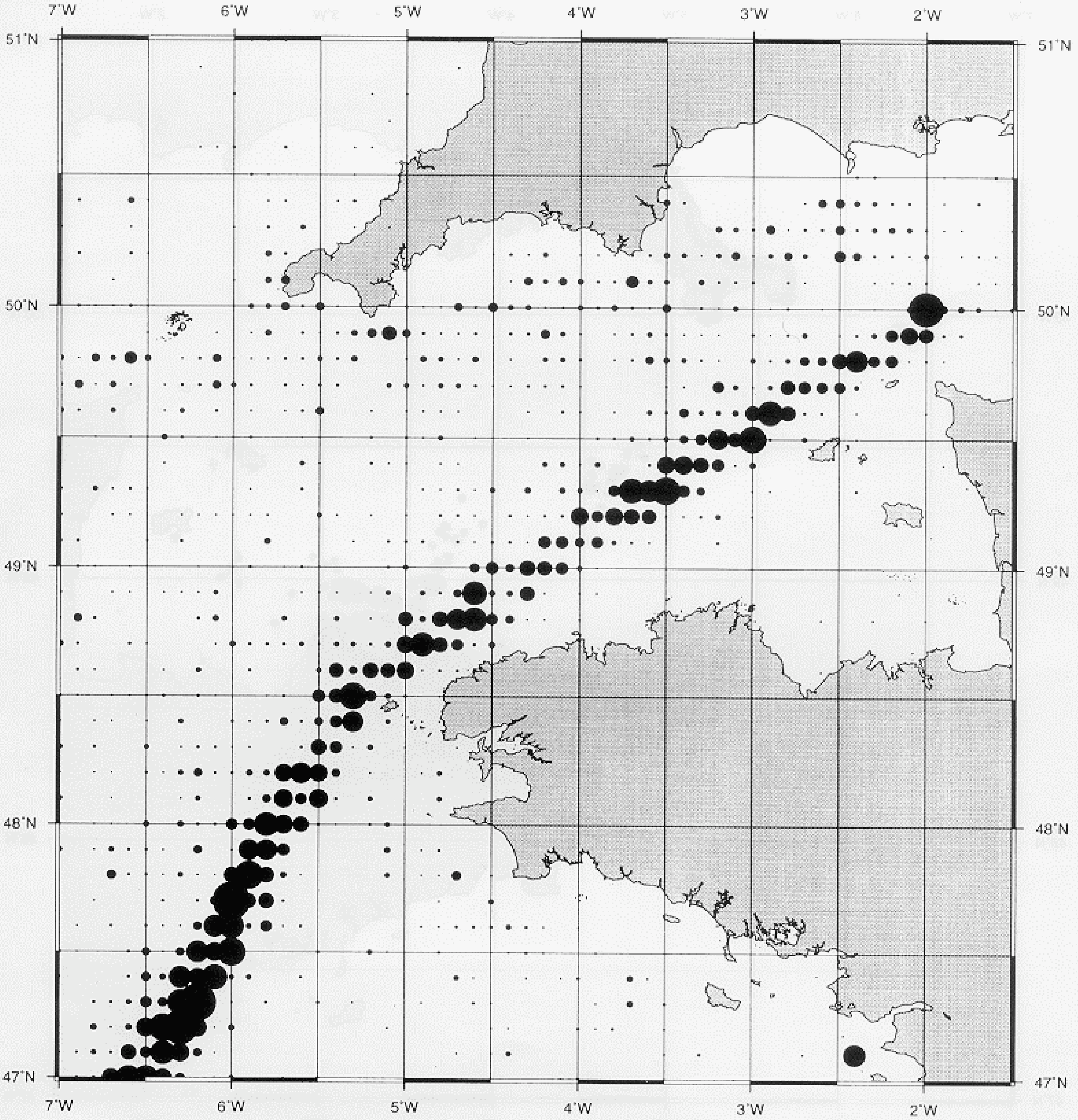

Fig. 6 Density of wind observations during the *Torrey Canyon* accident. (The size of the points is related to the number of observations).

for the large droplets $d > d_c$. The critical diameter d_c is:

$$d_c = \frac{9.52\nu^{2/3}}{\sqrt[3]{g(1-\rho_0/\rho)}}$$

with ρ the seawater density and ν the viscosity. About 65–70% 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.

Numerical Simulation: The *Torrey Canyon* Example

The model was calibrated on a few well documented pollution incidents such as *Torrey Canyon*, English

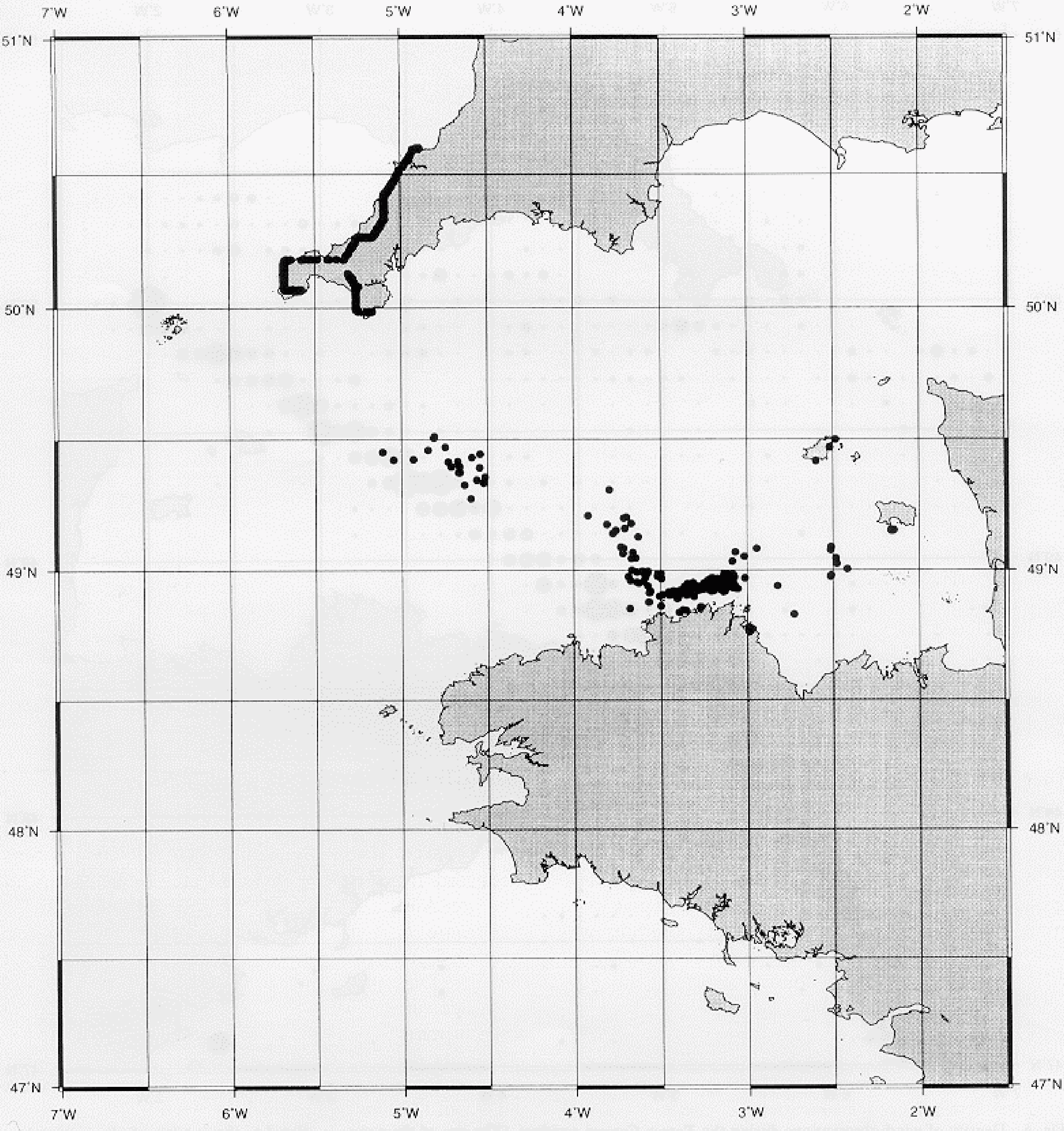

Fig. 7 Hindcast of the *Torrey Canyon* oil slick at 10 utc, 10 April 1967.

Channel, 1967 (Drici, 1994; Chaussard and Perrin, 1996), *Amoco Cadiz*, English Channel, 1978 (Drici, rd and Perrin, 1996; Chaussard and Perrin, 1996), *Tanio*, English Channel, 1980 (Chaussard and Perrin, 1996), Gulf War, Persian Gulf, 1991 (Dervillée and Jouvenot, 1993), *Aegean Sea*, La Coruna, Spain, 1992 (Daniel, 1995).

On 18 March 1967, the tanker *Torrey Canyon* ran aground on Seven Rocks reefs near the Scilly islands. 121 000 tons of crude oil were released into the sea. 30 000 tons were released immediately after the wreck. This slick moved across the Channel for 24 days and beached on the north coast of Brittany between Trébeurden and Bréhat island. Then it spread along the coast up to Morlaix river and Plouescat (Fig. 2). A second release (20 000 tons) spread along the Cornwall coastline. A third slick (50 000 tons) was released on 26 March when the

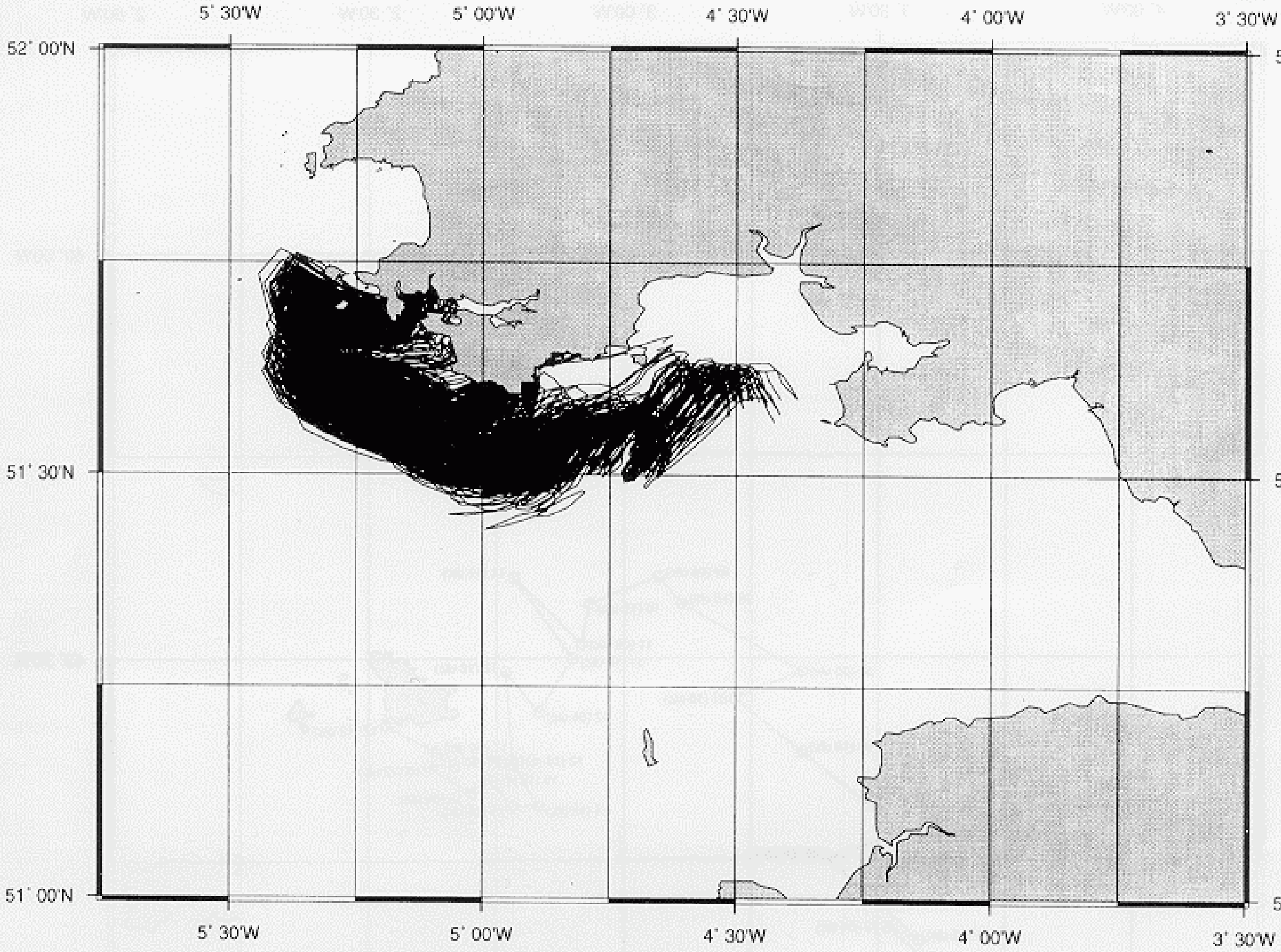

Fig. 8 Five day forecast trajectories of the droplets during the *Sea Empress* accident (starting from 5° 05′ W, 51° 32′ N).

wreck was broken into two parts. The slick moved across the Atlantic ocean offshore the Finistère coastline. It moved south until 2 May, and then moved to north east. Some limited pollution was reported on Douarnenez and Audierne on 19 May (Fig. 2). The last slick was burnt during the bombing of the wreck (28–30 March).

A two months simulation was carried out. A continuous release is assumed during 10 days, beginning on 18 March at 10 utc. During ten days, five droplets are released every 10 min. The atmospheric forcing, observed wind and pressure data, is issued from ships and buoys. An interpolation is made so that these data are available every 6 h on a 5′ grid mesh.

Figure 3 shows the trajectories of the droplets released from 18 March at 10 utc to 19 March at 14 utc. The temporal interval between each point is 6 h. The tide forcing appears clearly with a shift in the current every 6 h. The trajectories of the droplets fit exactly the observed trajectory. In particular, the simulated slick reached the coast on 10 April 1996 as it was observed.

Figure 4 shows the trajectories of the droplets released from 19 March at 14 utc to 25 March at 18 utc. All the droplets moved onto Cornish land.

Figure 5 shows the trajectories of the droplets released from 25 March at 18 utc to 27 March at 22 utc. During this period, winds were very light and the tide currents were predominant near the wreck. So the currents were alternatively north and south and the droplets moved alternatively to the south and to the north. Four packets of droplets moved to the north coast of Cornwall and three packets of droplets moved to the south. The trajectories of these droplets fit the observation during the first month of simulation and diverge after. The droplets move more slowly than observed across the Channel. The reason could be the lack of observations in this area (Fig. 6), so that the interpolation used observations closer to the coastline, and the winds were lower than actual winds.

Figure 7 shows the position of the droplets on 10 April 1967 at 10 utc. The first slick is reaching the coastline of Brittany. The second slick is entirely beached on the coastline of Cornwall. The third slick is in the middle of the Channel.

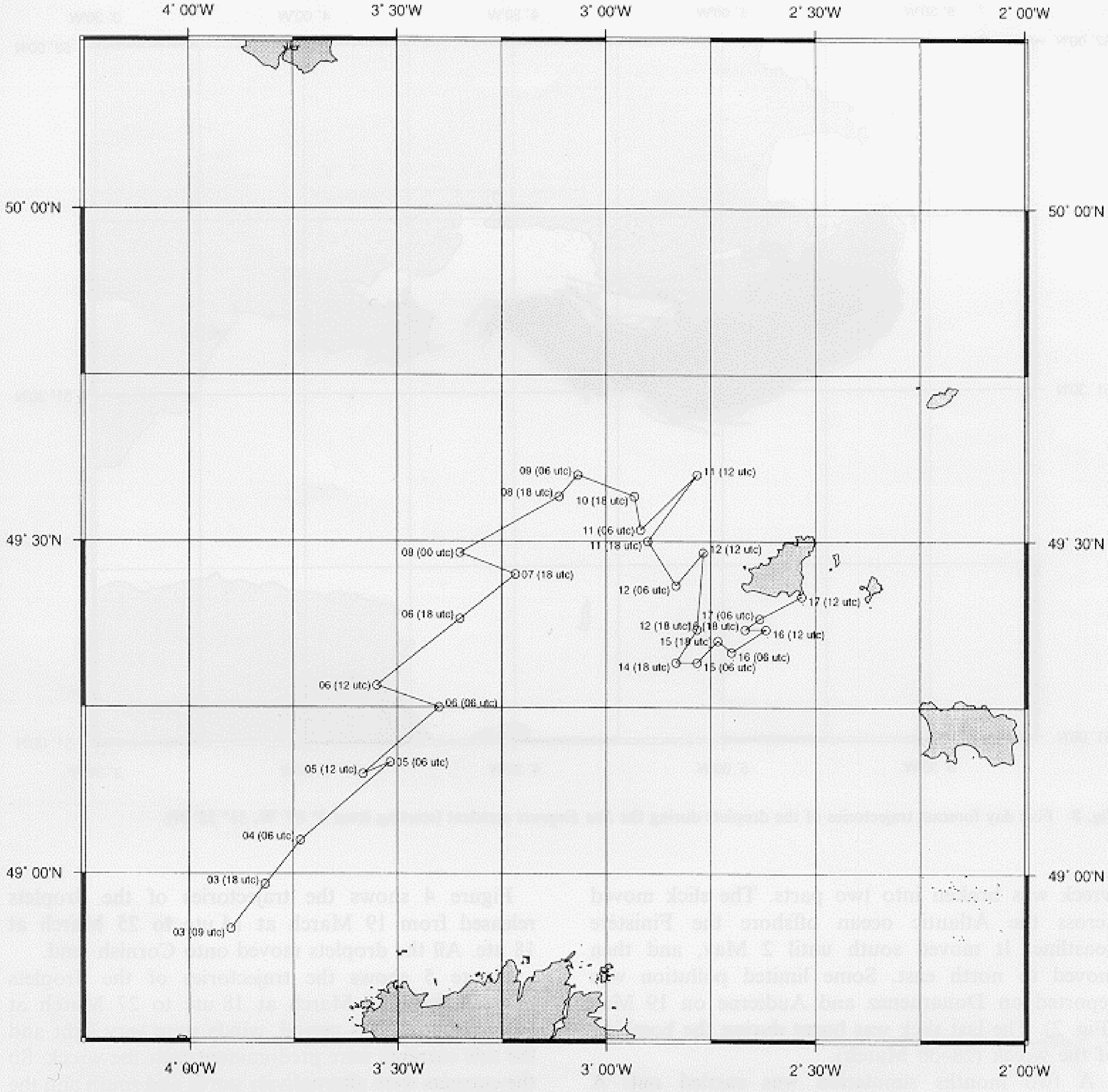

Fig. 9 Observed positions of the buoy during Antipol 95 (from 3 October 1995 to 17 October 1995).

The *Torrey Canyon* example showed that the model can accurately predict the movement of a slick provided that winds are accurate enough.

Real-Time Simulation: The *Sea Empress* Example

A meteorologist on duty at the marine service in Toulouse is able to run the model on request. He provides oil spill position, time and duration of the release and oil type (light crude oil, heavy crude oil, kerosene, gas oil, fuel oil, petrol). The model is then run for the required forecast period (typically 120 h). The output is oil spill position charts. A 120 h forecast can be carried out on a Cray C98 in a few minutes. This system enables an investigation of a forecast scenario to be made in real time.

During the *Sea Empress* accident (February 1996), CeDRE requested Météo-France to provide oil spill drift forecasts. Figure 8 shows the trajectories of the droplets for a five day simulation starting on the 22 February 1996 at 12 utc. The location of the slick was 5° 05′ W and 51° 32′ N. Wind and atmospheric pressure are provided by ECMWF model forecasts.

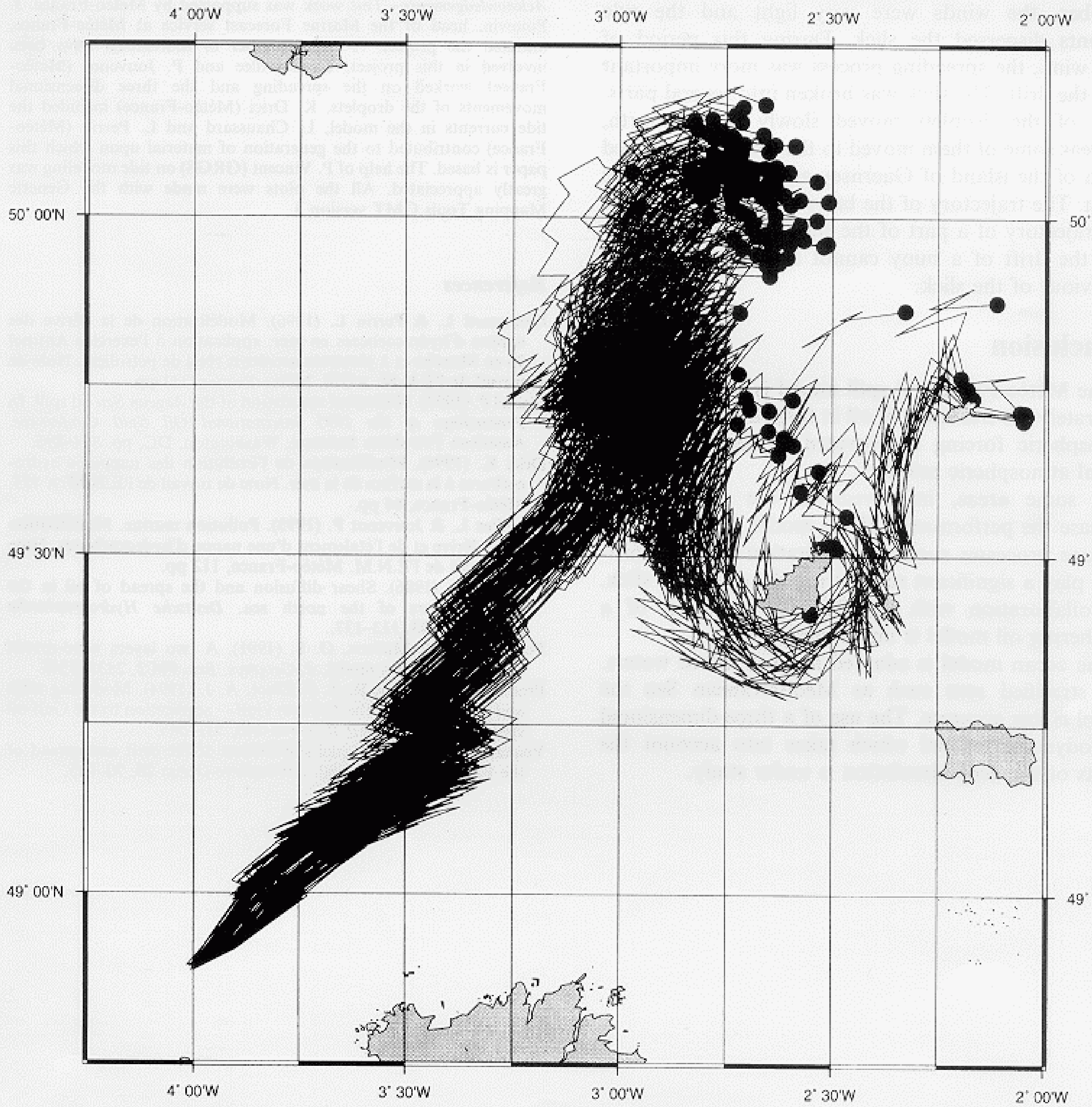

Fig. 10 Trajectories of the droplets (Antipol 95: from 3 October 1995 to 17 October 1995). The black disks indicate the position of the droplets on 17 October (12 utc).

First, the predicted slick moved to the west and then to the east which corresponded well with the observations.

An Exercise: Antipol 95

In association with CeDRE, the French Navy and Saudi Petroleum Overseas Ltd., Météo-France took part in the Antipol 95 exercise (3–4 October 1995).

Antipol 95 is a simulation of an accident with a tanker carrying 300 000 tons of light crude oil. The accident occurred north of Batz island (Brittany, English Channel) at 5 h 10 utc on 3 October 1995. The exercise included tug operations. A drifting buoy (NORDA type) simulated the oil slick drift. Figure 9 shows the trajectory of the buoy. For 2 days, Météo-France ran the model and sent oil slick drift forecasts to CeDRE. Figure 10 summarizes a 2 week model simulation. It shows the trajectories of the droplets starting from the position of the accident. There is one position every six hours. Wind and atmospheric pressure were issued from the ARPEGE model. At the beginning, the winds were Southwest and the droplets moved exactly as the buoy. From the 9

October, the winds were very light and the tide currents dispersed the slick. During this period of light wind, the spreading process was more important than the drift. The slick was broken into several parts: most of the droplets moved slowly to the north, whereas some of them moved to the south-east, passed south of the island of Guernsey and then went to the north. The trajectory of the buoy corresponds only to the trajectory of a part of the slick. It appears clearly that the drift of a buoy cannot represent the whole behaviour of the slick.

Conclusion

The Météo-France oil spill model is able to predict accurately the transport of oil in three dimensions. The atmospheric forcing is provided in real time by a global atmospheric model.

In some areas, improvements are necessary to increase the performance of the model.

Some processes such as evaporation or emulsification, play a significant role during the drift of a slick. In collaboration with CeDRE, the inclusion of a weathering oil model is under study.

The ocean model is adapted for well mixed waters. For stratified seas such as Mediterranean Sea the model is less accurate. The use of a three-dimensional hydrodynamic model which takes into account the effects of the deep circulation is under study.

Acknowledgements—This work was supported by Météo-France. J. Poitevin, head of the Marine Forecast service at Météo-France, initiated the project. A large number of individuals have been involved in this project. L. Dervillee and P. Jouvenot (Météo-France) worked on the spreading and the three dimensional movements of the droplets, K. Drici (Météo-France) included the tide currents in the model, L. Chaussard and L. Perrin (Météo-France) contributed to the generation of material upon which this paper is based. The help of P. Vincent (GRGS) on tide modeling was greatly appreciated. All the plots were made with the Generic Mapping Tools GMT version 3.

References

Chaussard L. & Perrin L. (1996). Modélisation de la dérive des nappes d'hydrocarbures en mer: application à l'exercice Antipol 95 en Manche et à plusieurs accidents réels de pétroliers. Note de travail de l'E.N.M. n°570. Météo-France, 111 pp.

Daniel P. (1995). Numerical simulation of the *Aegean Sea* oil spill. In *Proceedings of the 1995 International Oil Spill Conference*, American Petroleum Institute, Washington, DC, pp. 894–895.

Drici K. (1994). Modélisation de l'évolution des nappes d'hydrocarbures à la surface de la mer. Note de travail de l'E.N.M. n°453. Météo-France, 64 pp.

Dervillee L. & Jouvenot P. (1993). Pollution marine. Modélisation de la dérive et de l'étalement d'une nappe d'hydrocarbures. Note de travail de l'E.N.M. Météo-France, 112 pp.

Elliot, A. J. (1986). Shear diffusion and the spread of oil in the surface layers of the north sea. *Deutsche Hydrographische Zeitschrift* **393**, 113–137.

Poon, Y. K. & Madsen, O. S. (1991). A two layers wind-driven coastal circulation model. *J. Geophys. Res.* **96C2**, 2535–2548.

Proctor, R., Flather, R. A. & Elliot, A. J. (1994). Modelling tides and surface drift in the Arabian Gulf— application to the Gulf oil spill. *Continental Shelf Research* **145**, 531–545.

Venkatesh, S. (1990). Model simulations of the drift and spread of the Exxon Valdez oil spill. *Atmosphere-Ocean* **28**, 90–105.