A modelling study of the drift and fate of large oil spills in seven sub-regions of the North Sea and the English Channel

Project : BE-AWARE II
Author : Sébastien Legrand
Reference: MFC/2015/SL/BE-AWARE/modelling_report_v1.0
Document version: 1.1
Date: 2015/08/18 – updated on 2015/11/12

Contents

1 Introduction

The BE-WARE I and II projects are projects coordinated by the Bonn Agreement secretariat in order to further develop and coordinate risk reduction and the response capacities to face oil pollution in the greater North Sea. The projects are based on risk assessments, gap analysis and regional and sub-regional approaches. As part of the projects different alternative measures are analysed to ensure that investments in future response and risk reducing technologies deliver the optimal effect compared to their cost at the regional and sub-regional scale.

The BE-AWARE I project, which ran from 2012-2014, laid the ground for this analysis by assessing the risk of maritime accidents and oil spills both now (2011) and in the future (2020). However, in order to assess which methods and technologies will be most effective in reducing the risk for accidents and in optimising the response to oil pollution, further analysis is required.

BE-AWARE II therefore models the outflow of oil from the spills predicted in BE-AWARE I for ten different response or risk reducing scenarios, taking into consideration the hydrodynamics of the North Sea Region as well as different oil recovery methods. This will be combined with an analysis of the environmental and socioeconomic sensitivity of the region to assess the damage in the different scenarios. Based upon these and the cost of implementing the measures, risk management conclusions will be developed specifically for each of the 5 project sub-regions (Figure 1).

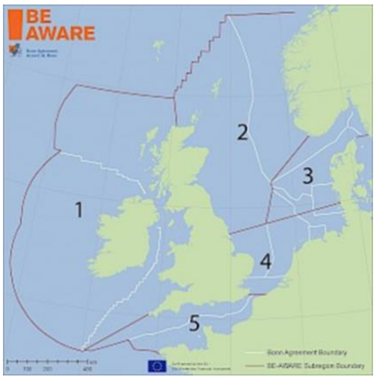


Figure 1 The 5 sub-regions of the BE-AWARE projects

The project is a two year initiative (2013-2015), co-financed by the European Commission (DG ECHO), with participation from the Bonn Agreement Secretariat, and the authorities responsible for oil spill response in Belgium, Denmark, France, the Netherlands, Norway, Sweden and the United Kingdom, and co-financing from Ireland and Germany. COWI has been mandated as main consultant to carry out most of the technical work. RBINS-MUMM is acting as sub-consultant, providing its expertise in the North Sea hydrodynamics and operational oil spill modelling.

COWI's strategic model is based on a system of models describing the full chain of the main processes involved. The model-system provides "the risk of spilled oil at a certain place in the model area where the oil originates from likely and unlikely accidents of any type at any part of the model area in any weather condition taking into account the effect of the response capacity on site" (BE-AWARE Method's note, version 4.1).

Since the project frames does not allow explicitly simulating all the possible accidents using three-dimensional oil drift and fate model, COWI's strategic model includes assumptions and simplifications. In order to validate the latter, RBINS-MUMM has been tasked to simulate with its model OSERIT the drift and fate of 10,000m^3 of light crude oil released from 7 predefined locations around the North Sea and the English Channel.

This report presents and discusses the simulation results and is organised as follows. The methodology is explained in section 2. This includes a comprehensive description of the OSERIT model and of the processes it is able to simulate in section 2.1 and a detailed presentation of the simulated scenarios in section 2.2. Section 3 presents the simulations results. Although simulations have been performed in three dimensional (i.e. including the sub-surface drift), the discussion is deliberately oriented towards the time evolution of the surface fraction of the slick. In addition, in order to prevent useless repetitions, only the results of the first simulation are fully described. The other results are mainly presented in comparison to this simulation. In the fourth section, similarities and differences are discussed in order to draw attention on processes that are not taken into account in COWI's strategic model. Finally, conclusions and recommendations are presented in the last the section.

2 Method

2.1 OSERIT

This chapter presents a description of the three-dimensional oil spill drift and fate model OSERIT.

OSERIT is an acronym for 'Oil Spill Evaluation and Response Integrated Tool', a 3D oil spill model that was developed by RBINS-MUMM modellers to provide Belgian decision makers[1] with relevant information on oil drift and fate for the first few days of a pollution.

Balancing on the one hand the state-of-the-art techniques in oil spill modelling and on the other hand the operational needs of the spill responders as well as the reality of the field during an emergency event (large uncertainties on oil type and released volume; limited, sparse and sometimes contradictory information available during a crisis management…), OSERIT shall simulate the dominant processes that drive the drift and fate of oil on the sea surface and in the water using a 'Lagrangian particles tracking technique' and empirical parameterizations.

The hereunder description presents the general principles of the OSERIT model. Interested readers can found an extended presentation of OSERIT's equations in Dulière et al. (2012).

According to the Lagrangian particles tracking technique, the oil spill can be divided into a large number of particles; each particle represents a fraction of the total oil volume and drifts and weathers independently from the other oil fractions.

Particles located at the sea surface behave as thin oil slicks that drift under the combined effect of winds (leeway drift), surface water currents and waves (Stokes drift) and that can

[1] i.e. MUMM duty personnel, Belgian Coast Guard Centres and other Belgian governmental authorities involved in oil pollution response at sea.

evaporate, emulsify and spread (Figure 2). Evaporation is computed following the analytical approach developed by Fingas (1996; 1997; 2011). Emulsification is computed as a function of oil characteristics and significant wave height as in Scory (2005). Following Garcia et al. (1999) the endogenous spreading[2] of oil over the water surface is simulated by adding to the drift velocity, random velocities computed from a time dependent diffusion coefficient. The latter is computed from a complex empirical parameterization as a function of time, oil volume, oil density, sea water density and sea water viscosity. Finally, oil density and oil viscosity is updated at each time step as a function of the fresh oil characteristic, sea water temperature, oil evaporated fraction, oil emulsified fraction and the volume of sea water trapped in the emulsion.

Under the action of breaking waves, oil slicks floating at the sea surface can partially be split into smaller droplets and propelled into the water column. The volume of oil that is naturally dispersed as sub-surface oil droplets, the size of these droplets and the depth at which they are propelled, depend on oil characteristic, oil weathering and sea state. OSERIT simulates natural dispersion by randomly selecting Lagrangian particles from the sea surface and propelling them to a depth that is proportional to the significant wave height as in Guo ansd Wang (2009). The natural dispersion rate is computed following Tkalich and Chan (2002). The radius of the naturally dispersed oil droplets is randomly set in the range between 0.1 and 3 mm.

Consequently, subsurface Lagrangian particles must behave in OSERIT as a cloud of small oil droplets that can drift under the influence of subsurface currents and waves. The horizontal and vertical turbulent diffusive transport is expressed using a random walk technique as in Wang *et al.* (2008). Finally, oil resurfacing is simulated by computing an upwards velocity that is a function of the oil droplet diameter, the oil density and the sea water density and the sea water viscosity. In OSERIT, subsurface oil does not weather. The subsurface oil density and viscosity remain therefore constant as long as oil has not resurfaced.

[2] Endogenous spreading is defined as the spreading of an oil slick floating at the sea surface due to the combined actions of gravity, interfacial tension between oil and seawater and the internal stresses inside the oil slick (Fay, 1971). External forces acting on the slick such as wind and current shear stresses as well as the resurfacing of submerged oil in the tail of a slick are not included in the endogenous spreading.

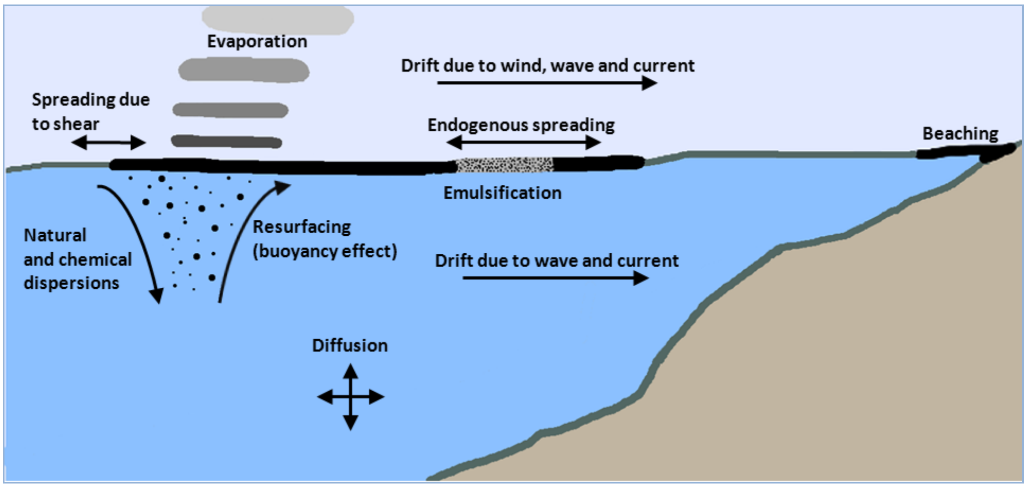


Figure 2 Processes included in the OSERIT oil spill drift and fate model

Figure 2 represents all the processes simulated by OSERIT. It is worth to remind that these processes are the leading processes during the first week of the pollution. However, other processes that are not implemented in OSERIT can drive the fate of the pollution on a longer time scale. Among these processes, let's just mention

- oil dissolution,
- oil oxidation (that lead the formation of the crust of the tarry masses),
- oil-sediment interaction,
- oil sedimentation,
- biodegradation,
- bioaccumulation (e.g. oil ingested by fishes).

These limitations must always be kept in mind when interpreting a simulation result.

2.2 Simulated scenarios

2.2.1 7 release locations

In this study, we analyse the drift and fate of a large oil spill released from 7 predefined sub-areas of the North Sea and the English Channel (Figure 3) under moderate South-West wind condition.

ID	latitude of release	longitude of release
1	55.344248°	-0.570362°
2	53.270657°	0.955147°
3	51.808296°	2.435936°
4	53.844237°	6.556097°
5	54.141761°	8.373349°
6	55.256874°	7.850822°
7	50.146886°	-1.076817°

Figure 3: The 7 release locations.
The limits of the map correspond with the domain covered by OSERIT's 3D version.

2.2.2 Initial conditions

For each of the 7 release locations, two simulations have been performed in spring conditions (one with beaching included, one without, see sections 2.2.4 OSERIT set-up). The initial conditions of all the simulations assumed a spill of 10,000 m^3 of Brent blend light crude oil, forming a circular slick at the sea surface of 1 km radius and about 3.18 mm thick (Table 1).

Oil characteristic	Oil type	Brent blend (Light crude oil)
	Oil volume	10,000 m^3
	Oil mass	~8,350 tons
	Weathering state	Fresh (viscosity at 15°C = 4.5 cSt; density = 0.835 kg/m^3)
Surface spill, circular shape	Radius	1 km
	Area	3.14 km2
	Oil Thickness	3.18 mm
	Bonn Agreement Oil Appearance Code	100% continuous true oil colour

Table 1 : Initial conditions

2.2.3 Met-ocean forcing

This study is based on OSERIT's 3D version as implemented at RBINS for operational applications. This version of the model covers the English Channel from 4°W and the North Sea up to 57°N (Figure 4) and requires met-ocean forcing from 3 different sources (Table 2):

- Atmospheric conditions (i.e. air temperature and wind at 10 meters above water surface) as forecasted by the global model of the UK Met Office
- Hydrodynamic conditions as forecasted by MUMM's operational hydrodynamic models OPTOS-NOS and OPTOS-BCZ (including 3D current, sea surface elevation and turbulent vertical diffusivity)
- Sea state as forecasted by MUMM's operational version of the model WAM (including wave period, direction and significant height)

Figure 4: Domain covered by the 3D version of OSERIT

In order to allow COWI to validate the results they obtained with their strategic oil spill model against OSERIT results (cf. method note), OSERIT simulations had to be done for a time period of 14 consecutive days during which a rather constant South-West wind(±60°) of about 7.5m/s (±2.5 m/s) was blowing on the whole North Sea and the English Channel. Even if these conditions correspond to the dominant winds, such wind conditions usually last only a couple of days after which wind speed or direction changes. However, the weather conditions generally match our selection criteria between the 15th of May 2011 and the 29th of May 2011 so that the met-ocean forcing have been rerun for that time period.

	Atmospheric forcing	Hydrodynamic forcing	Waves forcing
Parameters	• air temperature • wind at 10 meters above water surface	• 3D current • sea surface elevation • sea water temperature • turbulent vertical diffusivity	• significant wave height mean wave period • mean wave direction
Provider	UK met office (global NWP forecast)	RBINS-MUMM, models BCZ and NOS	RBINS-MUMM, WAM model
Time resolution	6 hours	1 hour	1hour
Space resolution	~60km	~750m in Belgian waters ~5km elsewhere	~2km

Table 2: Met-ocean forcing used by OSERIT. To obtain consistent and realistic forcing, RBINS-MUMM hydrodynamic and wave models have been rerun using the UK met office atmospheric forcing for the time period between the 15th and the 29th of May 2011.

2.2.4 OSERIT set-up

OSERIT set-up has been prepared activating all the processes described in section 2.1. As an acceptable trade-off between simulation accuracy and CPU time, the 10,000 m^3 oil spill has been discretized by 50,000 Lagrangian particles. Each particle initially stands for an oil volume of $0.2m^3$.

The model time step is of 10 minutes, meaning that the position and weathering condition of each particle is updated every 10 minutes taking into account the surface and subsurface drift due to wind, current and wave, natural dispersion, resurfacing, evaporation, emulsification and endogenous spreading.

Oil spill can also beach. In this case, two different extreme scenarios can be considered.

In the ***scenario with beaching activated***, every particle floating at the sea surface that reaches a land point of the model domain is stopped and no re-entering is possible. On the contrary, beaching of subsurface oil (i.e. dispersed in water column) is not permitted.

In the ***scenario with beaching not activated***, no particle is allowed to beach. This is done by blocking (i.e. not updating the position of) any particle that is pushed on-shore at a given time-step. However, the same particle can freely drift away at the next time step. This situation corresponds to a scenario in which the totality of the beached oil can 'be re-suspended' at the next high water and further continues its drift.

Of course, the reality is between these two extreme scenarios, when only a fraction of the beached oil is re-suspended at the next high water.

3. Results

For each of the 7 release locations, two simulations have been performed; the first one with beaching activated and the second one without beaching activated.

In this section, we present and explain the results of these 14 simulations. OSERIT simulates all processes conjunctly. The processes therefore influence each other, what makes the results analysis more difficult. Although OSERIT explicitly simulates the subsurface oil drift, we decided to mainly present the time evolution of the surface slicks, their position, area, thickness, density, viscosity, and weathering state. Indeed, all these parameters determine the efficiency of the combat strategies.

3.1 Interpreting OSERIT results

3.1.2 Mass balance

The mass balance plot is a convenient way to analyse the time evolution of all the different processes in a single plot (Figure 5).

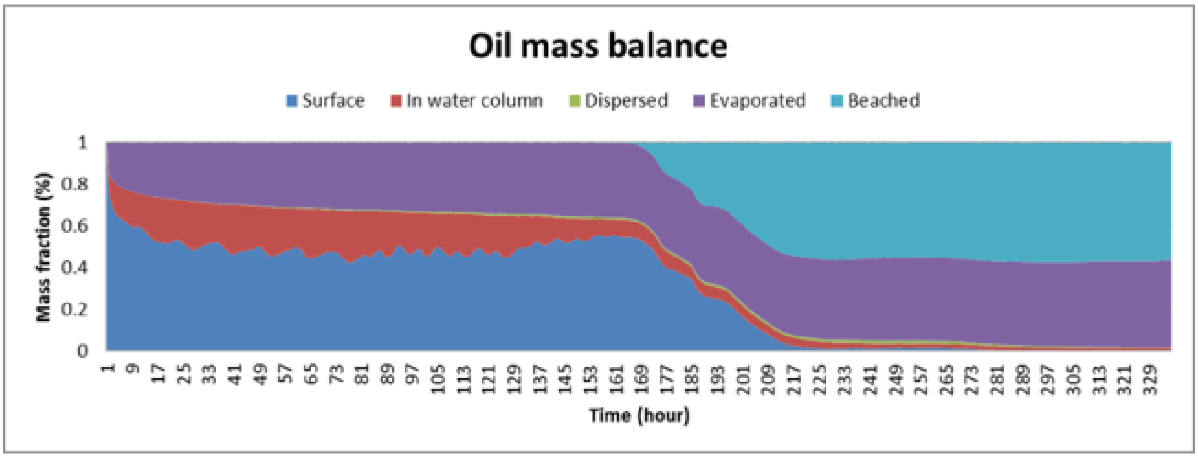


Figure 5: The mass balance graph presents the time evolution of the initial fresh oil volume in terms of 5 fractions.

Summarising the behaviours of all the Lagrangian particles used in the simulation, the mass balance plot shows the time evolution of the fractions of the oil volume

- that is floating at the sea surface, forming a slick with a thickness larger than 0.04 µm;
- that is naturally dispersed in the water column (the subsurface drift is explicitly computed in the simulation);
- that is evaporated in the atmosphere;
- that has beached on the shoreline or that has drifted out of the model area;
- that is floating at the sea surface but forming a too thin slick to be detectable (dispersed). The thickness of this slick is smaller than 0.04 µm (Table 3).

To be consistent in time, these fractions are computed without taking into account the volume of the seawater that is trapped in the emulsion.

For instance, the mass balance plot in Figure 5 clearly illustrates the dynamic equilibrium there exists between on the one hand the action of the breaking waves that naturally dispersed part of surface into small oil droplets that mix within the water column and on the other hand the buoyancy of the dispersed droplets that drives oil resurfacing. This plot also shows that in this simulation, 20% of the oil volume was evaporated during the first 12 hours of the pollution and that another 25% during the following 13 days.

Code	Oil appearance	Oil slick thickness (m)	Oil volume per km^2
-	Hardly visible by human eye	< 4 *10-8 m	< 0.04 m^3/ km^2
1	Sheen	4*10^{-8} - 3 *10^{-7} m	0.04 – 0.3 m^3/ km^2
2	Rainbow	3*10^{-7} - 5 *10^{-6} m	0.3 – 5 m^3/ km^2
3	Metallic	5*10^{-6} - 5 *10^{-5} m	5 – 50 m^3/ km^2
4	Discontinuous true oil colour	5*10^{-5} - 2 *10^{-4} m	50-200 m^3/ km^2
5	Continuous true oil colour	≥ 2 *10^{-4} m	≥ 200 m^3/ km^2

Table 3: Bonn Agreement Oil Appearance Code

3.1.1 Oil spill density and viscosity

Oil density ρ and viscosity ν are the basic quantities that evolve as a function of the evaporated oil fraction, the emulsified oil fraction and the volume of sea water contained in the emulsion. In oil spill modelling, these quantities are important because they are usually used as a proxy to estimate the efficiency of the various combat strategies.

In the report, the plotted density and viscosity are actually the algebraic mean of all the quantities associated to every Lagrangian particles, independently from their location and drift status.

Generally speaking, because of the rapid evaporation of the lighter chemical compounds contained in the oil, oil density and viscosity rapidly increases during the first 12 hours of the simulation. After this, the oil density and viscosity evolves more steadily as a function of the evaporation and emulsification.

3.1.3 Oil slick shape, thickness and position

One of the drawbacks of the Lagrangian particles tracking technique is that there is neither a direct nor a standard method to retrieve the actual position, shape and thickness of the simulated oil slick.

The method developed in OSERIT consists in clustering the Lagrangian particles floating at the sea surface as a function of their position. For each cluster the slick thickness is computed as the ratio between the oil volume still contained in all the Lagrangian particles of the cluster and the cluster area.

The smart idea in OSERIT is to link the grid resolution Δx used for the particle clustering to the oil volume V_o initially contained in the slick, the number of Lagrangian particle N used to discretized the slick and the threshold thickness h_{min} (=0.04 µm) as defined in the Bonn Agreement Oil Appearance Code:

$$\Delta x = \sqrt{\frac{V_o}{N * h_{min}}}$$

Therefore, the smallest the oil volume initially associated to each Lagrangian particle, the most accurate will be the computed slick shape and thickness.

In our scenario, $V_o = 10{,}000\text{m}^3$ and N = 50,000 so that the grid resolution for the particle clustering $\Delta x \approx 5km$.

Computing oil thickness at each time steps provides valuable pieces of information on the slick position, its size, shape and dispersion. For instance, the development of the sheen tail is clearly a consequence of the resurfacing of oil that has been naturally dispersed within the water column and that has drifted slower than surface oil because it was no more pushed by the wind.

3.2 Spill off the North-Eastern English coast

The first release location lies at 60 km off the North-Eastern English coast (55.34°N, 0.5703°W). Because of the South-West wind, the spill crossed most of the central North Sea in 14 days to arrive at about 150 km of Danish coastline.

3.2.1 Simulation with beaching activated

Figure 6 shows the time evolution of the oil density, oil viscosity, oil mass balance and oil slick spreading as computed by the simulation from the release location #1. The evolution of the oil slick during the first hours after the oil release is dominated on the one hand by the evaporation of the light oil compounds and on the other hand by natural dispersion within the water column.

After only 6 hours, 21% of the initial oil volume is evaporated and another 20.4% is naturally dispersed in the water column. These percentages respectively increase to 24% and 26% after 12 hours and 26% and 34% after 24 hours. Otherwise said, 50% of the initial oil volume was no more recoverable after 12 hours and 60% after 24 hours.

The fast evaporation of the light compounds has also a significant impact on the oil density and oil viscosity. After 24 hours, oil density and viscosity respectively increases up to 878 kg/m^3 (+43 kg/m^3 with respect to fresh oil) and 25cSt (+400% with respect to fresh oil).

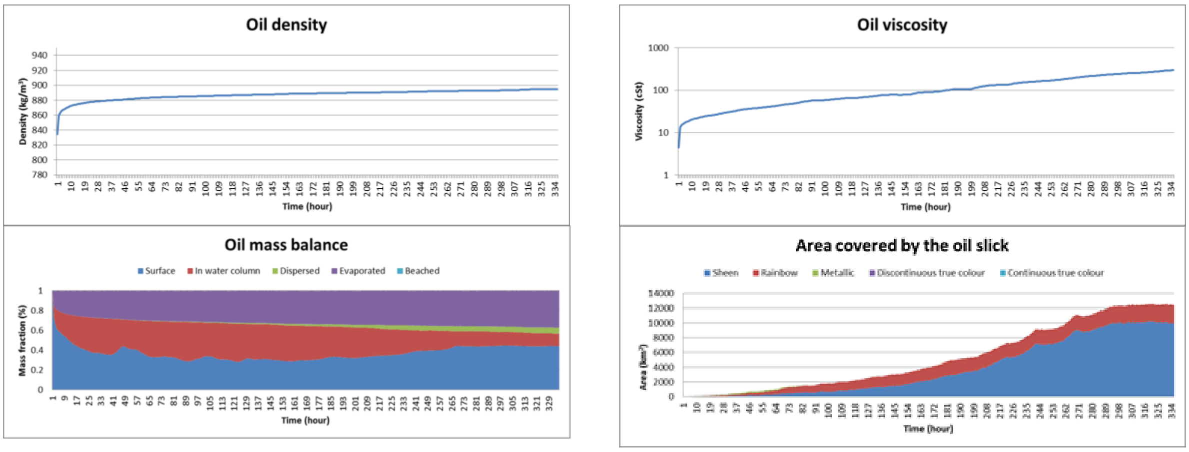
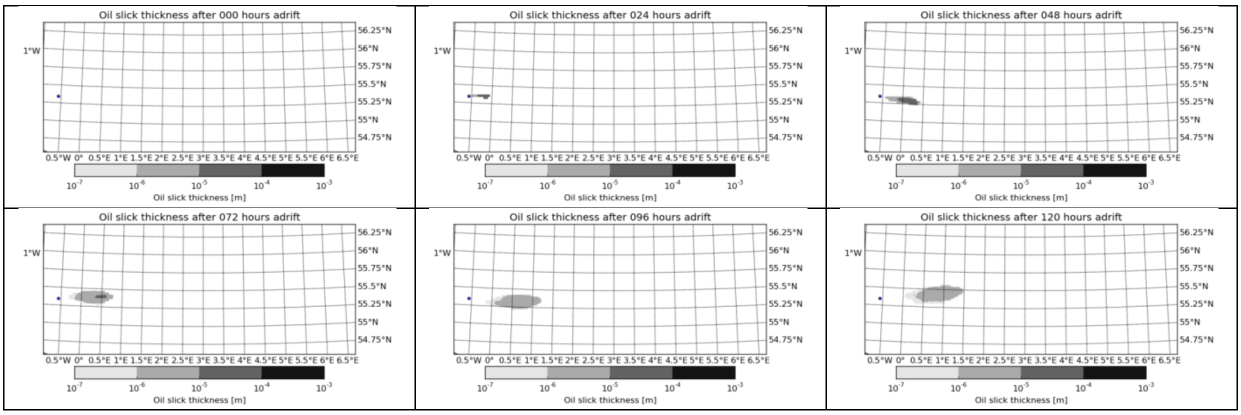


Figure 6: Time evolution of the oil density, oil viscosity, oil mass balance and oil slick spreading (release location #1, beaching activated).

Endogenous spreading is another important process during the first hours of the spill. If initially the spill was covering an area of ~3.14 km^2 of continuous true oil colour, the spill thickness rapidly decreases because of the high evaporation and natural dispersion rates, but also because the endogenous spreading. After only 6 hours, the total area of the slick was of 50 km^2 out of which 10km^2 was of discontinuous oil true colour and 30 km^2 was of metallic colour. After 12 hours, the slick area increased up to 110 km^2 out of which 15km^2 was of discontinuous true oil colour and 50 km^2 was of metallic colour. After 24 hours, the slick area increased up to 260 km2, out of which 30km^2 was always of discontinuous true oil colour and 110 km^2 was of metallic colour. Discontinuous true oil colour disappeared after 33 hours and metallic colours disappeared after 89 hours.



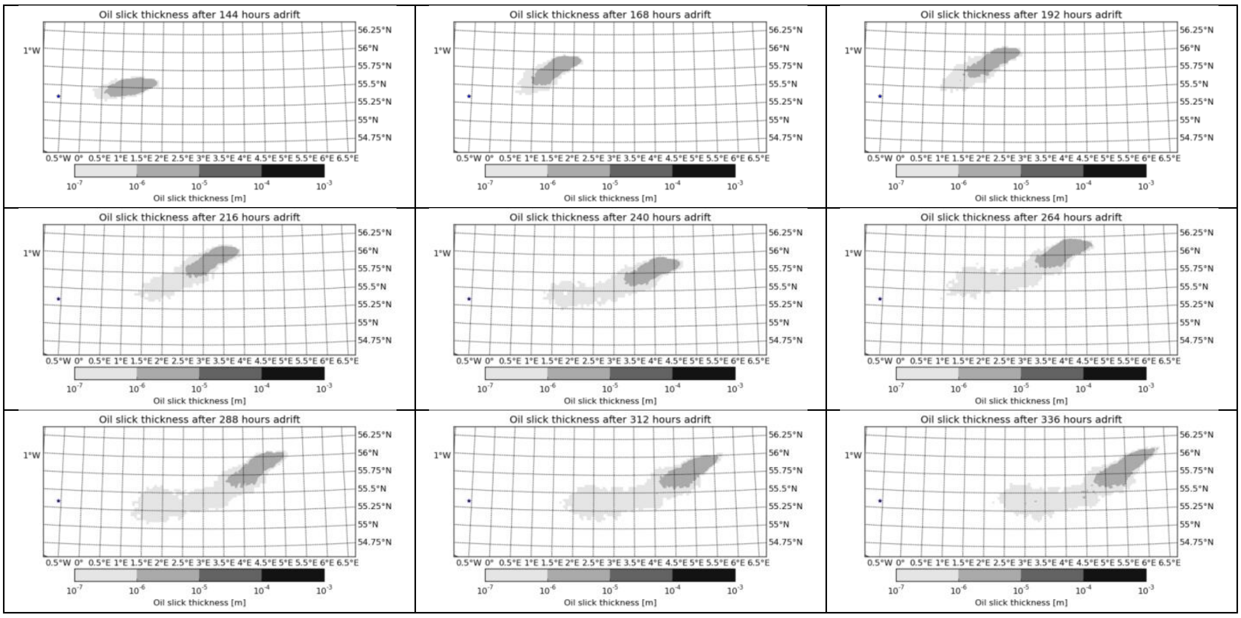


Figure 7 : Time evolution of the surface slick shape, thickness and displacement (release location #1, beaching activated).

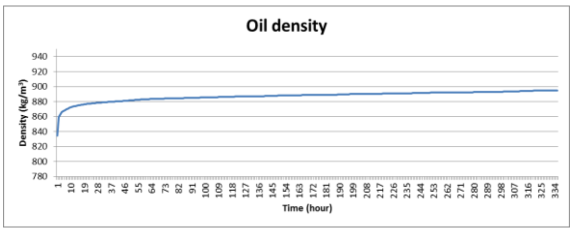
The mass balance plot suggests that, after 24 hours, a dynamic equilibrium was reached between resurfacing and natural dispersion. The proportion of oil being at the sea surface or being naturally dispersed in the water column is mainly driven by the significant wave height. It is important to insist on the dynamic character of this equilibrium. This is the key process in the formation of the rainbow and sheen tail at the rear of the oil slick. Indeed, on the one hand, oil droplets dispersed in the water column drifts slower than oil slick at the sea surface. On the other hand, turbulence enhances the subsurface dispersion of the oil droplets so that when they resurface, they usually cover a much larger area. Figure 7 clearly illustrates this behaviour during the 14 days of the simulation. In particular, the figure shows how the thicker part of the slick tends to be aligned with the wind direction.

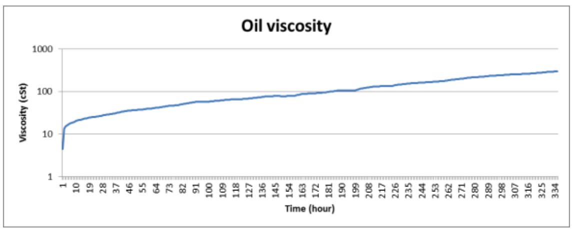
3.2.2 Simulation with beaching not activated

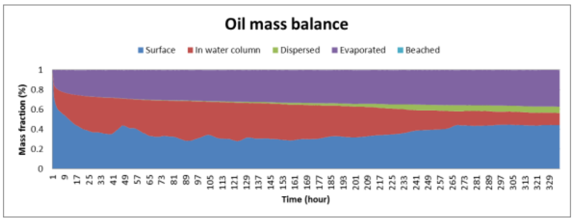
Because the oil slick does not strike any coastline during its drift, the results of the simulations with and without beaching activated are similar in all respects.

However, reminding that OSERIT simulates endogenous spreading, natural dispersion in the water column as well as turbulent vertical mixing of the subsurface droplets using several flavours of random walk and Monte Carlo techniques, similarities between Figure 6 and Figure 8 and between Figure 7 and Figure 9: Time evolution of the surface slick shape, thickness and displacement
(release location #1, beaching not activated).

should convince the reader of the statistical robustness of both simulations results.







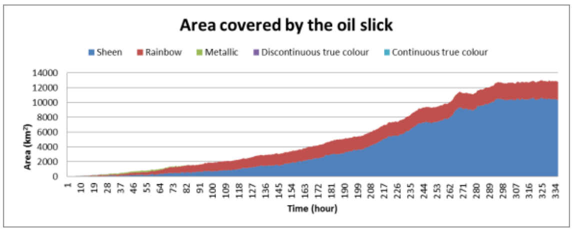


Figure 8: Time evolution of the oil density, oil viscosity, oil mass balance and oil slick spreading (release location #1, beaching not activated).

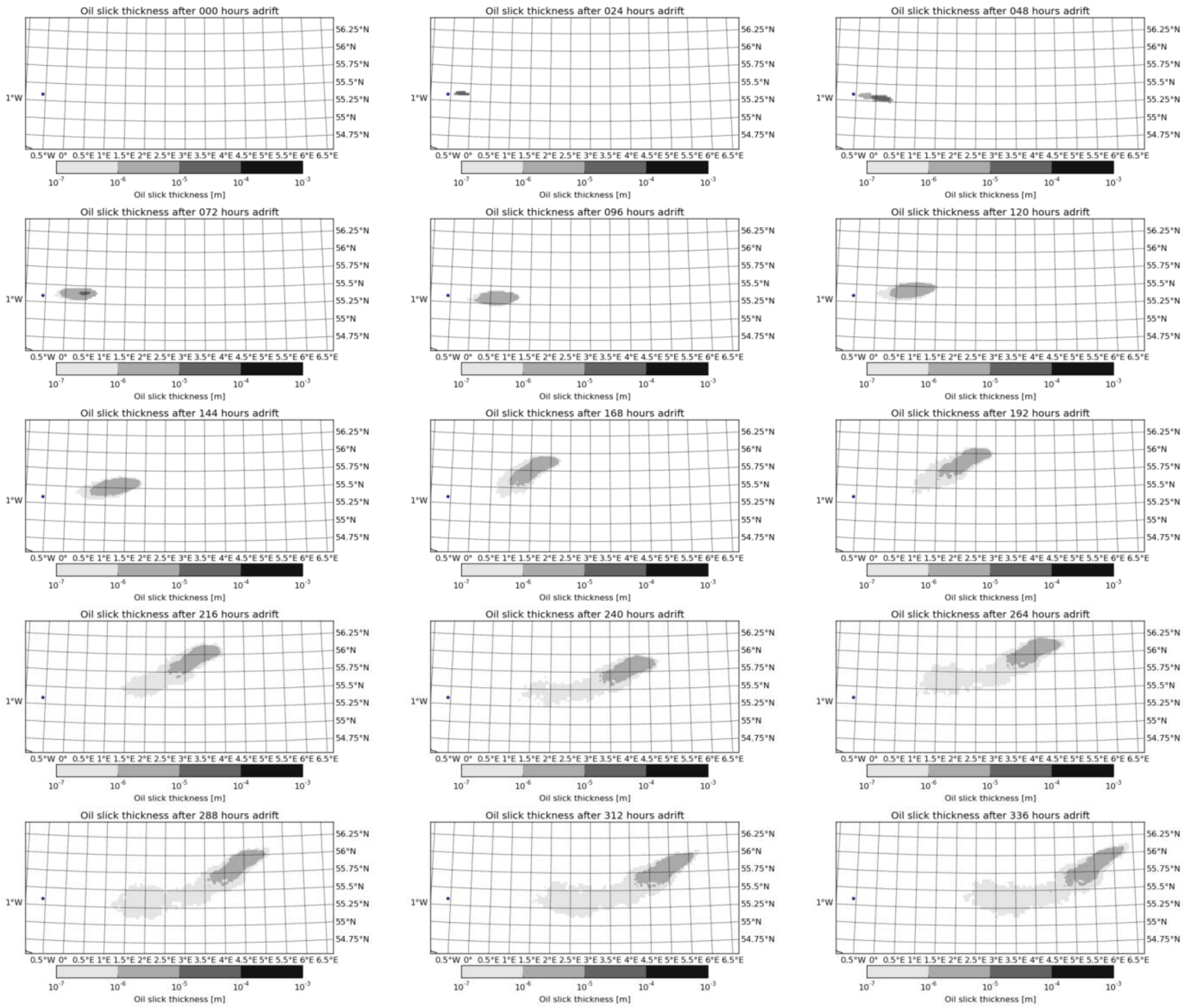


Figure 9: Time evolution of the surface slick shape, thickness and displacement (release location #1, beaching not activated).

3.3 Spill off the Eastern English coast

3.3.1 Simulation with beaching activated

Although the second release location (53.270657°N, 0.955147°E) is still situated off the Eastern English coast at only 250 km further south than the first release location (Figure 3), the drift and fate of both oil spills are completely different.

About the fate

Mainly due to smaller waves, the natural dispersion of oil within the water column was less efficient than in the simulations for the first release location (Figure 10 versus Figure 6). So, after 24 hours, 52% (versus 40%) of the initial oil volume was still floating at the sea surface, 28% (versus 26%) was evaporated and only 20% (versus 34%) was dispersed in the water column.

As a direct consequence, the thicker part of the slick was less eroded, permitting the persistence of a metallic slick during all the simulations. The area covered by this metallic slick slowly increased from 30 km^2 after 24 hours adrift up to 300 km^2 at the end of the simulation.

Another direct consequence of the fact that there is less oil naturally dispersed in the water column is that there is also less oil available for resurfacing. The sheen and rainbow tail was therefore developing slower to peak at ‘only’ 5,000km^2 (versus 12,000 km^2 in the simulations for the first release location). Actually a significant part of the resurfaced oil (up to 3.5% of the initial oil volume) were forming not-detectable slick.

Finally, because oil volume floating at the sea surface was larger than in simulations for the first release location, a larger proportion of the slick had emulsified, what explains the slight increase of the oil density (900 kg/m^3 versus 895 kg/m^3) and viscosity (500 cSt versus 300 cSt).

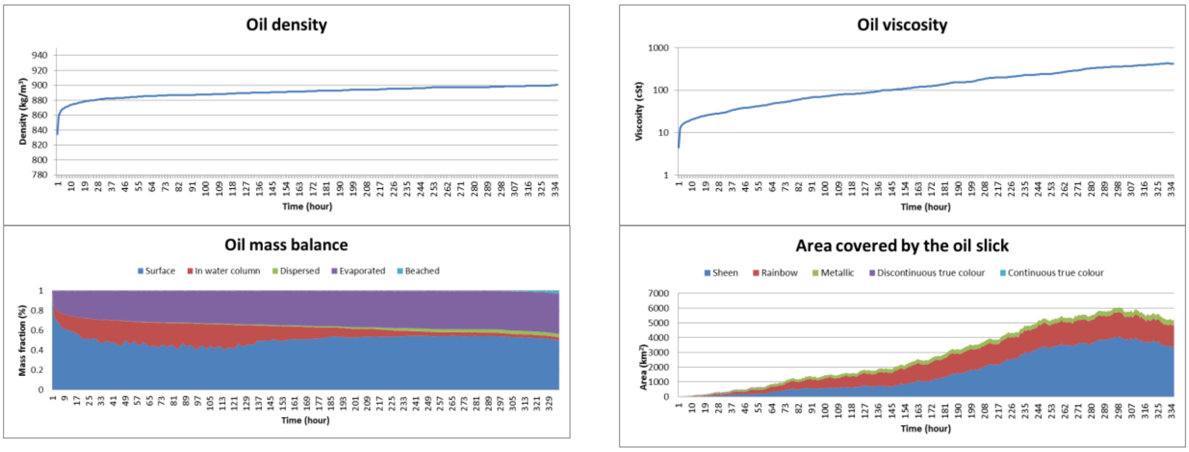


Figure 10: Time evolution of the oil density, oil viscosity, oil mass balance and oil slick spreading (release location #2, beaching activated).

About the drift

In this simulation, the general drift trajectory (a tilted ‘S’ shape) is constraint on the one hand by the South-West wind that tends to push the slick North-Eastwards and on the other hand by the residual tidal currents that tends to force the slick to follows the coastline, south-eastward along the English coastline and the North-eastward close the Dutch coastline (Figure 11).

In this particular simulation, the sheen and rainbow tail of the slick came close to the Dutch Wadden islands, leading to limited oil beaching (about 2% of the initial oil volume). However, with a slightly different wind conditions, a massive oil beaching would have been possible.

At the end of the simulation, the slick was threatening the German bight.

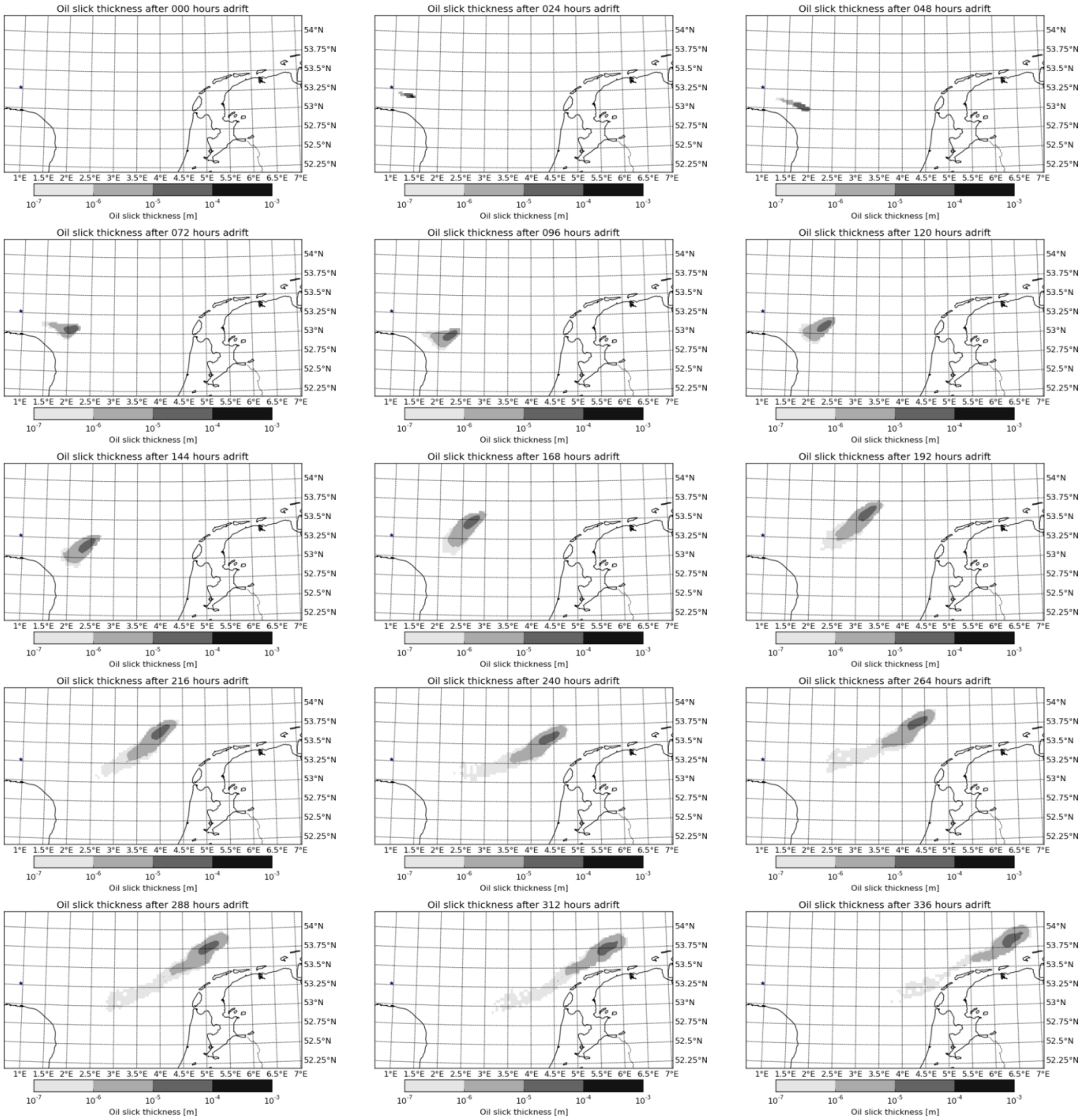


Figure 11: Time evolution of the surface slick shape, thickness and displacement (release location #2, beaching activated).

3.3.2 Simulation with beaching not activated

The simulation with beaching not activated is similar to all respects with the previous simulation. However, the snapshots after 312 and 336 hours adrift (Figure 13) show that the sheen and rainbow tail narrower and thicker than in the simulation with beaching activated (Figure 11).

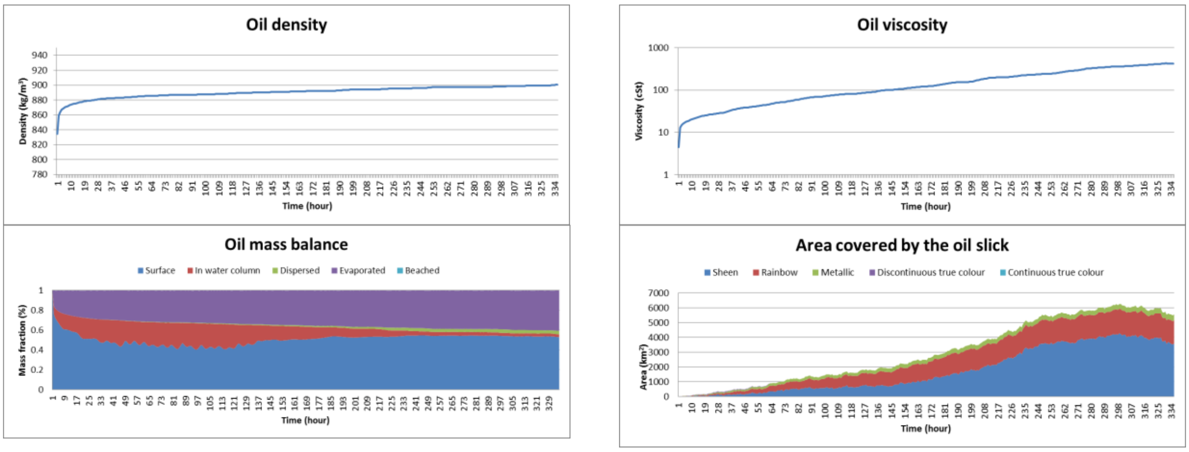


Figure 12 : Time evolution of the oil density, oil viscosity, oil mass balance and oil slick spreading (release location #2, beaching not activated).

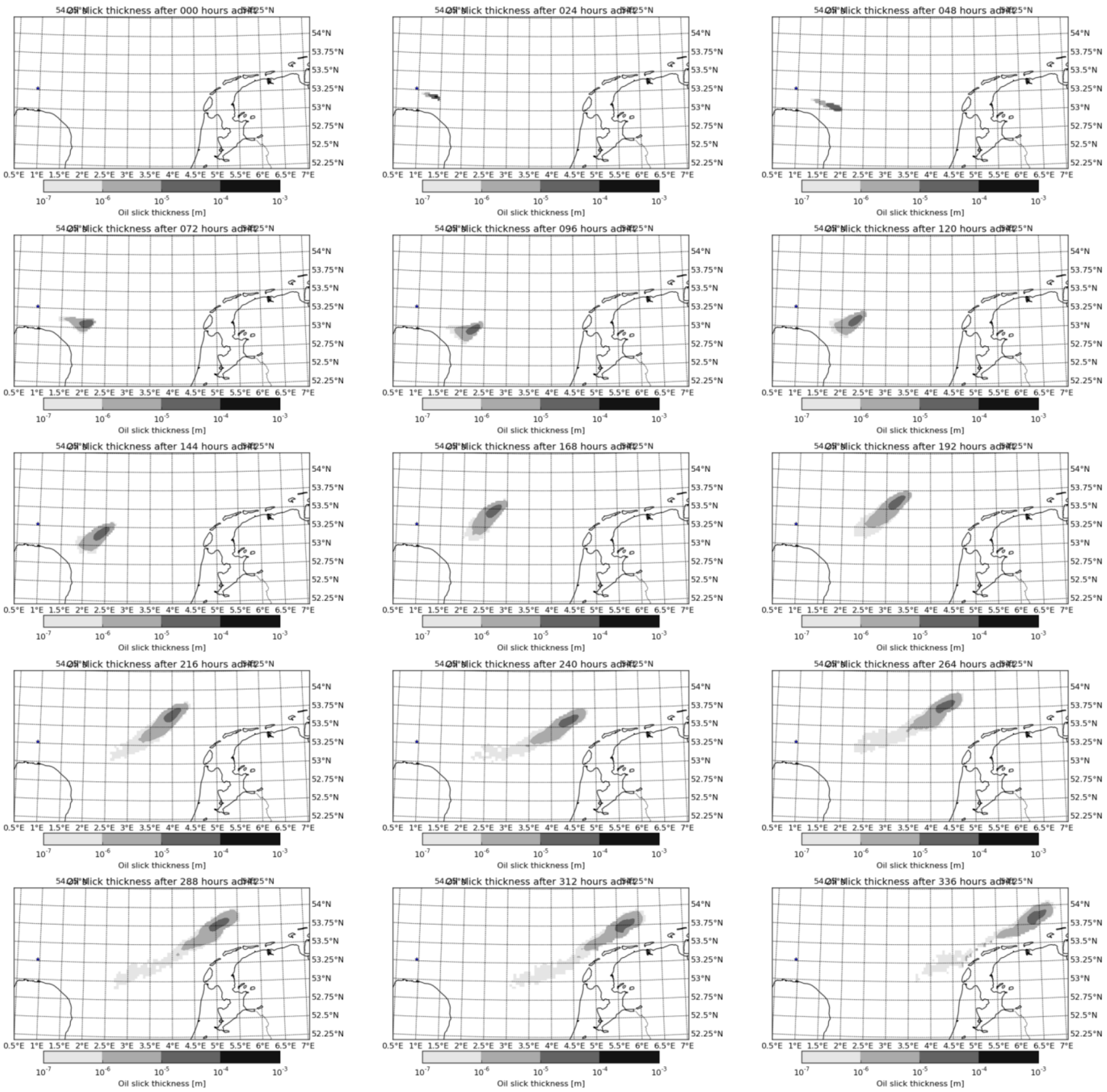


Figure 13: Time evolution of the surface slick shape, thickness and displacement (release location #2, beaching not activated).

3.4 Spill in the southern bight of the North Sea

3.4.1 Simulation with beaching activated

The third release location (51.8°N, 2.44°E) is located in the middle of the North Sea southern bight at 65 km away from the closest English coast and 75 km from the closest continental (Dutch) coast.

The interaction between wind, waves and tides mainly pushes the slick eastwards for the first 6 days, followed by a massive beaching between the 7th and the 9th days (Figure 15). At the end of this simulation, 60% of the initial oil volume beached along the 70 km of coastlines separating the Rhine river mouth to The Hague, the remaining 40% having been evaporated.

During the 6 days adrift that preceded the massive beaching, only 20% of the initial oil volume was naturally dispersed in the water column and the slick mainly weathered under the influence evaporation, emulsification and endogenous spreading. In particular, just before hitting the coastline, the metallic slick was covering an area of 320 km^2, i.e. 13% of the total slick area.

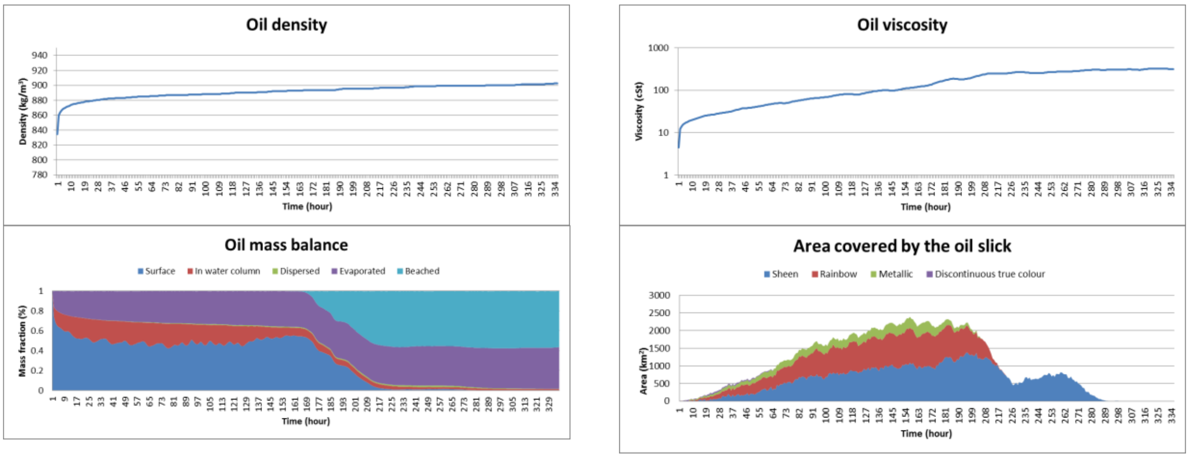


Figure 14: Time evolution of the oil density, oil viscosity, oil mass balance and oil slick spreading (release location #3, beaching activated).

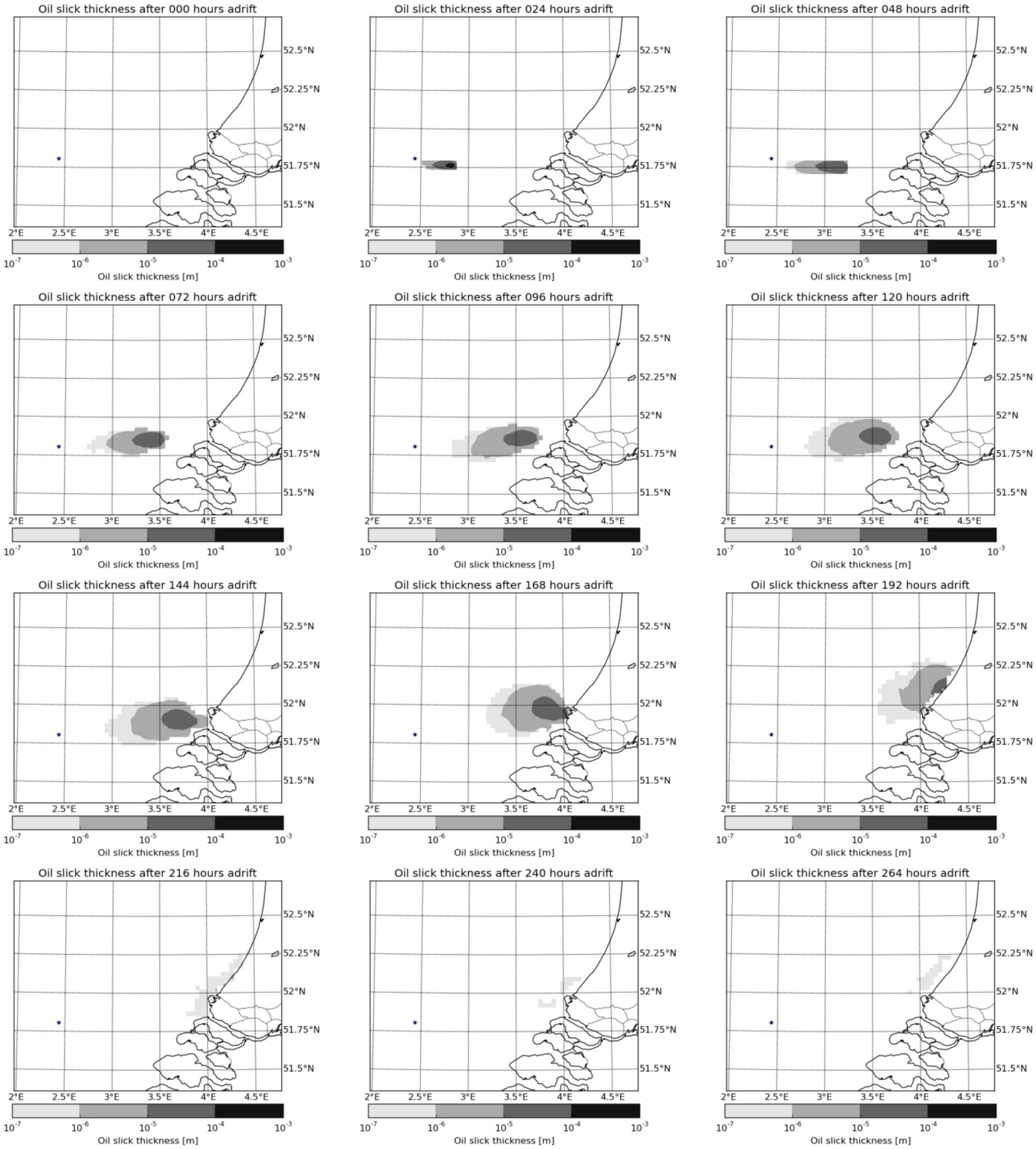


Figure 15: Time evolution of the surface slick shape, thickness and displacement (release location #3, beaching activated).

3.4.2 Simulation with beaching not activated

The simulation with beaching not activated mimics the scenario in which the totality of the beached oil is re-suspended at the next high water to further continue its drift. Due to technical limitation, OSERIT simulates this situation by not updating the position of a Lagrangian particle every time it would drift on land. As a result of this trick, the massive beaching that occurs at day 7, is represented by an accumulation of Lagrangian particles very close to the shore; a drastic decrease of the slick area and a drastic increase of the slick thickness greater than 0.5mm.   Because of the wind direction and of the ellipsoidal shape of the tidal currents, the re-suspended slick can only moved a few kilometres before beaching again. After a succession of beaching and re-suspension for 7 days, the slick has only progressed of 60 km away from the initial beaching location, in the direction of Ijmuiden.

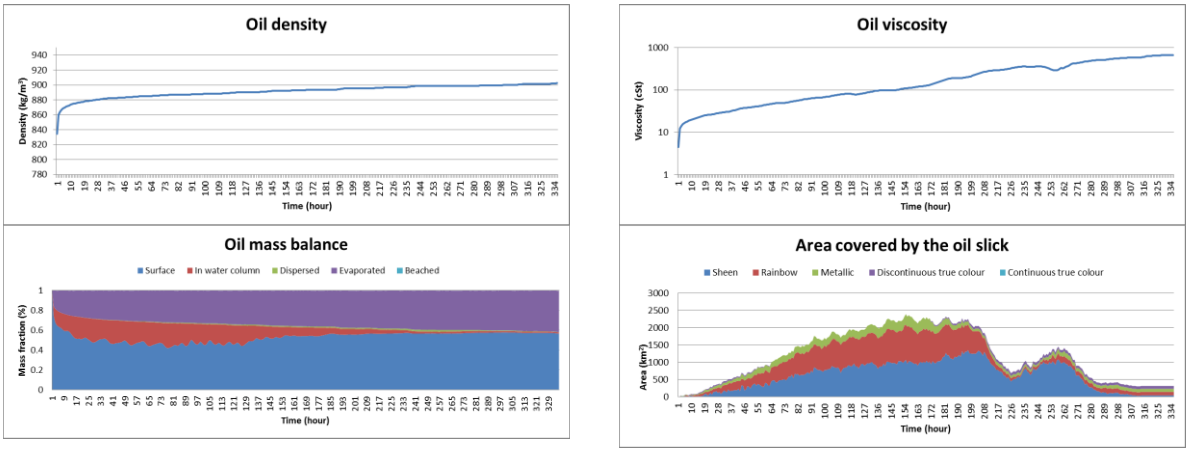


Figure 16: Time evolution of the oil density, oil viscosity, oil mass balance and oil slick spreading (release location #3, beaching not activated).

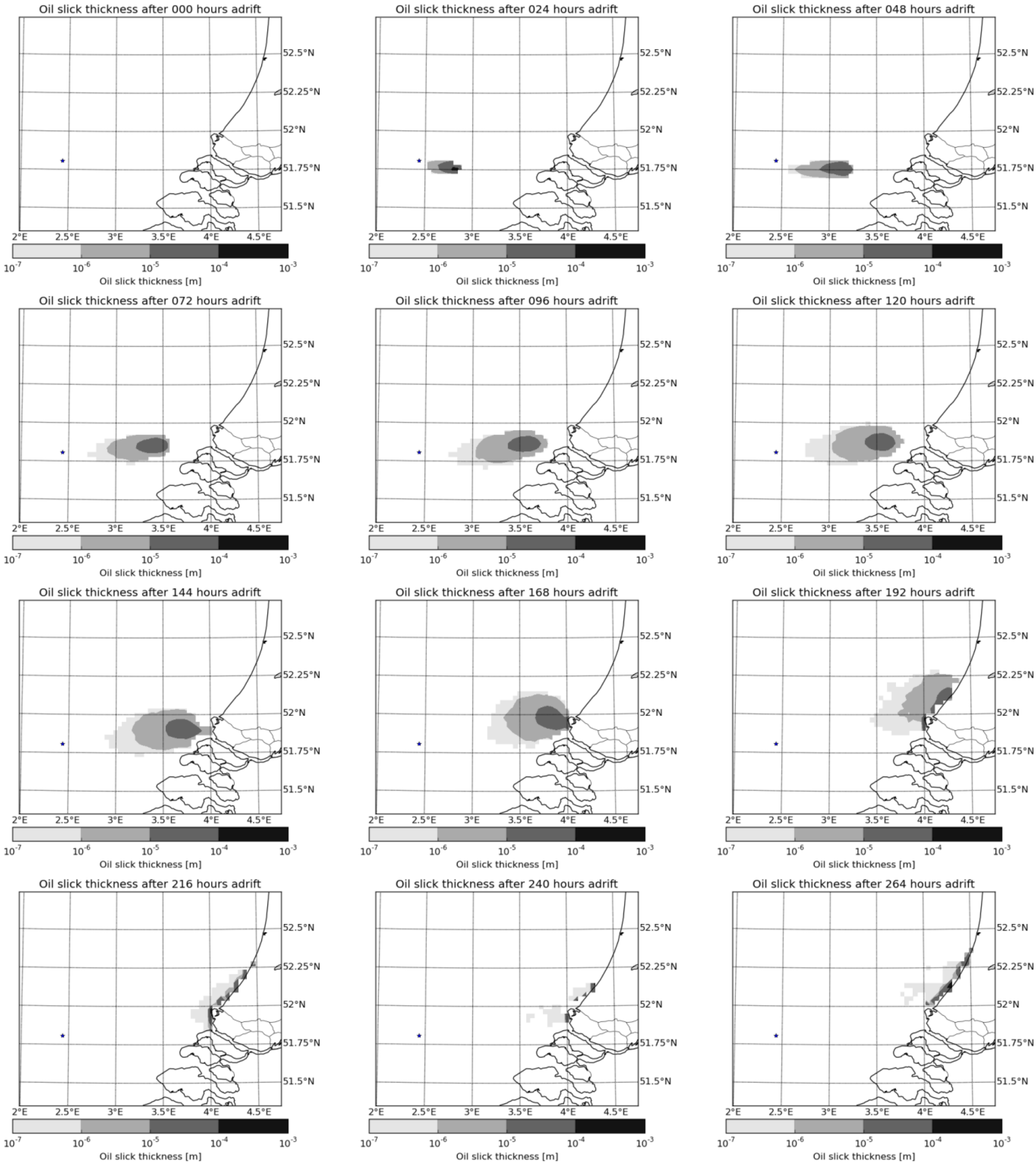


Figure 17: Time evolution of the surface slick shape, thickness and displacement (release location #3, beaching not activated).

3.5 Spill at the East entry of the German Bight

3.5.1 Simulation with beaching activated

The fourth release location is located at the western limit of the German bight (53.84°N, 6.55°E).

This simulation is characterized by 2 beaching events. The first beaching event (56% of the initial oil volume) happened after only 46 hours adrift along the German Wadden Island of Langeoog. The second beaching event happened after 10 days adrift between Büsum and the Elbe river mouth (Figure 18 and Figure 19).

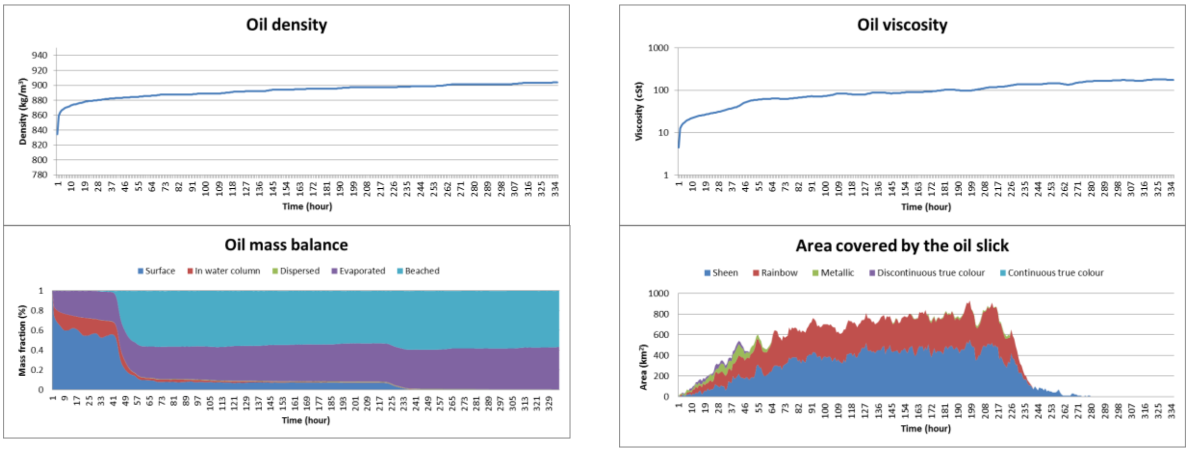
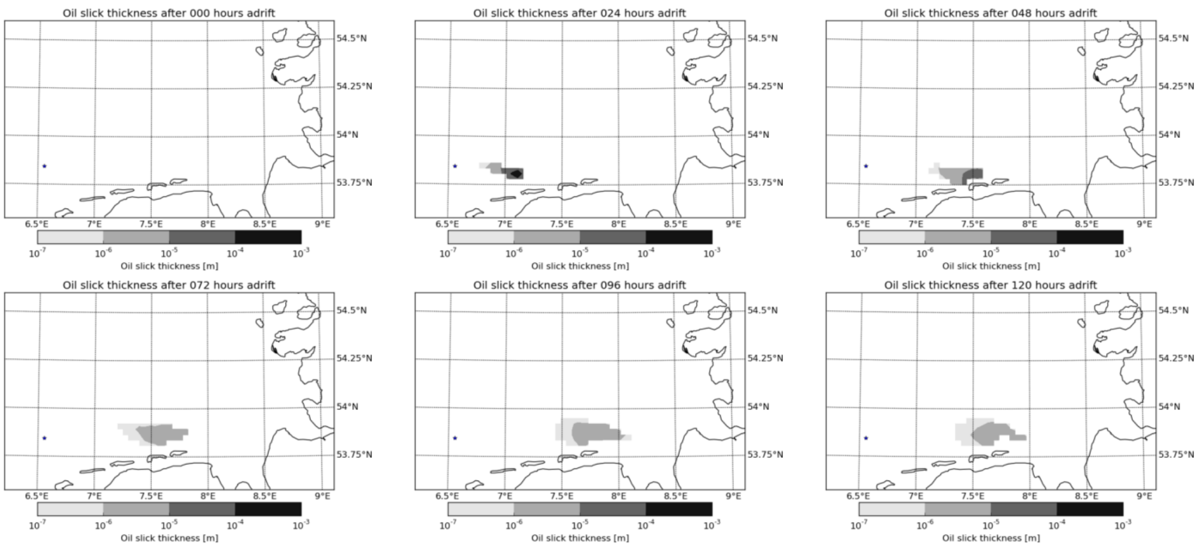


Figure 18: Time evolution of the oil density, oil viscosity, oil mass balance and oil slick spreading (release location #4, beaching activated).



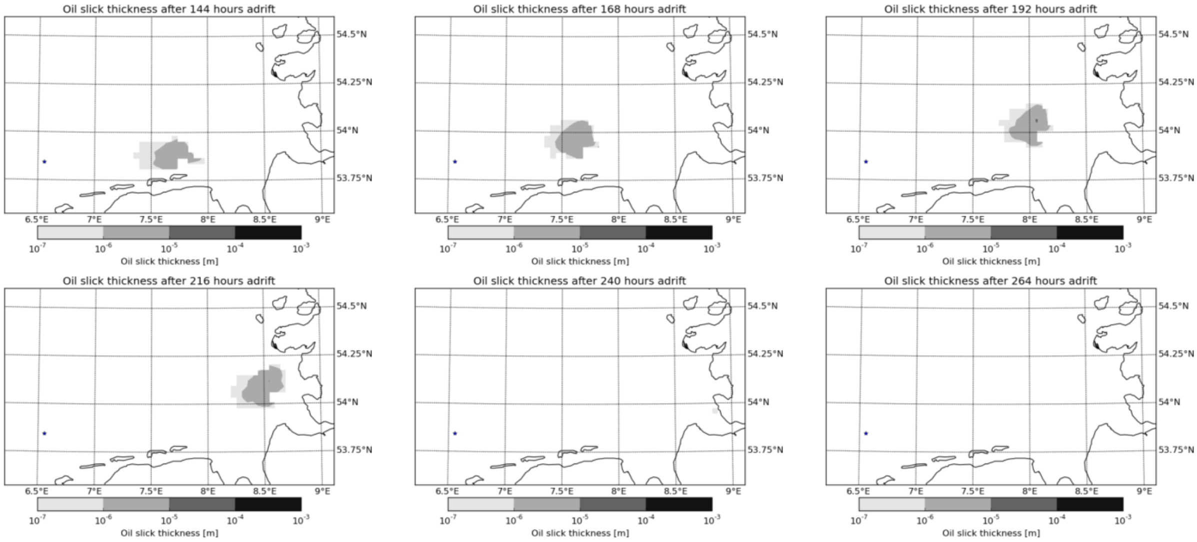


Figure 19: Time evolution of the surface slick shape, thickness and displacement (release location #4, beaching activated).

3.5.2 Simulation with beaching not activated

This simulation shows how the re-suspension of the oil that had beached along the Langeoog Island can generate two thick slicks, distant of about 20 km from each other. These slick hit the continental coast between Büsum and the Elbe river mouth after 10 days adrift. During the last 4 days of the simulation, naturally dispersed oil droplets continue to resurface here and there in the German bight.

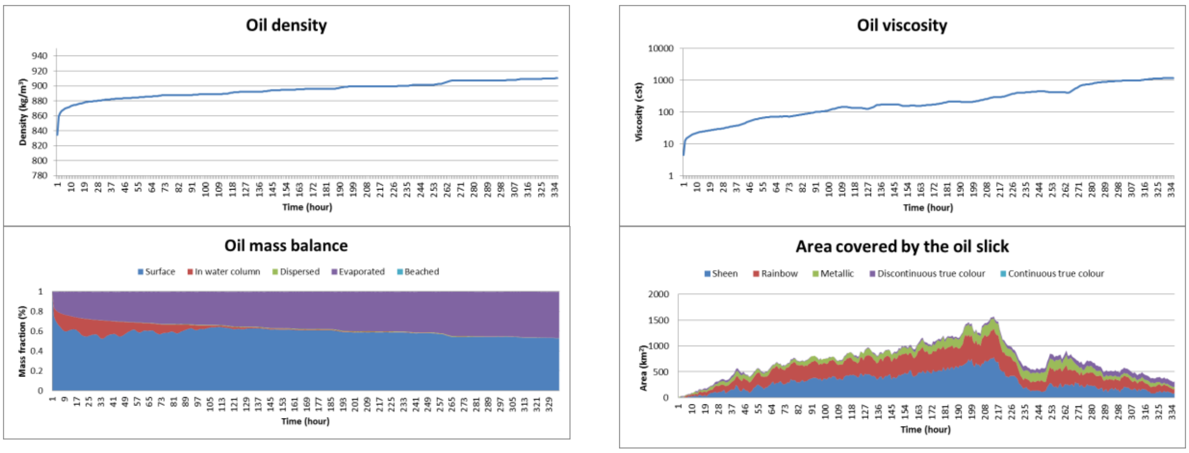


Figure 20: Time evolution of the oil density, oil viscosity, oil mass balance and oil slick spreading (release location #4, beaching not activated).

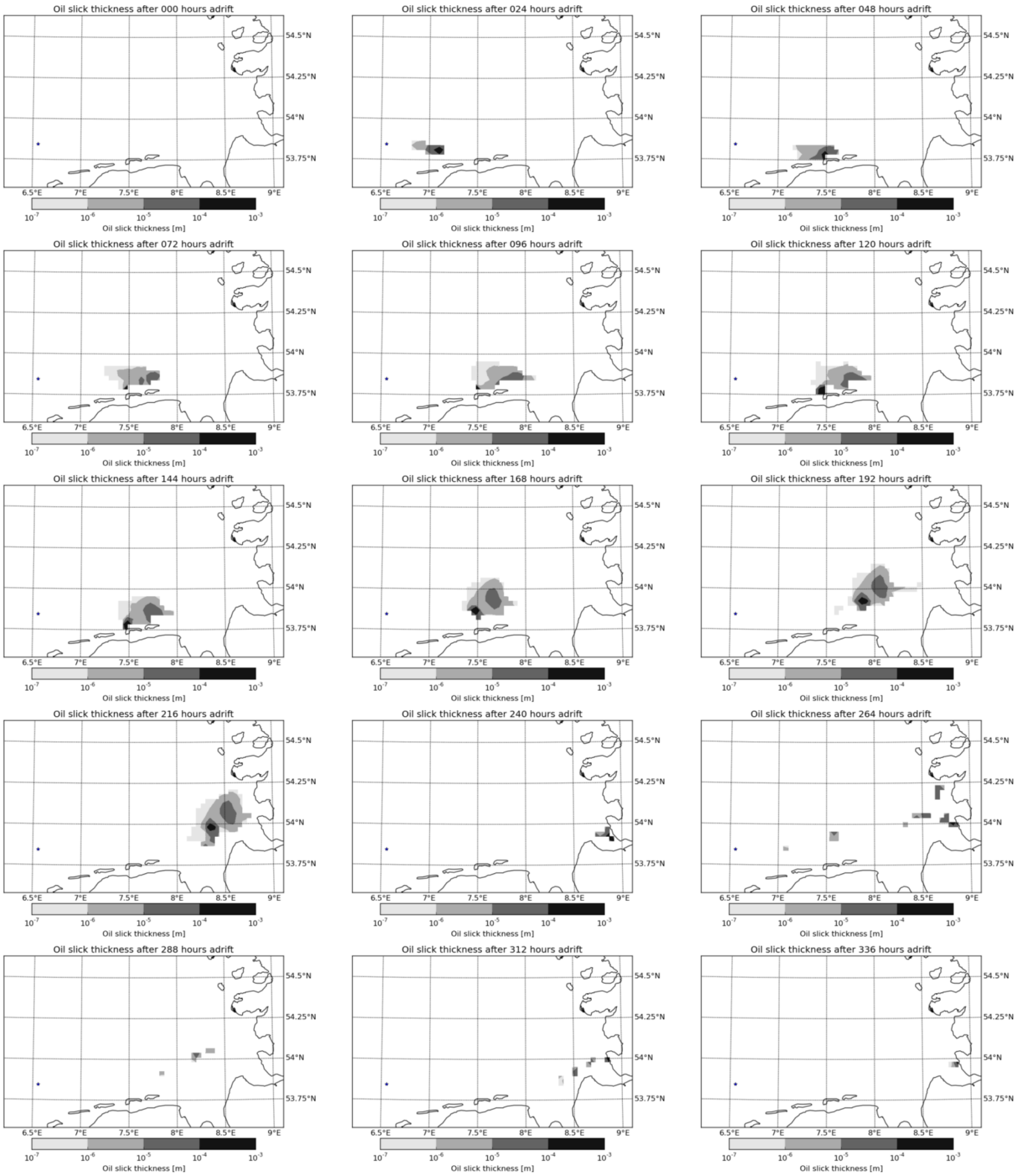


Figure 21: Time evolution of the surface slick shape, thickness and displacement (release location #4, beaching not activated).

3.6 Spill in the German Bight

The fifth release location (54.14°N and 8.37°E) is unfortunately located along the trajectory presented in the previous subsection.

3.6.1 Simulation with beaching activated

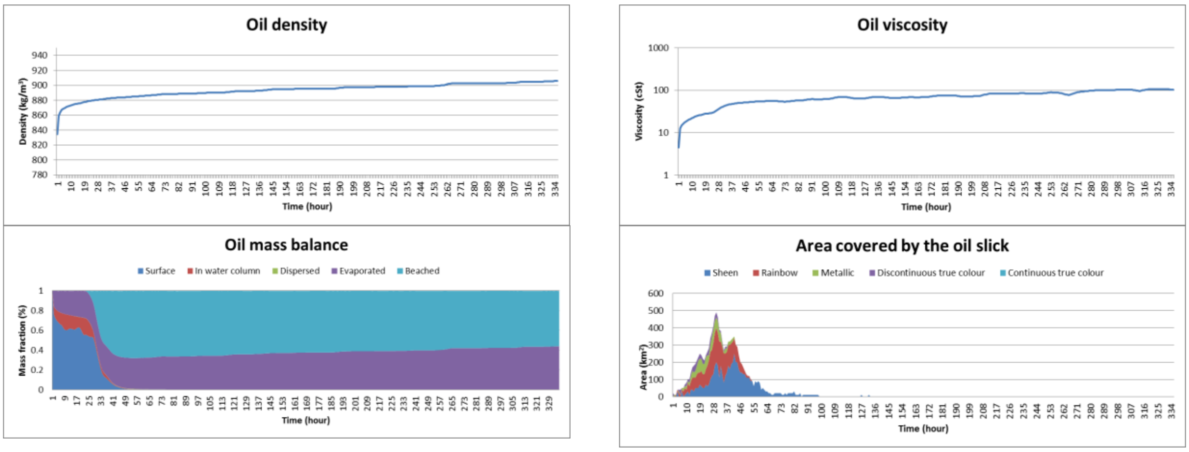


Figure 22: Time evolution of the oil density, oil viscosity, oil mass balance and oil slick spreading (release location #5, beaching activated).

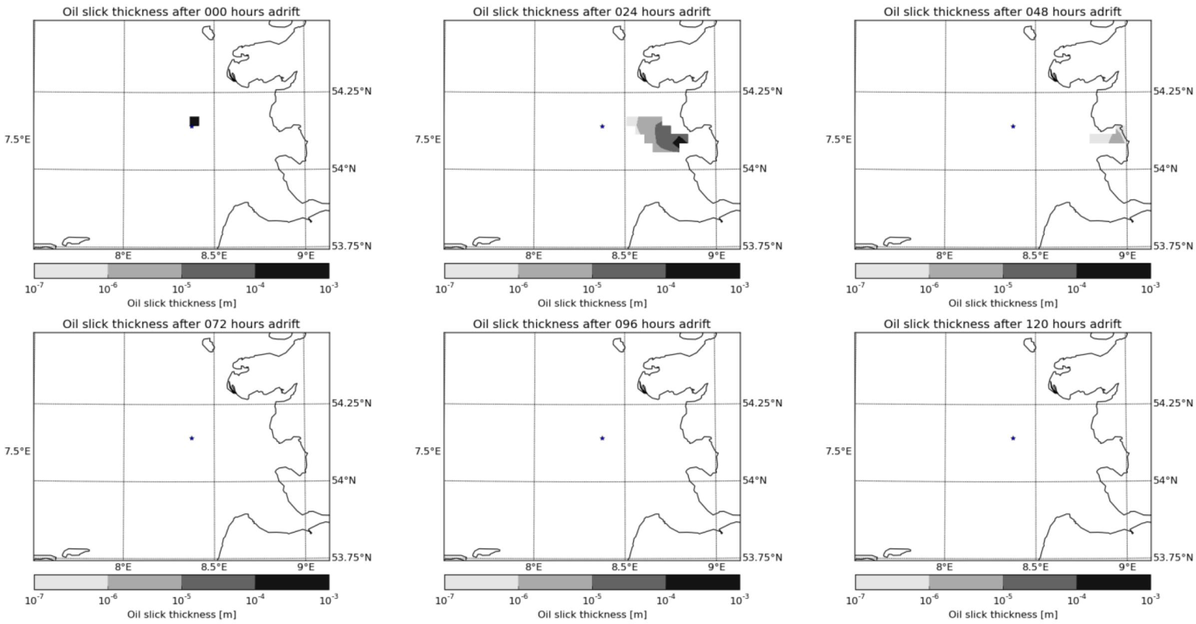


Figure 23: Time evolution of the surface slick shape, thickness and displacement (release location #5, beaching activated).

3.6.2 Simulation with beaching not activated

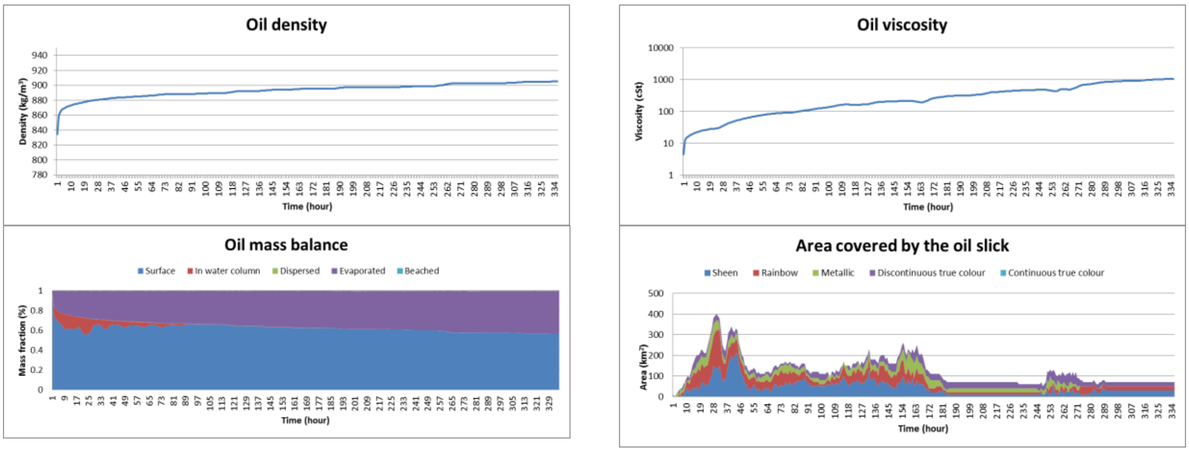


Figure 24: Time evolution of the oil density, oil viscosity, oil mass balance and oil slick spreading (release location #5, beaching not activated).

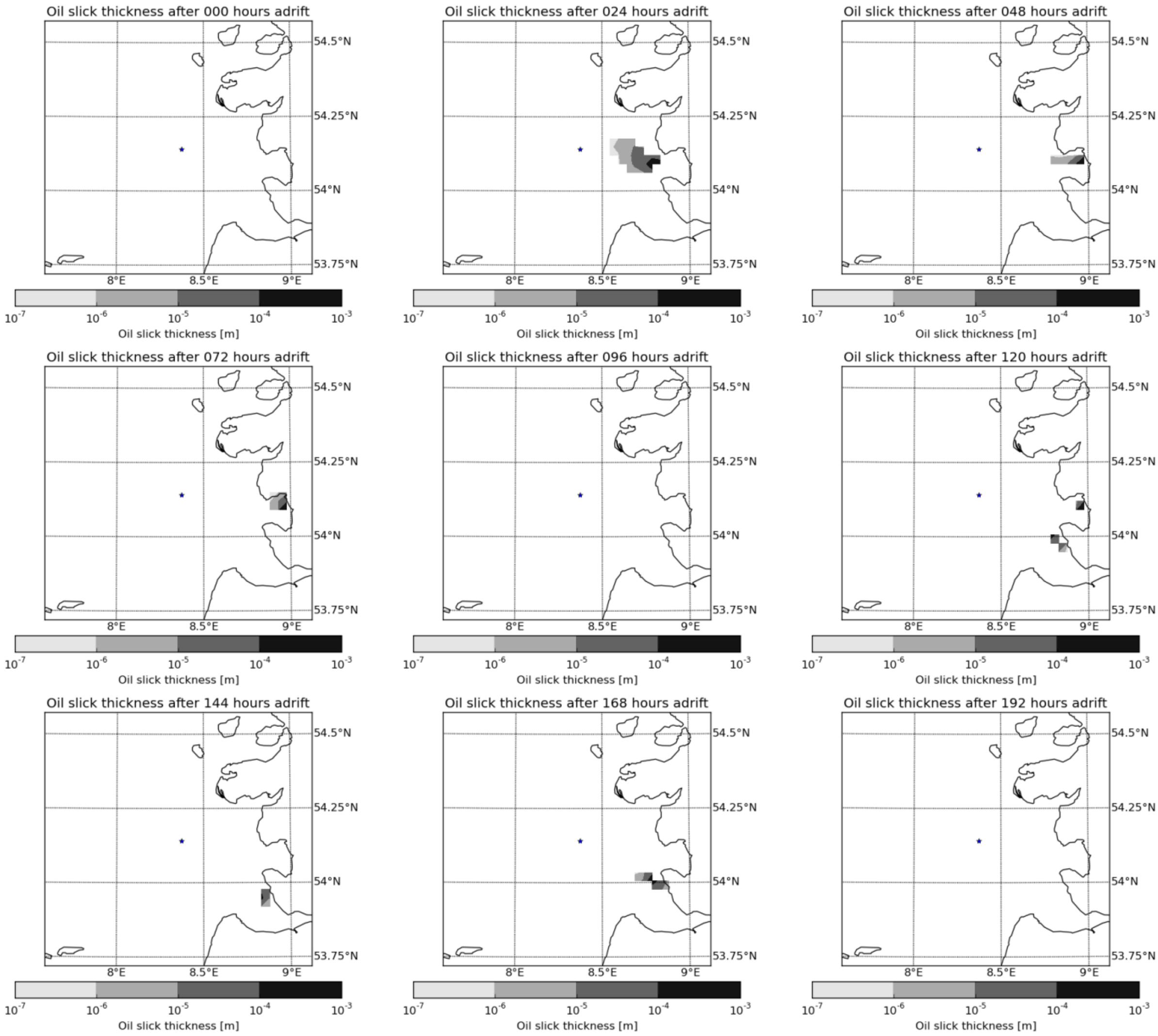


Figure 25: Time evolution of the surface slick shape, thickness and displacement (release location #5, beaching not activated).

3.7 Spill off the Danish coastline

3.7.1 Simulation with beaching activated

The sixth release location (55.25°N, 7.85°E) is located at only 40 km from Esbjerg. Pushed eastward by the wind, the oil slick reaches the Rømø Island in less than 48 hours (Figure 26 and Figure 27) before eventually recirculating in the complex network of tidal channels and mudflats between Rømø and Fanø (Figure 27).

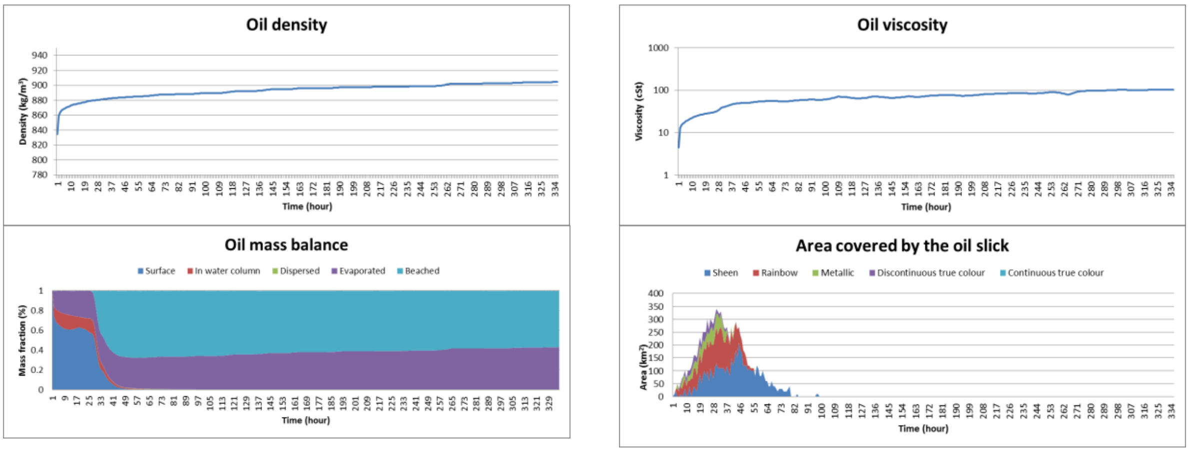


Figure 26: Time evolution of the oil density, oil viscosity, oil mass balance and oil slick spreading (release location #6, beaching activated).

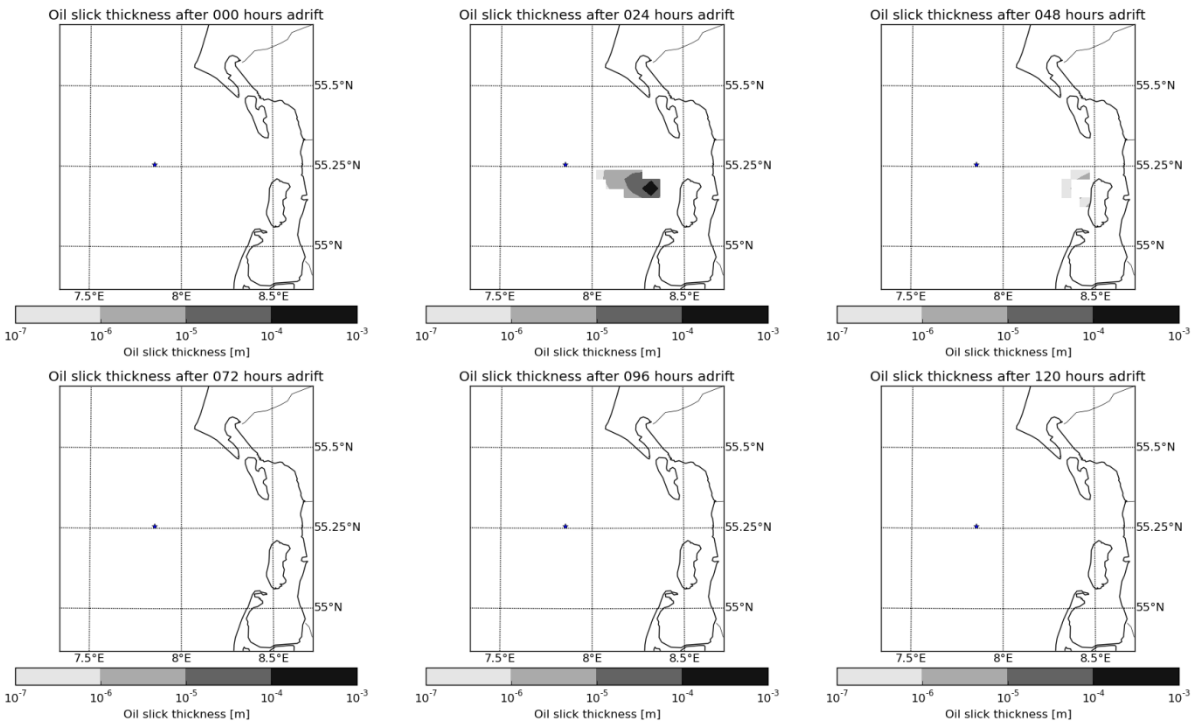


Figure 27 Time evolution of the surface slick shape, thickness and displacement (release location #6, beaching activated).

3.7.2 Simulation with beaching not activated

This simulation is similar to the simulation with beaching activated. However, the thickness of the re-suspended drastically increases to reach an average thickness close to 0.5 mm. As a result the oil viscosity also increases by one order of magnitude with respect to the simulation with beaching activated.

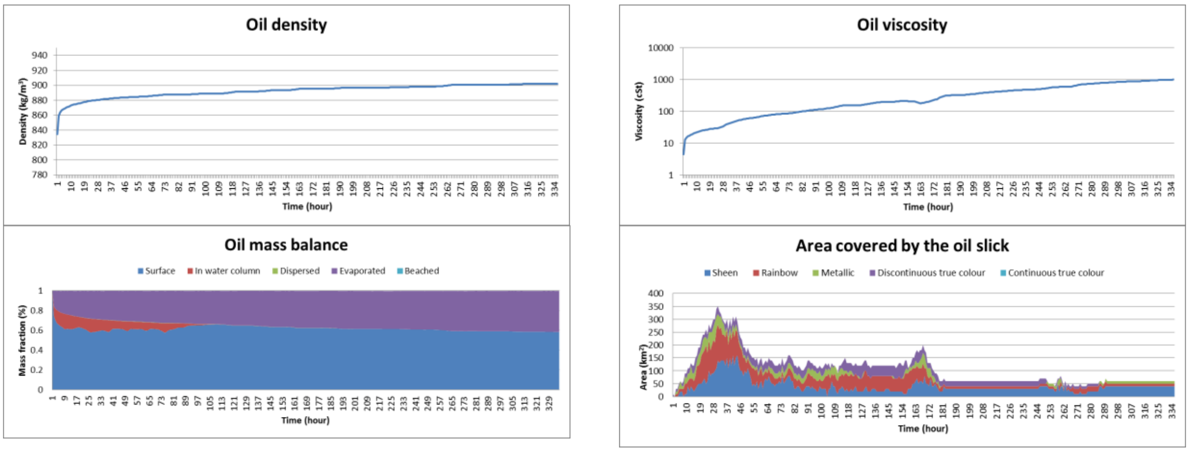
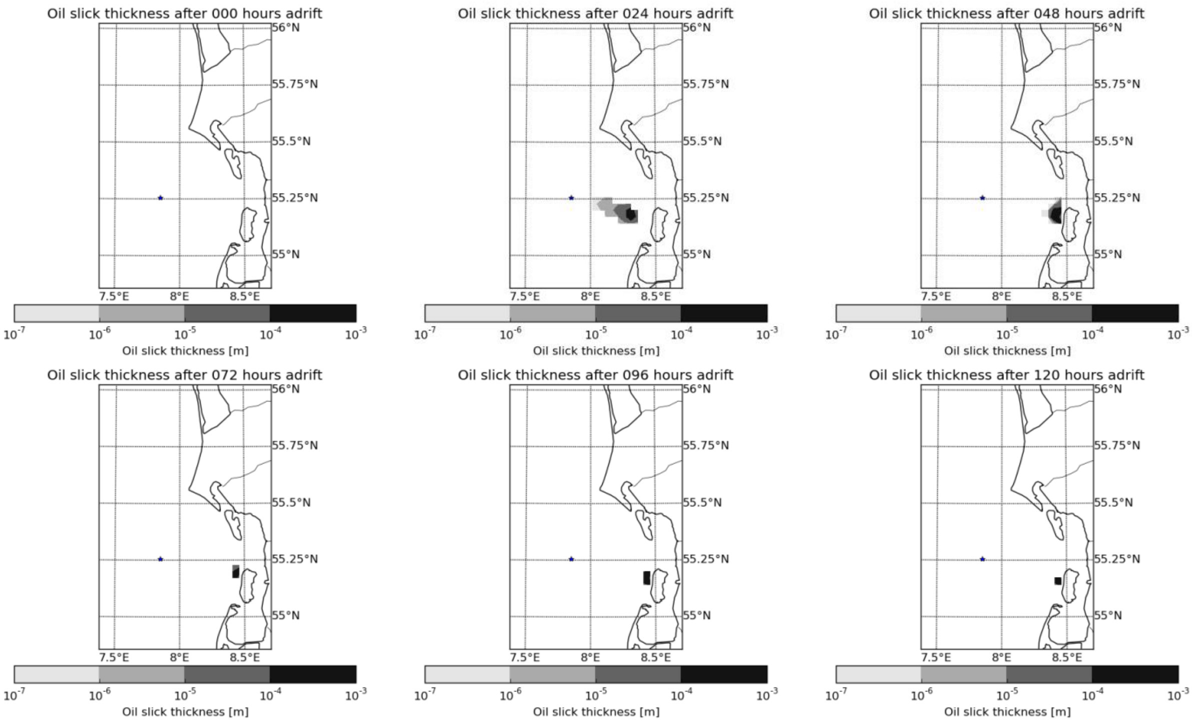


Figure 28: Time evolution of the oil density, oil viscosity, oil mass balance and oil slick spreading (release location #6, beaching not activated).



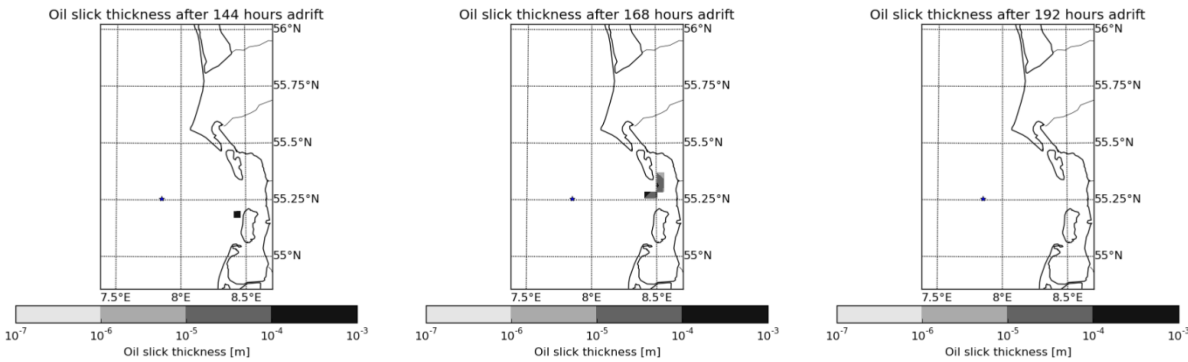


Figure 29: Time evolution of the surface slick shape, thickness and displacement (release location #6, beaching not activated).

3.8 Spill in the English Channel (release location: 50.14°N, 1.07°W)

3.8.1 Simulation with beaching activated

The seventh release location (50.14°N and 1.07°W) lays in the English Channel.

During the two first days of the simulation, a relatively strong wind blew from West which, on the one hand, pushed the slick towards the French coast and on the other hand enhanced the natural dispersion of the slick within the water column: almost 40% has been naturally dispersed after 24 hours!

Between the 3rd day and the 7th day, the wind slowed down and the wave height decreased in such a way that the slick was only progressing of a few kilometres per day towards the French coast. The rate of oil resurfacing was larger than the rate of oil that was naturally dispersed. The thicker, metallic part of the slick stops to be eroded by natural dispersion and evolve mainly because evaporation, emulsification and endogenous spreading. The resurfaced oil progressively formed a sheen and rainbow tail that covered up to 3,000 km^2 at the end of the 6th day adrift. In comparison the metallic part of the slick covers 160 km^2 at the same time. Finally, between the 7th and the 12th day adrift, the slick hit the French coast of Normandy between Le Havre and Le Crotoy.

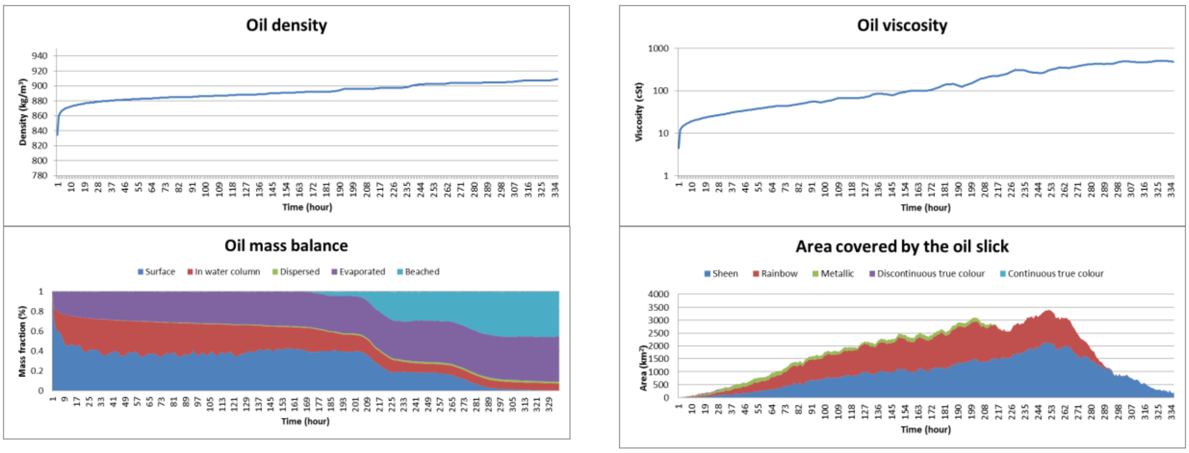


Figure 30: Time evolution of the oil density, oil viscosity, oil mass balance and oil slick spreading (release location #7, beaching activated).

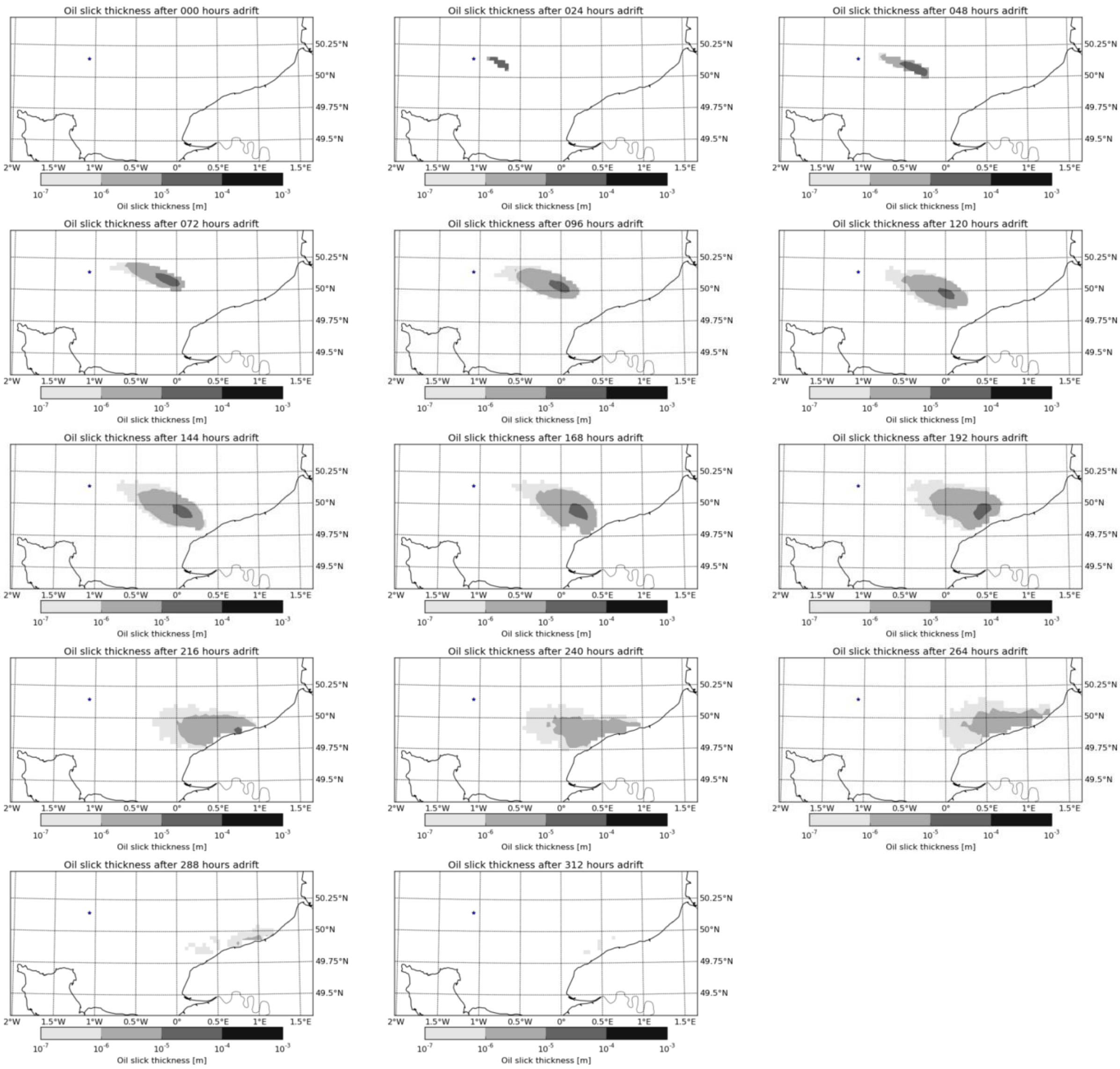


Figure 31: Time evolution of the surface slick shape, thickness and displacement (release location #7, beaching activated).

3.8.2 Simulation with beaching not activated

The simulation with beaching not activated is similar in all respects with the simulation with beaching activated. However, two differences can be noted. First, because of the relatively calm wind and the weakness of the residual currents, the re-suspended oil does not drift far away from the beach it initially reached. Second, because re-suspended oil continues to weather, the average oil viscosity at the end of this simulation is twice larger than the viscosity in the simulation with beaching activated (860 cSt versus 440 cSt).

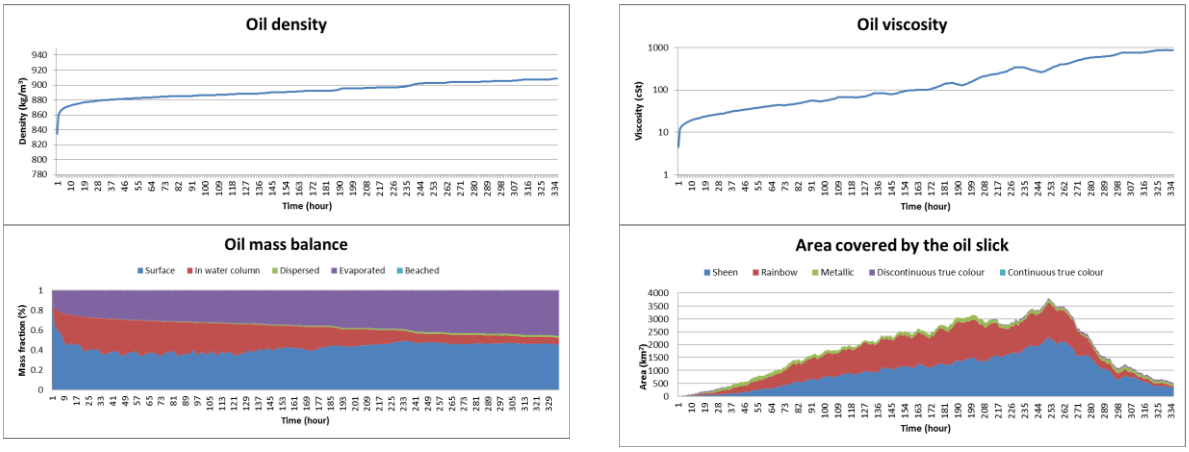


Figure 32: Time evolution of the oil density, oil viscosity, oil mass balance and oil slick spreading (release location #7, beaching not activated).

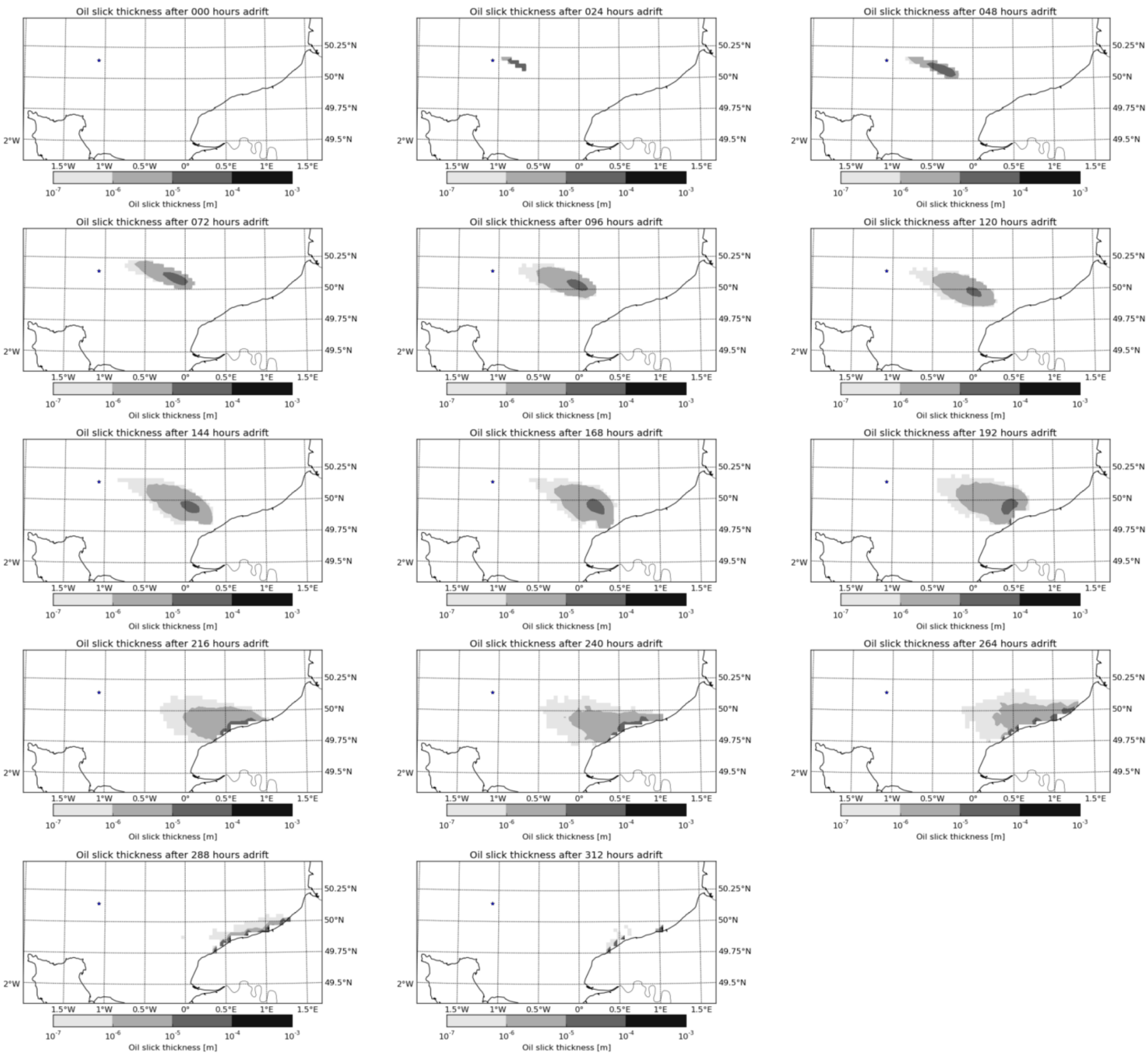


Figure 33: Time evolution of the surface slick shape, thickness and displacement (release location #7, beaching not activated).

4 Discussion

14 simulations have been performed with the three-dimensional oil drift and fate model OSERIT.

Using realistic met-ocean forcing produced by operational weather prediction model and hydrodynamic and waves models, OSERIT simulates the drift and fate of an oil spill under the influence of wind, waves, surface currents (including tidal currents), oil endogenous spreading, evaporation, emulsification, natural dispersion of oil slick into the water column, the subsurface drift and diffusion and finally oil resurfacing.

Each OSERIT run simulated the drift and fate of 10,000m^3 of Brent blend (light crude oil) that has been released from 7 predefined locations around the North Sea and the English Channel. Each simulation lasts 14 days, between the 15th and the 29th of May 2011 noon. This time period has been chosen because of the relatively constant wind of 7.5m/s (+/- 2.5 m/s) blowing from South West (+/-60°).

For each release location, two different beaching scenarios have also been considered corresponding respectively to the case where 0% or 100% of the beached oil volume can be re-suspended and continue to drift further away. Reality often lies between these two extremes.

Each simulation therefore corresponds to a very specific pollution and can hardly be transposed to another location, met-ocean condition or oil type. However, their comparison can illustrate several key processes influencing the time evolution of the oil pollution.

About evaporation

Evaporation dominates the evolution of the spill during the first hours of the pollution, explaining the rapid evolution of the oil density and viscosity in that time period. In the presented simulations, about 25% of the spill is evaporated after 24 hours and 45% after 14 days. Although these percentages are rather stable in all the presented simulations, these figures can significantly change with seasons and oil type.

About beaching

Each simulation have been performed with two different extreme beaching scenarios according to which respectively 0% and 100% of the beached oil is re-suspended and further continue its drift. Our simulations shows that when the wind blows from the sea perpendicularly to the shore, the re-suspended oil tends to remain confined close to the shore and cannot drift far away from its initial beaching location. On the contrary when the wind blows alongshore, the re-suspended oil can continue to drift far away from the initial beaching location, occasionally resulting to cross national pollution involving large amount of oil (cf Figure 21).

About natural dispersion, subsurface drift and turbulence diffusion and resurfacing

The simulations illustrate the importance of the competition between the natural dispersion and the oil resurfacing in the ‘erosion’ of the thicker part of the slick.

In the range of the significant wave height considered in the simulation (between 1 and 4 m), an equilibrium between can be reached the natural dispersion rate and the oil resurfacing rate in such a way that 10% to 35% of the initial oil volume is naturally dispersed within the water column. This oil continuously resurfaces and contributes to the development of a sheen and rainbow tail in the wake of the spill.

The development of the sheen and rainbow tail largely depends on the actual subsurface drift of the oil droplets. Taking the risk to oversimplify, our simulations suggest that the deeper oil droplets can reach, the longer the subsurface drift will last and the further away the droplets will resurface at the rear of the main slick. This simple view suggests that the area covered by the sheen and rainbow tail will be larger if the significant wave height (intrusion depth of the droplets) is large; if the bathymetry is deep (turbulent vertical mixing can entrain a small fraction of the dispersed oil droplets close to the sea bed) and if the subsurface currents are small.

With the considered met-ocean condition***, this process largely dominates the oil endogenous spreading after 24 hours.***

5 Conclusion

This report presents and discusses the results of 14 oil drift and fate simulations of 10,000m^3 of light crude oil released from 7 locations around the North Sea and the English Channel using realistic met-ocean conditions in the case of a moderate South West wind of 7.5 m/s.

Each simulation is very specific and can therefore be hardly transposed to other meteorological conditions or other oil types. However, they illustrate the importance of taking into consideration beached oil re-suspension as well as the competition between natural dispersion and resurfacing. The latter largely contributes to the oil slick spreading after the second day adrift and the development of a sheen and rainbow tail at the rear of the slick. The area covered by the tail quickly increased up to several thousands of square-kilometres, potentially threatening all the oil sensitive resources in the impacted area.

References

COWI, BE-AWARE II Method Note. Version 4.1. Bonn Agreement report, May 2015, 86 p.

V.Dulière, F. Ovidio and S. Legrand. Development of an Integrated Software for Forecasting the Impacts of Accidental Oil Pollution- OSERIT. Final Report. Brussels: Belgian Science Policy 2013 – 65 p. (Research Programme Science for a Sustainable Development)

Fay, J. A. (1971) Physical processes in the spread of oil on a water surface. Proc. Joint Conf. Prevention and Control of Oil Spills, Washington, DC.

Fingas, M. (1996) The evaporation of oil spills: variation with temperature and correlation with distillation data. In: Proceedings of the 9th Arctic Marine Oil Spill Program (AMOP), technical seminar, Canada. Environment Canada, Ottawa, Quebec, Canada, pp. 29-72.

Fingas, M. (1997) The evaporation of oil spill: prediction of equations using distillation data. Proceedings of the 20th Arctic and Marine Oil Spill Program (AMOP), Technical seminar. Environment Canada, pp. 1-20.

Fingas, M. (2011) Oil spill science and technology. Edited by M. Fingas, Elsevier/Gulf Professional Publishing, Boston, MA, ISBN-13: 978-1856179430, 1192 pp.

Garcia-Matinez, R. and H. Flores-Tovar (1999) Computer Modeling of Oil Spill Trajectories with a high Accuracy Method. Spill Science & Technology Bulletin, 5 (5/6), pp. 323-330.

Guo, W.J. and Y.X. Wang (2009) A numerical oil spill model based on a hybrid method. Marine Pollution Bulletin, 58, pp. 726-734.

Scory, S., 2005. The use of mathematical models for estimating oil pollution damage at sea, in: Maes, F. Ed. Marine resource damage assessment: liability and compensation for environmental damage. pp. 211-252.

Tkalich, P., and E.S. Chan, 2002. Vertical mixing of oil droplets by breaking waves. Marine Pollution Bulletin, 44, pp. 1219-1229.

Wang, S.D., Y.M. Shen, Y.K. Guo, and J. Tang, 2008: Three-dimensional numerical simulation for transport of oil spills in seas. Ocean Engineering, 35, pp. 503-510.

Operational Directorate Natural Environment
OD Nature | OD Natuur | DO Nature

Colophon

This report was issued by RBINS/OD Nature in August 2015 and updated in November 2015, as a deliverable prepared for COWI in the framework of the project BE-AWARE II.

Status: ☐ Draft

☒ Final version

☐ Revised version of document

☐ Confidential

Available in: ☒ English

☐ Dutch

☐ French

If you have any questions or wish to receive additional copies of this document, please send an e-mail to sebastien.legrand@naturalsciences.be, quoting the reference or write to:

RBINS / OD Nature
100 Gulledelle
B-1200 Brussels
Belgium

Phone: +32 2 773 2111
Fax: +32 2 770 6972
http://www.mumm.ac.be