A NUMERICAL STUDY OF MOVEMENTS OF AN OIL SLICK ON THE SEA SURFACE IN THE PERSIAN GULF FROM 25 JANUARY 1991 TO 1 FEBRUARY 1991*

P. Daniel , J. Poitevin
Météo-France
Toulouse, France

ABSTRACT

Potential problems concerning oil contamination waters has led researchers to develop effective numerical models to forecast oilslick movements.

By a simple but realistic approach movement depends on all sort of currents. These currents are superpositions of permanent currents, tidal current and currents provided by wind and atmospheric pressure effects.

Météo-France for marine forecasts used two global atmospheric models which produce forecasts of wind field and pressure field at sea level.

So a depth integreted ocean current model was developped to simulate currents using an efficient split-explicit finite difference scheme.

By this shallow water model initialized by wind and pressure fields, currents forecasts were produced.

The domain (23°N , 31° S) X (47° E , 58° E) of the currents forecasts model was chosen to simulate the oil slick pollution in the Persian Gulf during the last week of january 1991.

On this time period a crude oil slick moved from Kuwait coast governed by currents.

On meteorological aspects wind above the oil slick was at the beginning north-west 20 knots, the atmospheric model produced

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wind forecasts slowly veering south east. Wind forecasts were confirmed by meteorological analyses.

The main results of our study are to produce currents forecasts, position of oil slick forecasts. It will be shown a remote sensing determination of a presence or absence of oil slick by analysis of the backscattered winds given by satellites as ERS1.

1.0 INTRODUCTION

One year and a half ago, on the 19, 21, 23 or 26 january according to contradictory sources, Iraq opened the spigots of Kuwait main super tanker loading pier: the Sea Island terminal, 16 km offshore from the coast of Kuwait. Through pipes leading from giant storage tanks, millions of liters of crude oil had been poured straight into the water. At the same time, a half dozen of tankers were beeing emptied into the Gulf near Mina al-Bakr. The Iraquis may have released up to 800 000 tons, twenty times as much as the Exxon Valdez. 560 km of Saoudian coast were affected by the oil spill.

In order to fight this ecologic disaster, techniciens must know where is the oil slick and where it goes. This study provides a model for the prediction of its movements and a first approach o remote sensing determination of the slick.

2.0 THE MODELS

The surface water current is assumed to be the main factor influencing the motion of the oil slick. Hence, a two-dimensiona deterministic hydrodynamic model is used to provide surface current velocities and an oil slick model to provide the positions of the slick.

2.1 THE CURRENT MODEL

2.1.1 Equations of the model

The main short term variations in ocean circulation, particularl in a closed basin like Persian Gulf, are due to the surface wind stress and the atmospheric surface pressure. As a result, baroclinic effects can be neglected for predictions of sea circulation over periods of a few days in the Persian Gulf. Henc a depth-integreted model has been adopted for current prediction he model is driven by wind stresses, by atmospheric pressure radients, and by quadratic bottom friction. It includes non inear advection terms.

he equations of motion are:

$$\&u/\&t= fv - g\&s/\&x - 1/r_w \&P/\&x - (u\&u/\&x+v\&u/\&y) + (F_{sx}-F_{bx})/r_w h$$

$$\&v/\&t=-fu - g\&s/\&y - 1/r_w \&P/\&y - (u\&v/\&x+v\&v/\&y) + (F_{sy}-F_{by})/r_w h$$

he equation of continuity is:

$$\&s/\&t = -\&(uh)/\&x-\&(vh)/\&y$$

ith

$\&()/\&t$, $\&()/\&x$, $\&()/\&y$: partial dérivatives
f : Coriolis parameter
h : water depth
P : atmospheric surface pressure
u,v : components of the depth-integreted current
s : sea surface elevation
g : gravitational acceleration
r_w : density of water
F_{sx}, F_{sy} : surface wind stress
F_{bx}, F_{by} : bottom friction

2.1.2 Integration Procedure

The model solves the nonlinear shallow water equations, which are integreted forward in time on a Arakawa C-grid (Mesinger and Arakawa 1976) using a split-explicit finite difference scheme. The numerical solution scheme is decribed in detail in Hubbert and al. (1990), together with a stability analysis.

2.1.3 Wind and bottom stresses

The surface wind stress is computed using the quadratic relationship:

$$Fsx = c_d\ r_a\ (U^2 + V^2)^{1/2}\ U$$

$$Fsy = c_d\ r_a\ (U^2 + V^2)^{1/2}\ V$$

with

U,V : componants of wind velocity 10 m above the sea surface
r_a : density of air
c_d : drag coefficient

For wind speeds below 25 m/s c_d is given by the expression (Smith and Banke 1975):

$$c_d = (.63 + .066(U^2 + V^2)^{1/2})\ 10^{-3}$$

For wind speed above 25 m/s the dependence of c_d on wind is reduce and is given by:

$$c_d = (2.28 + .033((U^2 + V^2)^{1/2} - 25.))\ 10^{-3}$$

The bottom stress is computing using the quadratic relationship with the depth-integrated current:

$$F_{bx} = r_w\ K\ (u^2 + v^2)^{1/2}\ u$$

$$F_{by} = r_w\ K\ (u^2 + v^2)^{1/2}\ v$$

with

K : bottom friction coefficient (K = .002)

2.1.4 Bathymetry

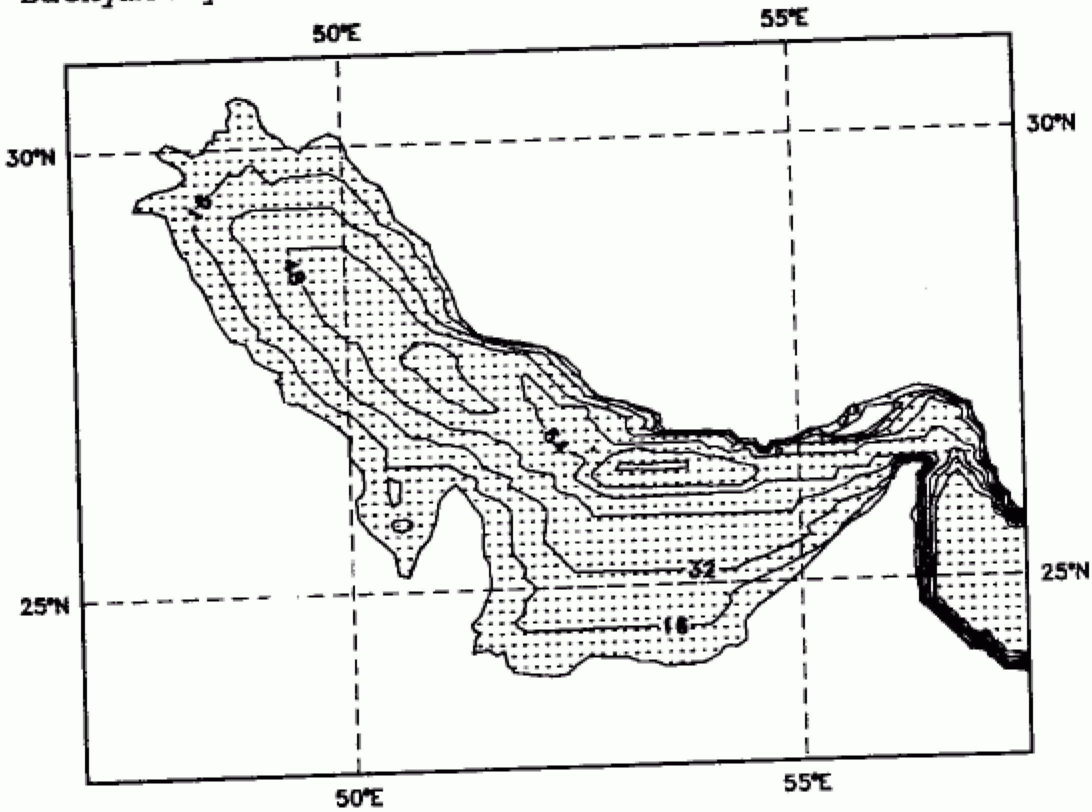


Figure 1. Bathymetric contours of the Persian Gulf at contour intervals of 16 m..

2.1.5 boundary conditions

At coastal boundaries the normal component of velocity is zero. At open boundaries the sea surface elevation is set equal to barometric displacement due to the deviation of the surface pressure from a specified mean value (1013.25 hPa):

$$s = (101325-P)/r_w g$$

2.1.6 grid mesh and time step

The grid mesh is 13.89 km.(1/8 degree) and the time step used for a stable solution is 4 minutes.

2.2 THE OIL SLICK MODEL

The slick is assumed to consist of an ensemble of small discrete quantities of mass or parcels. The movement of each parcel is assumed to be independent of the movement of other parcels in the ensemble. The mass concentration of oil is depicted by the number of parcels in a given area. The transport of the slick parcel is due to the advecting current and is simulated using a lagrangian approach. With this approach, the problem of numerical instability is eliminated and the source and sink terms can be included easily.

3.0 NUMERICAL SIMULATION

In order to test the accuracy of the present model, it is used to simulate the wind-driven currents in the Persic Gulf during the last week of january 1991.
On this time period a crude oil slick moved from Kuwait coast governed by currents.

3.1 ATMOSPHERIC FORCING

3.1.1 The data

The European Centre for Medium range Weather Forcasts (ECMWF) model provides a good source of atmospheric forcing data at the sea surface. The archieved analyses produce an atmospheric-forcing data-set containing nine days of six-hourly surface pressures and winds at 10 m with a resolution 1 x 1 degrees. A bilinear interpolation provides a 1/8 x 1/8 degrees data set. The result of this interpolation is shown on figure 2.

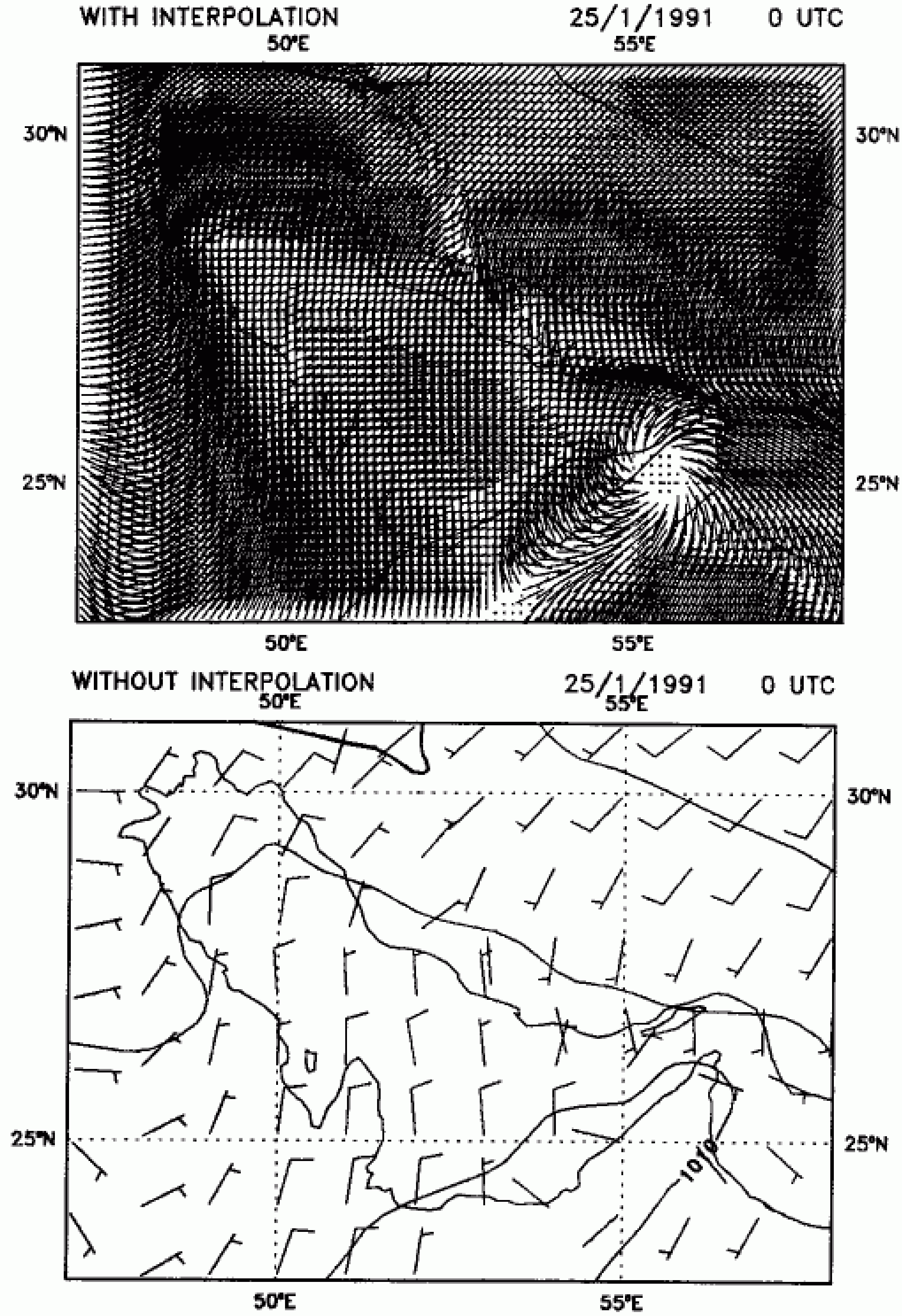


Figure 2 Synoptic chart showing mean sea level pressure and wind at 10 m with and without interpolation

3.1.2 Synoptic conditions during the spill period

On 25 january and 26 january, a surface high pressure center over Irak associeted with moving lows over the south of Saudi Arabia produced moderate northwesterly to northeasterly winds. By 12 UTC on 27 january a surface high pressure centre strengthened over Irak and produced northwesterly winds. The presence of a low over Gulf of Oman produced the intensification of those winds up to 20 kt over the Persic Gulf.
By 12 UTC on 29 january the ridge of high pressure moved to the east and by 06 UTC on 30 january the winds became from southeast over the north part of Persic Gulf. By 00 UTC on 31 january a low pressure centre formed over Kuwait and the southeast winds strengthened up to 20 kt. This low filled on 1 february and the winds shifted to north and became moderate.(figure 3)

3.2 CURRENT MODEL RESULTS

Several model simulations were conducted with different starting date in order to test the spin up period. It seems to be around two days. Finaly, the 20 january was chosen as a starting date. Figure 3 shows the currents for the period 25 january-1 february. The general circulation of the Gulf is characterized by a large cyclonic gyre driven by north-westerly winds which prevail all over the year (S.H.O.M.,1990). The model reproduces this flow. Indeed, north to north-west winds blow during the first days of the simulation. The gyre intensifies on the western and southern side along the coast of Saudi Arabia. By 30 january, the south-east winds affects the currents and the gyre decays into eddies. (figure 4)

3.3 OIL SLICK MOVEMENT

Positions of oil slicks cannot be seen on the NOAA satellite imagery. Only the fumes over sea island can be seen.
Three spills were considered: one from Sea Island and two others from tankers sinked near Mina al-Bakr and Fao. A continuous spill is assumed since 25 january at 00 utc. Oil was released in discrete parcels at 4-minutes intervals. The results are shown in figures 5. The lack of data concerning the actual positions of the slicks doesnot permit to conclude on the accuracy of the model; but the general movement of the slicks (towards south) fits the description made by the media (Time, 11/2/1991) during the Gulf war.

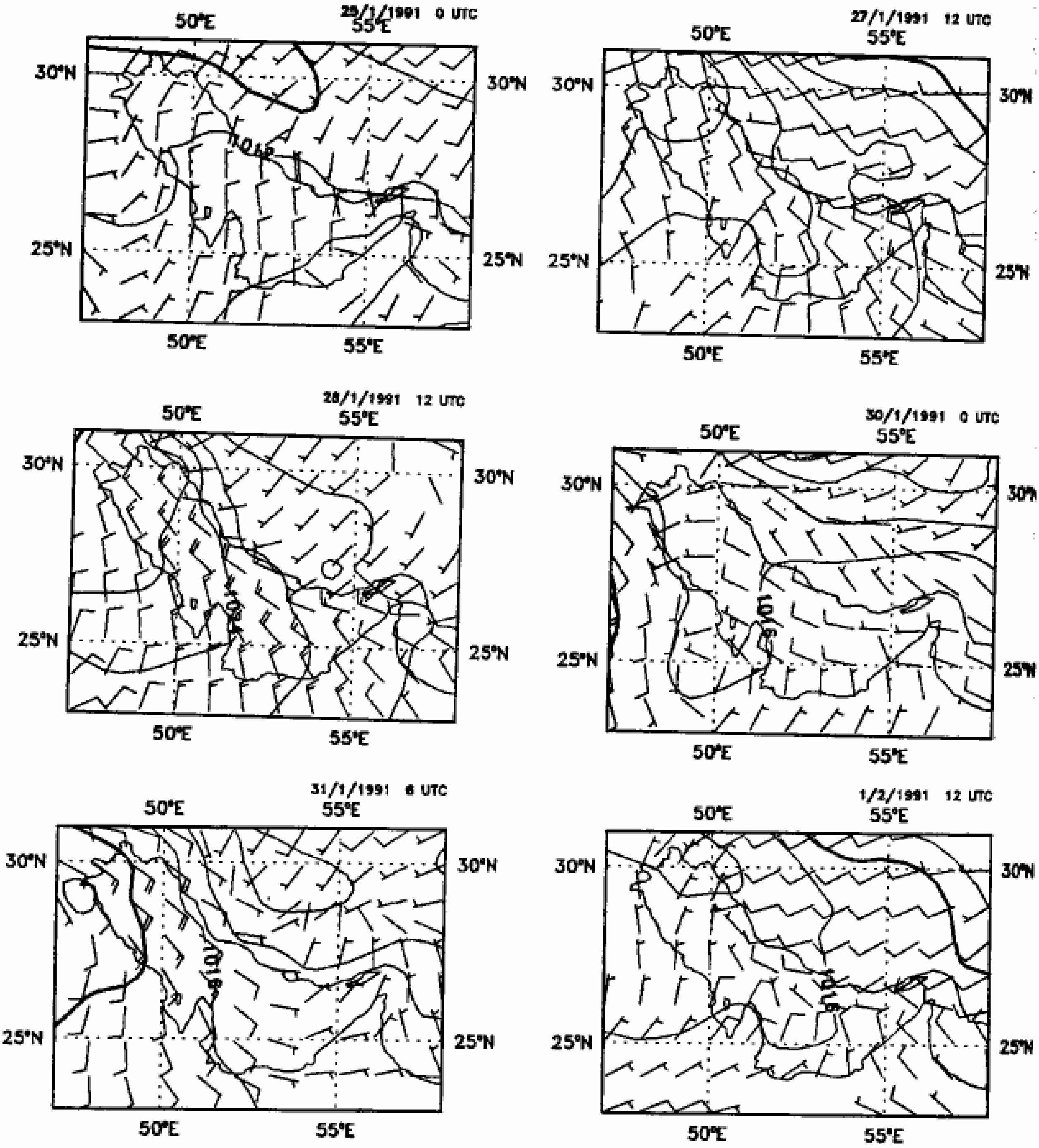
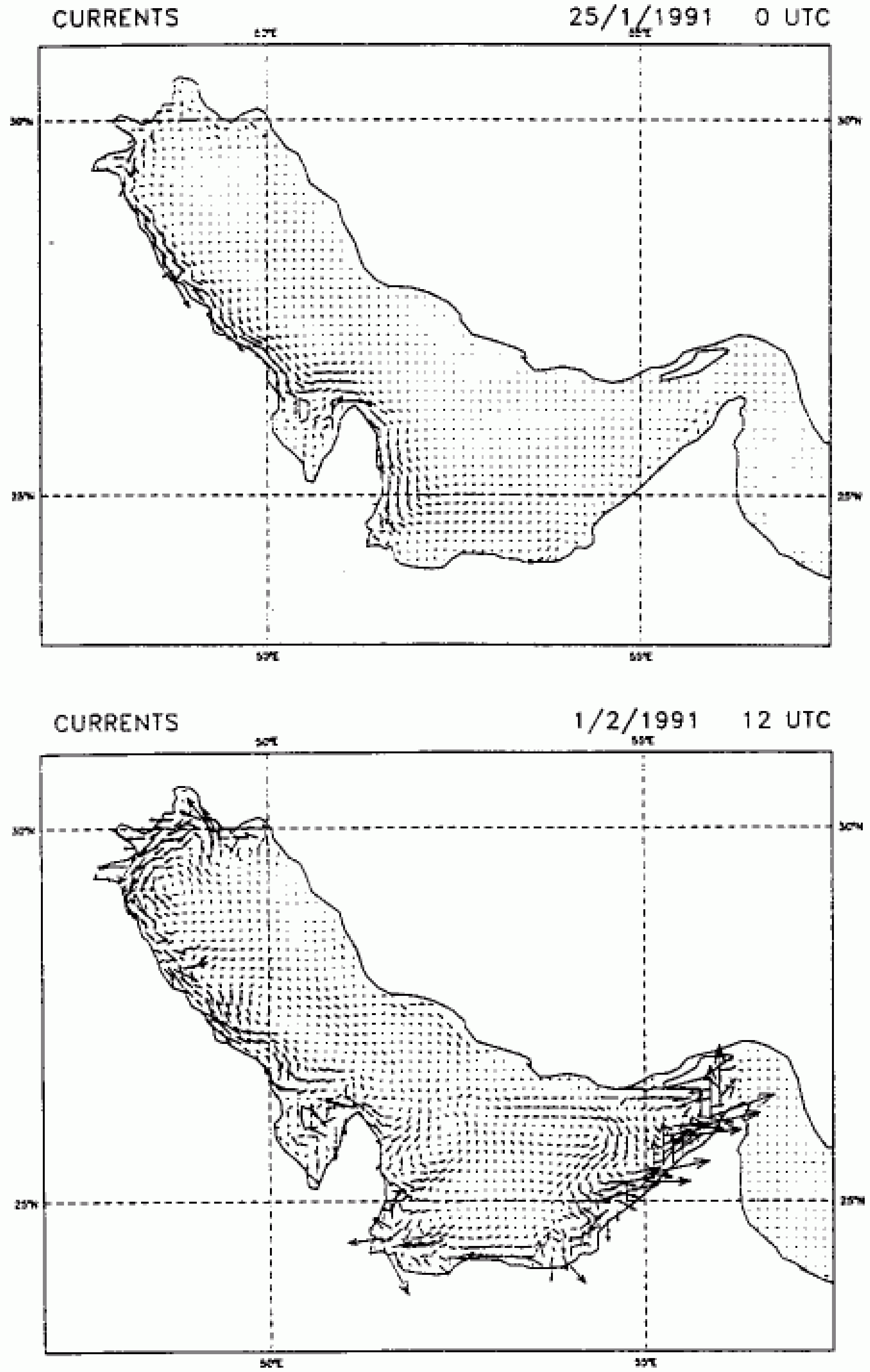


Figure 3. Synoptic charts showing mean sea level pressures and winds at 10 m for the period 25 january-1 february 1991.



gure 4. Depth-integrated currents predicted from the model for the period 25 january-1 february 1991.

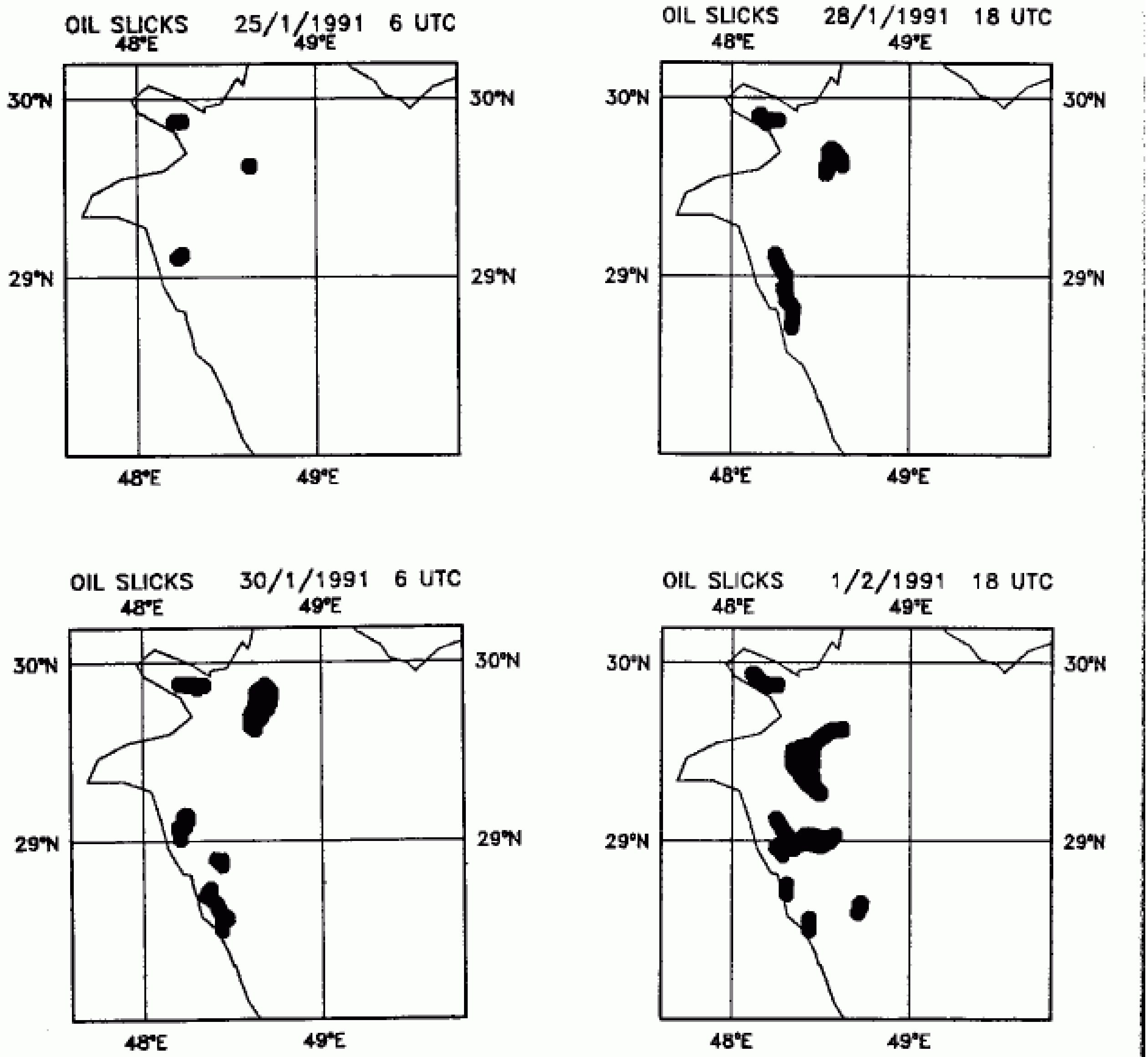


Figure 5. Model simulated oil slicks for the period 25 january-1 february 1991.

4.0 REMOTE SENSING APPROACH

resence of oil slicks decreases the backscattered response as it howed in J.Poitevin and C.Kharif, 1992, hence the wind field bserved by this instrument also decreases. By a meteorological nalysis and a comparison between wind field analysis and remote ensing wind field it can be seen anomalies related to the ocean ature

5.0 CONCLUSION

he model for oil slick predictions described here is built round a deterministic hydrodynamic model. The wind-driven water urrents are computed using depth-averaged shallow-water quations. The oil slicks are directly avected by those currents ith a lagrangian approach. A simulation was made for the Persian ulf during the period 25 january-1 february 1991. The movements f the slicks were reasonably well simulated according to the bservations related by the media.
his work on the Persian Gulf made with atmospheric analyse data s now extended everywhere in real time in order to produce oil licks movements forecasts calculated with atmospheric forecast ata. The quality of these forecasts increases by backscattered ind assimilation, soon this assimilation will be completely one.
This developing work will continue with modelling the physical rocesses such as spreading, evaporation, dissolution, etc.

6.0 ACKNOWLEDGEMENTS

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