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REPORT

Oil in Ice - JIP

Report no.: 35

Modelling of oil in ice with OSCAR

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Preface

SINTEF has in cooperation with SL Ross Environmental Research Ltd and DF Dickins Associates LLC on behalf of the oil companies AGIP KCO, Chevron, ConocoPhillips, Shell, Statoil and Total initiated an extensive R&D program; *Joint industry program on oil spill contingency for Arctic and ice covered waters.* This program was a 3-year program initiated in September 2006 and finalized in December 2009.

The objectives of the program were;

- To improve our ability to protect the Arctic environment against oil spills.
- To provide improved basis for oil spill related decision-making:
- To advance the state-of-the-art in Arctic oil spill response.

The program consisted of the following projects:

- P 1: Fate and Behaviour of Oil Spills in Ice
- P 2: In Situ Burning of Oil Spills in Ice
- P 3: Mechanical Recovery of Oil Spills in Ice
- P 4: Use of Dispersants on Oil Spills in Ice
- P 5: Remote Sensing of Oil Spills in Ice
- P 6: Oil Spill Response Guide
- P 7: Program Administration
- P 8: Field Experiments, Large-Scale Field Experiments in the Barents Sea
- P 9: Oil Distribution and Bioavailability

The program has received additional financial support from the Norwegian Research Council related to technology development (ending December 2010) and financial in kind support from a number of cooperating partners that are presented below. This report presents results from one of the activities under this program.

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Funding Partners

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Report

Modelling of oil in ice with OSCAR

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ABSTRACT

In May 2009, a large-scale field experiment (FEX2009) took place in the marginal ice zone in the Barents Sea. Fresh crude oil was released uncontained between the ice floes to study oil weathering and spreading in ice by multiple sampling throughout the six-day experiment, including meteorological and oceanographic (MetOcean) data. The objective of the comprehensive sampling program was to acquire more knowledge of how the presence of ice influences the distribution and spreading of oil on the surface and in the water column.

Here, the MetOcean parameters that are recorded have been used to improve and verify the Oil Spill Contingency and Response (OSCAR) model. A new version of the OSCAR model (OSCAR 6.0) has been developed as a part of this project. The present versions of the SINTEF OSCAR and OWM models take the ice-coverage as an adjusting parameter into the calculations. The ice cover affects weathering, spreading, evaporation of surface oil, as well as drifting of oil with ice. This project has demonstrated that in order to get good results from the modelling of oil spill in ice, both good current and wind data from the time of interest is important. Even though the simulation with measured current and wind data showed a good resemblance with the measured ice drift, further field data over longer periods of time is necessary to improve the model. Nevertheless, the data collected during FEX2009 will be used as a test scenario for verification of future versions of the OSCAR model

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1 Introduction

This study has been an add-on activity to the Joint Industry Program to develop and advance the knowledge, methods and technology for an oil spill response in Arctic and ice-covered waters (Oil-in-Ice JIP). The JIP summary report (Sørstrøm et al., 2010) gives an overview of the total program and the technical reports.

In May 2009, a large-scale field experiment (FEX2009) took place in the marginal ice zone in the Barents Sea, northeast of Hopen Island (N77.6, E30.9). The research vessel “Lance” was used and 7000 litres of Troll fresh crude (naphthenic oil) were released uncontained between the ice floes to study oil weathering and spreading in ice. The processes for the drift, spreading and weathering of oil were monitored by multiple sampling throughout the six-day experiment. Meteorological and oceanographic data were collected for monitoring wind speed and direction, air temperature, currents and wave height. In addition, the recording of ice drift and ice field deformation was carried out by deploying a large number of GPS recorders on selected ice floes both in and around the oil slick. The recordings from the GPS systems on the ice floes, the position of the ship, and aerial surveillance from helicopter and field observations during sampling have all been used to estimate the spreading of oil-in-ice and the approximate dimensions of the oil slick. Data on the potential bioaccumulation of oil components in the water column were collected by passive absorption devices (semi-permeable membrane devices known as SPMDs), while dissolved hydrocarbons in the water column were sampled by in situ large-volume water sampler (Kiel In Situ Pump, KISP). The chemical monitoring showed low, but detectable, concentrations in the range between 0.1 (background) to 1.5 ppb dissolved hydrocarbons and 4 (background) to 32 ppb total hydrocarbons from the KISPs (Faksness et al., 2011). The water soluble oil fraction (WSF) is of special interest since the components dissolved (e.g. naphthalenes, phenanthrenes, dibenzothiophenes and phenols) in an oil slick or from the dispersed oil droplets beneath a slick, is considered to be the major contributor to any ecological effects from oil spills (Neff et al., 2006).

The objective of the comprehensive sampling program during FEX2009 was to acquire more knowledge of how the presence of ice influences the distribution and spreading of oil on the surface and in the water column. Here, the MetOcean parameters that are recorded have been used to improve and verify the Oil Spill Contingency and Response (OSCAR) model. OSCAR, which is developed at SINTEF, is a tool for quantifying the drift and spreading of an oil slick, the effectiveness of various response methods and for quantitative environmental risk screening in the marine environment. OSCAR includes an oil weathering model, an oil spill combat model, and a 3-dimentional oil trajectory and chemical fates model (Reed et al., 1995 and 2001). A new version of the OSCAR model (OSCAR 6.0) has been developed as a part of this project, improving the oil spill fate and behaviour in ice covered areas, and the OSCAR-simulations presented in here are modelled with this version.

2 Input to the OSCAR simulations

The OSCAR simulations have been performed using the MetOcean data from the field experiment as input, as well as the chemical composition of the crude oil given in Table 2.1. Air temperature, wind speed and direction were recorded every 10 minutes by a weather station onboard the RV "Lance". The current speed and direction were measured by using a Doppler profiling device (RDCP) in one location and two single point current meters (Seaguards) in another. An accelerometer (Gyro motion sensor SMC S-108) and a Seawatch Mini Buoy were used for monitoring of the ice floe movements such as heave, pitch, and roll. All MetOcean recordings are reported and discussed in Faksness et al. (2010).

Table 2.1 Input to OSCAR: Composition of Troll B Fresh (SINTEF ID 2009-0702).

Group no	Group abbreviations	% distribution
1	C1-C4 gasses (dissolved in oil)	0.00
2	C5-saturates (n-/iso-/cyclo)	0.90
3	C6-saturates (n-/iso-/cyclo)	0.75
4	Benzene	0.05
5	C7-saturates (n-/iso-/cyclo)	1.50
6	C1-Benzene (Toluene) et. B	0.31
7	C8-saturates (n-/iso-/cyclo)	3.29
8	C2-Benzene (xylenes using O-xylene)	1.11
9	C9-saturates (n-/iso-/cyclo)	1.32
10	C3-Benzenes	0.87
11	C10-saturates (n-/iso-/cyclo)	2.70
12	C4 and C4 Benzenes	0.04
13	C11-C12 (total sat + aro)	4.55
14	Phenols (C0-C4 alkylated)	0.02
15	Naphthalenes 1 (C0-C1-alkylated)	0.29
16	C13-C14 (total sat + aro)	8.11
17	Unresolved Chromatographic Materials (UCM: C10 to C36) 0 0 0	0.00
37	Metabolite 1	0.00
38	Metabolite 2	0.00
18	Naphthalenes 2 (C2-C3-alkylated)	0.40
19	C15-C16 (total sat + aro)	7.40
20	PAH 1 (Medium soluble polyaromatic hydrocarbons (3 rings-non-alkylated <4 rings)	0.27
21	C17-C18 (total sat + aro)	7.43
22	C19-C20 (total sat + aro)	6.60
23	C21-C25 (total sat + aro)	7.55
24	PAH 2 (Low soluble polyaromatic hydrocarbons (3 rings-alkylated 4-5+ rings)	0.35
25	C25+ (total)	44.2

The input parameters to the OSCAR model are given in Table 2.2 below. The current and wind field used were measured during the field work by the RDCP current profiler and by Lance, respectively. It has been assumed that both the current and the wind are uniform in the model area.

Table 2.2 Input parameters to OSCAR.

Input parameter	**Input**
Release position	77.928° N, 30.960° E
Start of simulation	2009-05-15 08:00 (NST)
Simulation time	5 days
Release start	2009-05-15 08:30 (NST)
Oil type	Troll B Crude
Released amount	7 m^3
Current	Profile measured by the RDCP
Wind	Measured by Lance
Wind drift rate	3.0 %
Ice cover	80 – 90 %

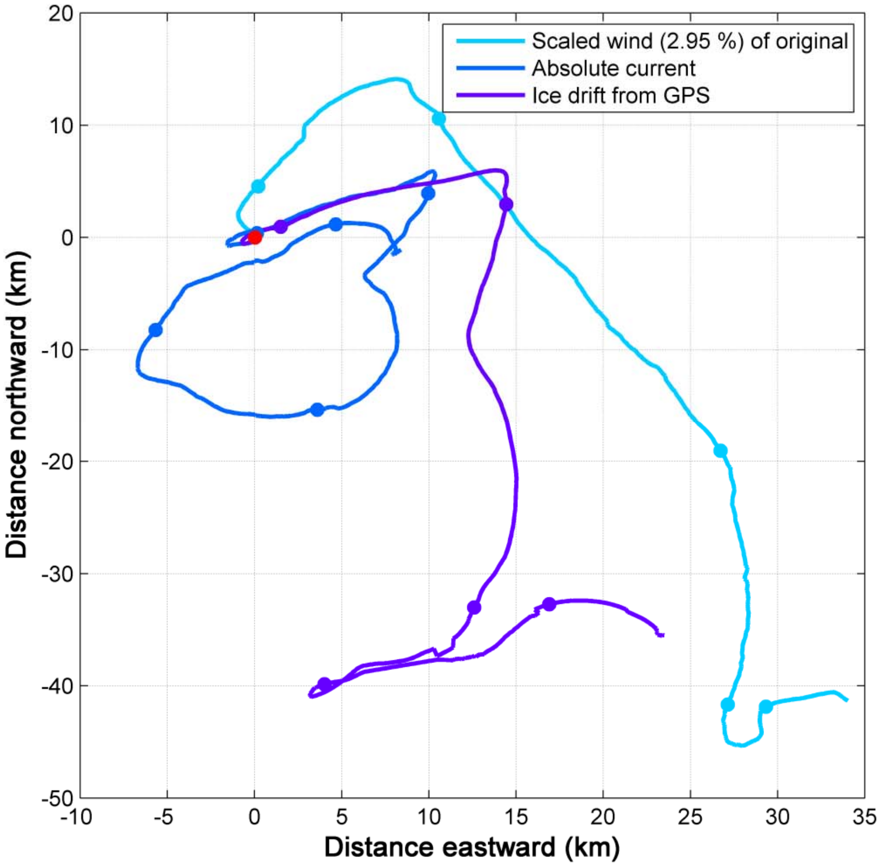

Figure 2.1 Progressive vector diagrams of the wind, current and ice drift (from GPS). The red dot denotes the start of the time series (same as start of oil release), and the dots on the time series gives the position at midnight from May 16th – 20th. Please note that the ice drift is not used as an input in the modelling. The absolute current is the measured current corrected for the ice drift.

3 Results from the OSCAR simulations

The present versions of the SINTEF OSCAR and OWM models take the ice-coverage as an adjusting parameter into the calculations. The fractional ice cover is provided as digitized grids. The ice cover affects weathering, spreading, evaporation of surface oil, as well as drifting of oil with ice. The drift rate has been modified by the Froude number (on the basis of flow velocity and block thickness) and for the Coriolis' effect (due to rotation of the earth: 35 degrees rotation to the right (CCW) for 1 m thick ice) on ice in the OSCAR model. However, since the drifting of oil slick with ice has not been understood well due to lack of enough experimental data / observations, the sub-model modifying the drift rate was discarded in these simulations.

3.1 Simulation with 80 – 90 % ice coverage

The mass balance for the simulation with 80 – 90 % ice coverage is given in Figure 3.1. It can be seen that nearly all the oil stayed at the surface during the whole period. At the end of the simulation, approximately 9.5 % of the oil had evaporated, 1.5 % was mixed down in the water column, and 1.9 % was decayed. The rest of the oil was still on the surface. The simulation shows that the oil slick kept together during the whole simulation period, (see Figure 3.2). In addition, this figure also shows that the oil slick spread somewhat during this period. This is in agreement with the observations during the field experiment.

When comparing the drift of the oil slick with the ice drift shown in Figure 2.1 it can be seen that there is a good resemblance between the simulation and the observations. The path of the oil slick in the simulation is similar to the ice drift from the GPS data, however, the direction in the simulation is skewed approximately 15° left of the observed path. The oil slick changed direction at approximately the same time as the observed ice drift. The prediction of the overall maximum total concentration of oil in the water column is shown in Figure 3.3. It can be seen that the oil is being mixed down in the water column during the first day, before the concentration reduces more and more towards the end of the simulation period. The vertical distribution along a section is also given in Figure 3.3. It shows that the oil is mixed down in the water column to approximately 12 m depth.

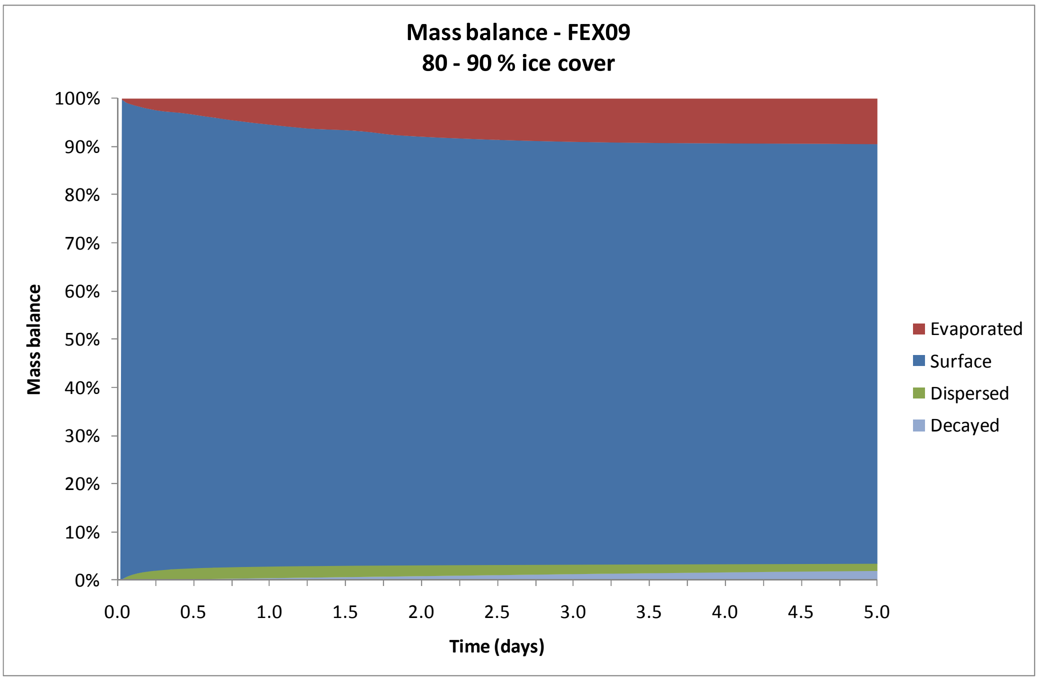

Figure 3.1 Mass balance from the simulation with an ice coverage of 80 – 90 %.

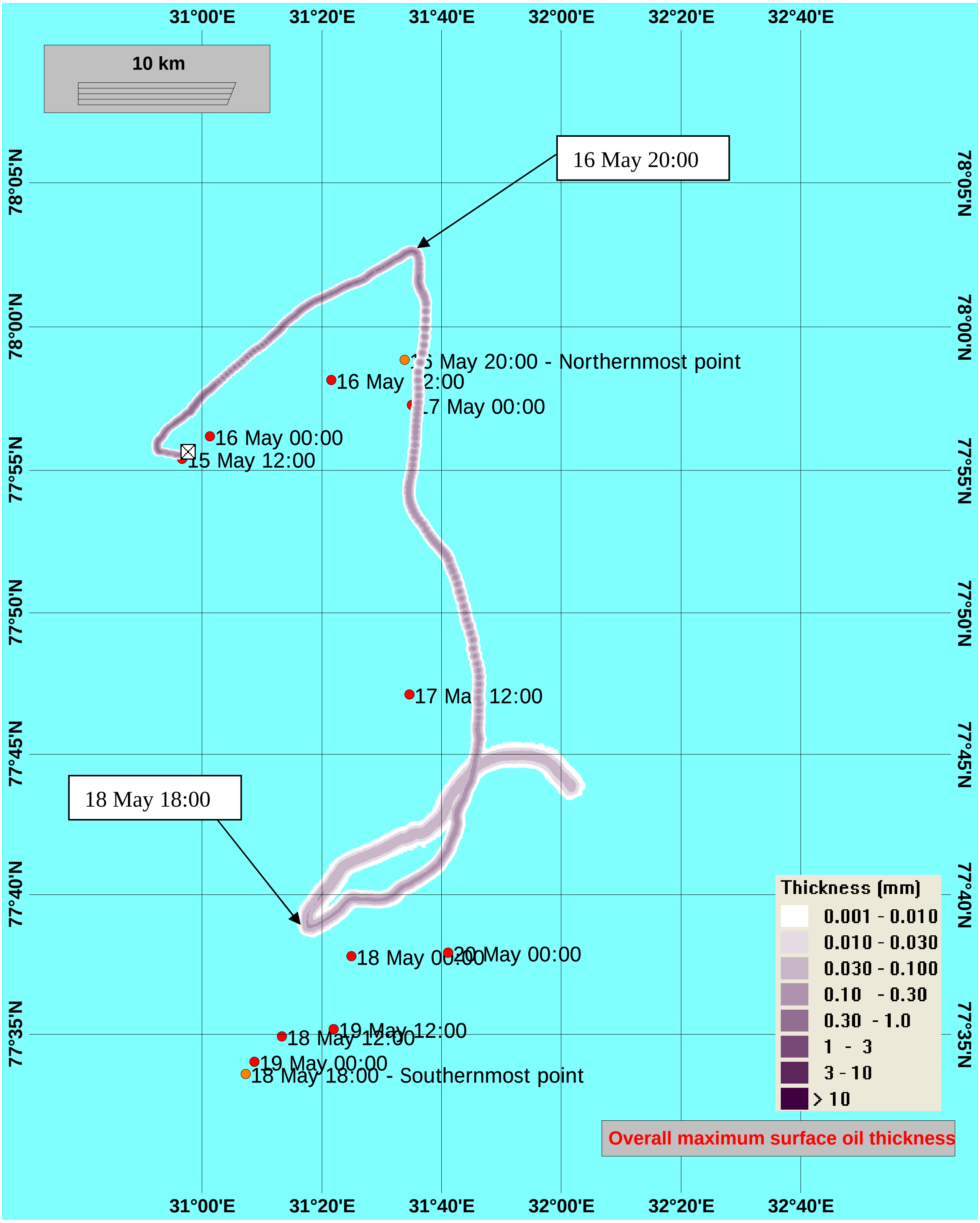

Figure 3.2 Prediction of surface oil spreading with 80 – 90 % ice coverage given as overall maximum surface thickness.

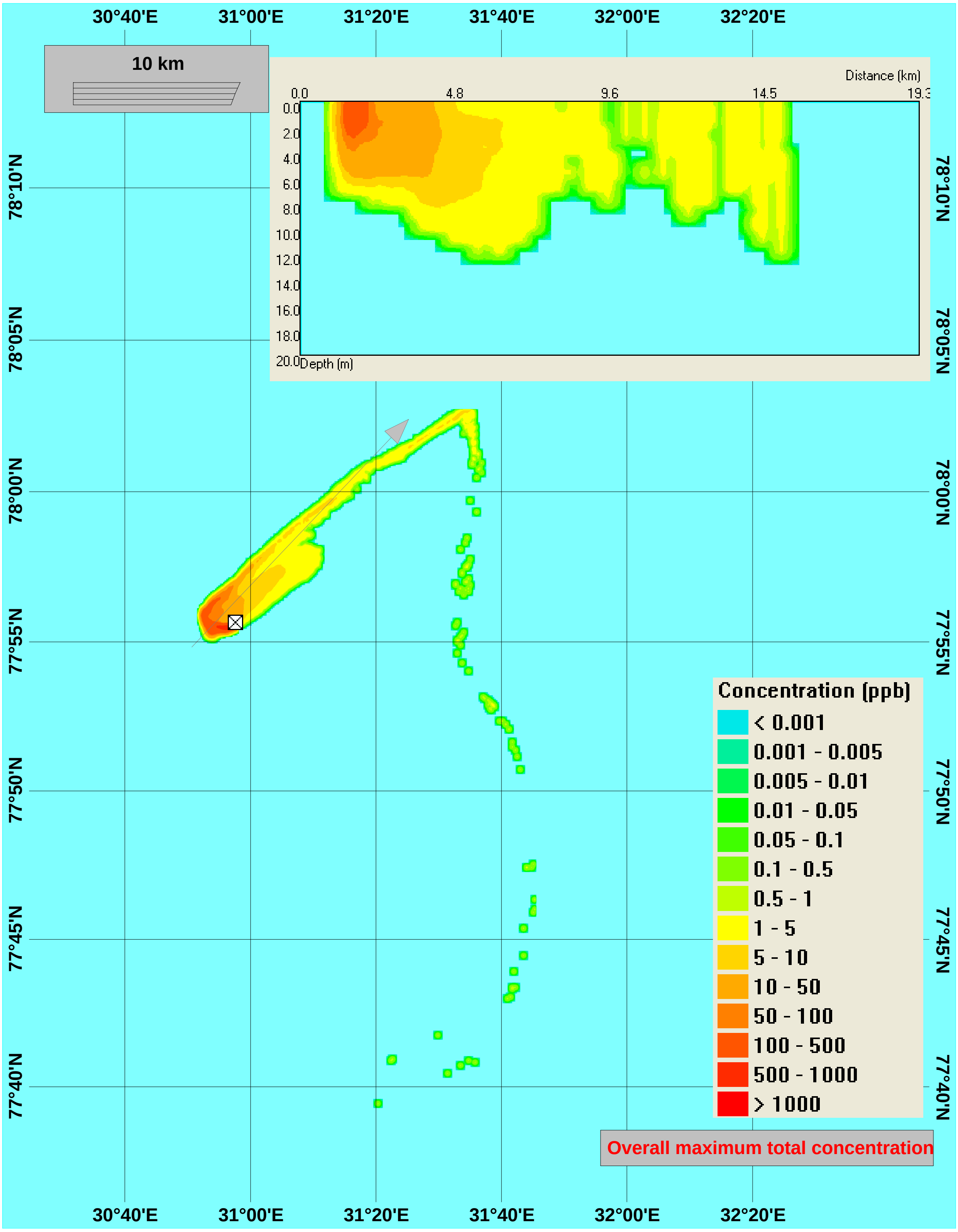

Figure 3.3 *Prediction of oil spreading in the water column with 80 – 90 % ice coverage given as overall maximum total concentration. The window in the figure shows the distribution in the water column along the cross section given by the arrow.*

3.2 Simulation without ice cover

The mass balance for the simulation without any ice cover is given in Figure 3.4. This figure shows that when the wind increase to more than approximately 6 m/s during the night of May 16th, the oil slick was starting to get mixed down in the water column. At the end of the simulation, only 3 % of the oil spill was still located at the surface. By this time, 31 % had evaporated, 2 % had decayed and the rest (64 %) had dispersed into the water column.

Figure 3.5 and Figure 3.6 show the prediction of oil spreading at the surface and in the water column, respectively. It can be seen that the oil slick broke apart and spread over a larger area (Figure 3.5) when the wind increased. The vertical distribution in Figure 3.6 shows that the oil was mixed down to approximately 30 m depth.

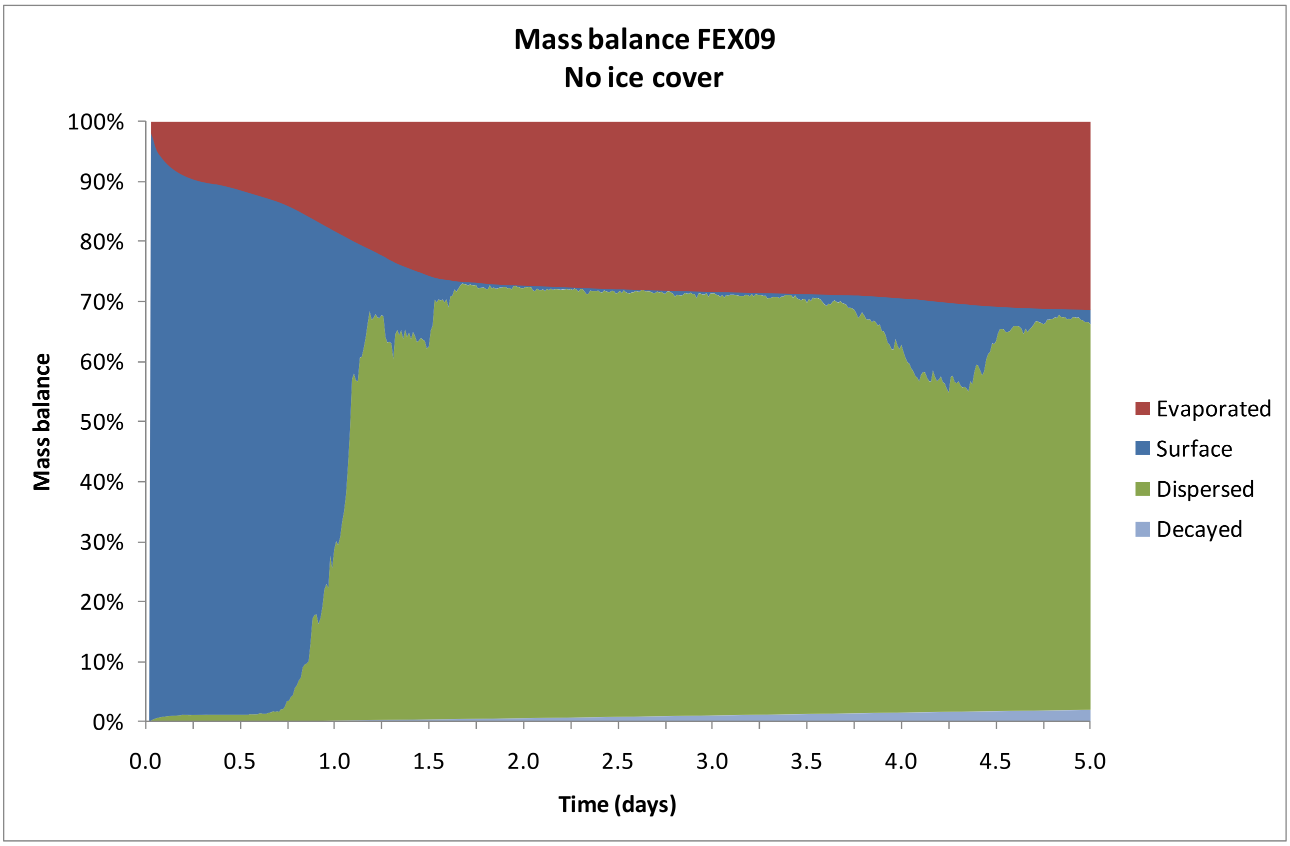

Figure 3.4 Mass balance from the simulation with no ice cover.

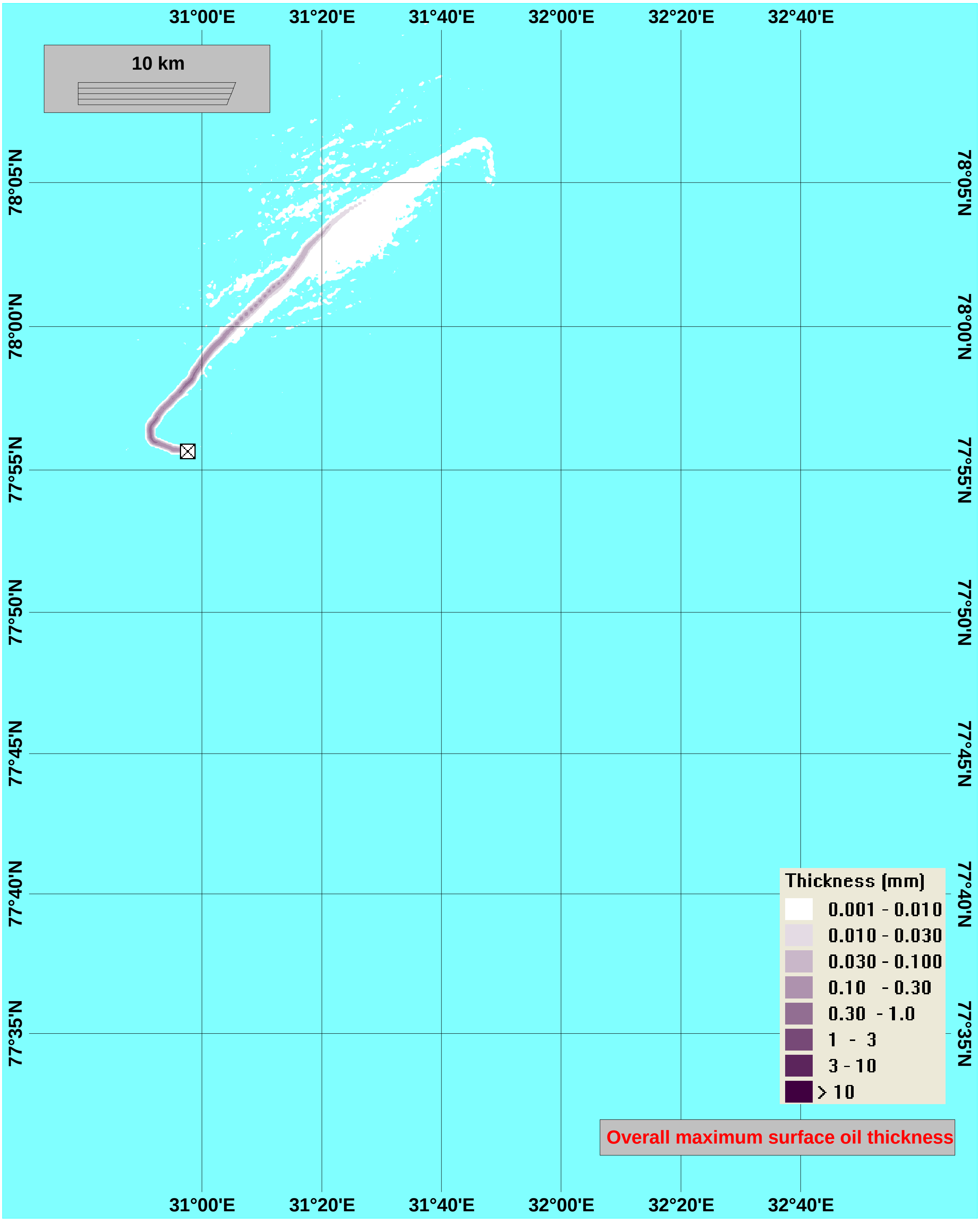

Figure 3.5 *Prediction of surface oil spreading with no ice coverage given as overall maximum surface thickness.*

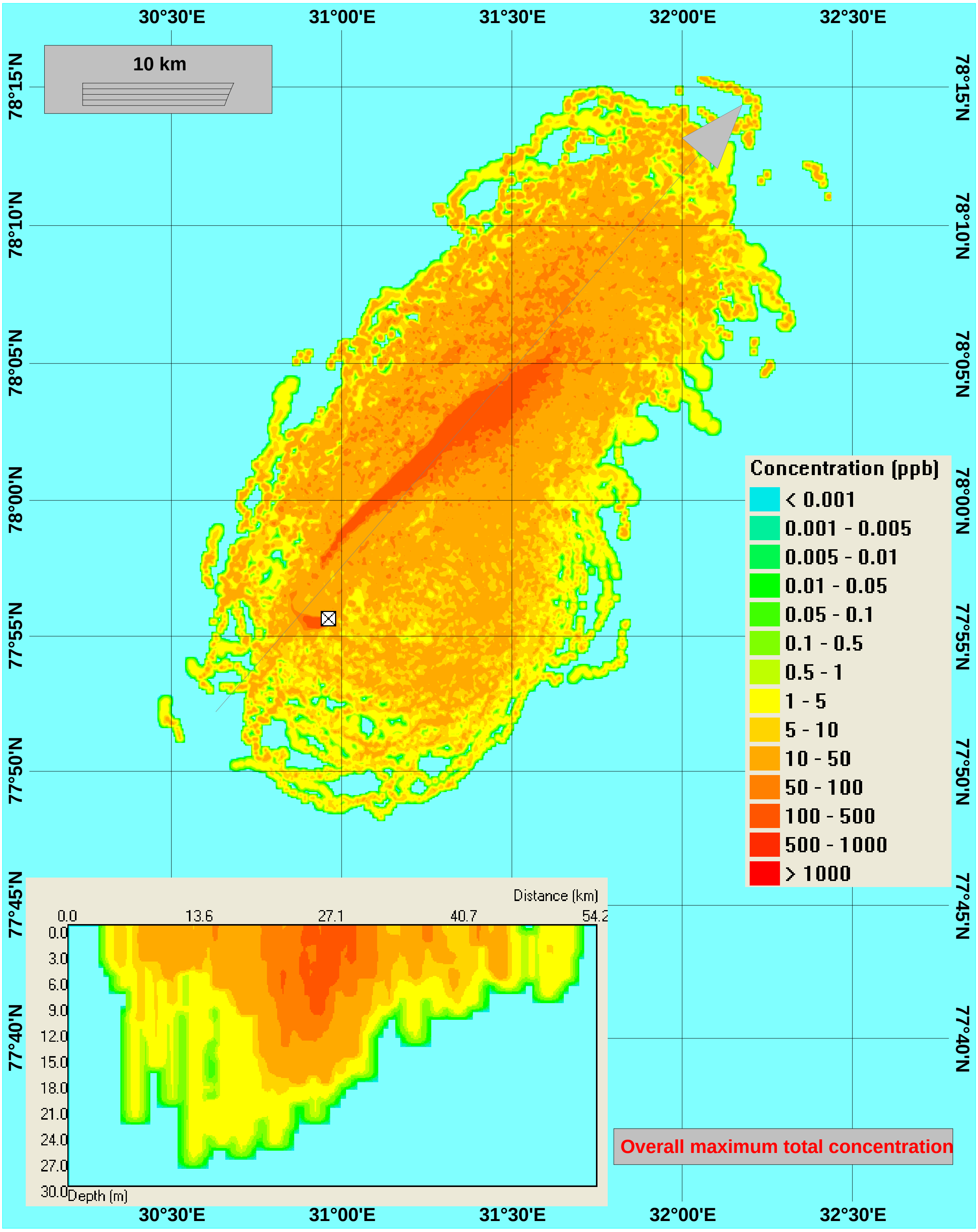

Figure 3.6 *Prediction of oil spreading in the water column with no ice coverage given as overall maximum total concentration. The window in the figure shows the distribution in the water column along the cross section given by the arrow.*

3.3 Comparison between the simulation with 80 – 90 % ice cover and with no ice

When comparing the simulation without any ice cover with the one with 80 – 90 % ice coverage, it can be seen that with no ice, the oil is much more influenced by the wind. When the wind increased to approximately 6 m/s, the oil was rapidly mixed down into the water column, whereas for the simulation with ice, the oil stayed on the surface during the whole simulation time. It can also be seen that the vertical distribution of the oil in the water column was larger for the simulation without ice.

4 Comparison between the simulation with 80 – 90 % ice cover and field data

Field samples of oil concentration 3 m below the ice were taken daily (except May 17th) at two different locations during the field campaign in May 2009. The total concentrations at the stations are given in Table 2.1 together with the maximum concentration given by the model. Snapshots of the concentration 1.5 and 29.5 hours after the release are given in Figure 4.1and Figure 4.2, respectively.

Table 4.1 Concentration in the water column

Date	Time	Station 2 Concentration (µg/L)	Station 3 Concentration (µg/L)	Simulation Concentration (µg/L) Total water column	Simulation Concentration (µg/L) 3 m depth
15.05.2009	10:00	-	5.2	890	110
16.05.2009	14:00	4.9	6.0	6.8	6.8
18.05.2009	14:00	15.0	8.5	2.1	2.1
19.05.2009	12:00	-	32.0	2.1	ND
20.05.2009	12:00	-	10.5	ND	ND

ND: Not detected

When comparing the model results with the field samples, it can be seen from Table 4.1 that the model gives too high concentration in the beginning of the simulation period. At 3 m depth the model gave a concentration of 110 µg/L, whereas the field sample from Station 3 showed a concentration of 5.2 µg/L. However, the sample was not taken in the middle of the oil spill. On May 16th and 18th, the results from the model are in agreement with the field data. There is less oil in the water column in the modelled results towards the end of the period, whereas the field data shows more oil. The highest concentration was measured on May 19th when an additional 4 m^3 of crude oil was spilled into the area at approximately 10 p.m. in connection with the in situ burning (Brandvik et al., 2010) and dispersant experiments (Daling et al., 2010). This spill is not included in the simulations. Nevertheless, both the measured concentrations in the water column and the predictions are low, which illustrates that concentrations predicted by OSCAR show the same trend as the measurements in the field.

Surface samples of the oil were collected at least once a day to follow the weathering properties, including the evaporative loss. The mass balance for the simulation with 80 – 90 % ice coverage was given in Figure 3.1. It can be seen that nearly all the oil stayed at the surface during the whole period. At the end of the simulation, approximately 10 % of the oil had evaporated. However, the experimental data from FEX2009 indicated an evaporative loss of more than 20 % (Brandvik et al., 2010). A few simulations with decreased ice cover was performed to investigate the how the model handled the evaporative loss. It was revealed that an ice cover of 30% was sufficient to get the model to predict 20% evaporative loss. The model seems to underestimate the evaporative loss in ice so a further improvement of predictions of evaporative loss at varying ice cover is needed.

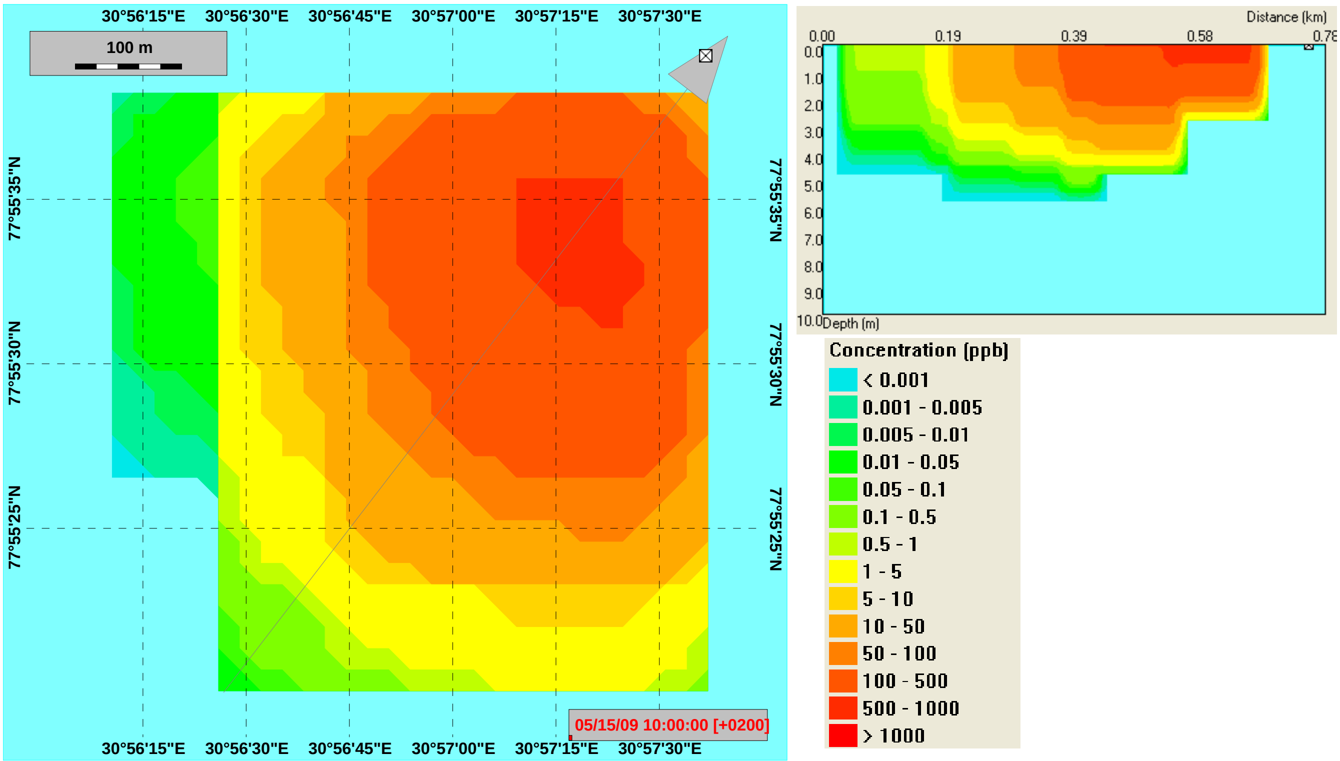

Figure 4.1 *The modelled total concentration at 10:00 on May 15th. The vertical cross section along the arrow is shown to the right.*

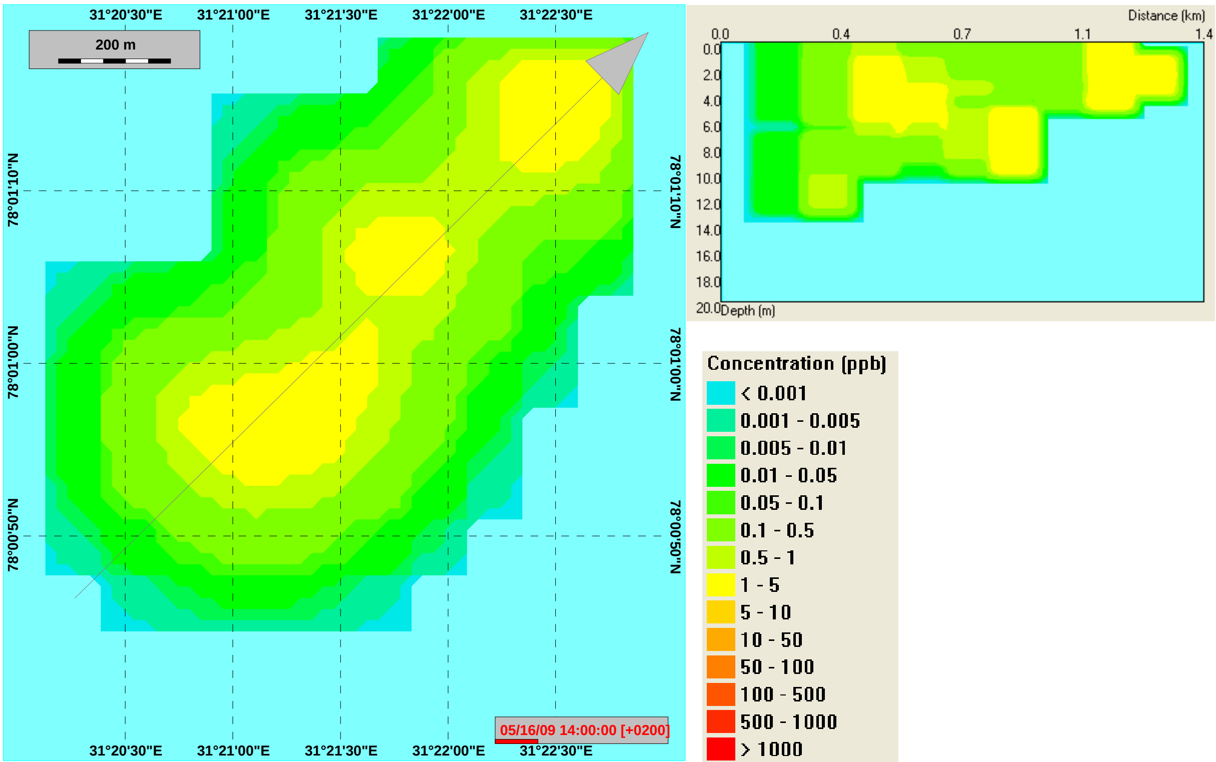

Figure 4.2 *The modelled total concentration at 14:00 on May 16th. The vertical cross section along the arrow is shown to the right.*

5 The importance of good input data

It is important to have input data of high quality in order to get the best possible results from a model simulation. The simulation with 80 – 90 % ice coverage has been run with measured current and wind from the same period as the oil spill.

As described in Section 3.1, there is a good resemblance between the simulated surface drift of the oil slick and the ice drift logged by GPS (see Figure 2.1 and Figure 3.2). In order to see the importance of having both wind and current data available, the simulation with 80 – 90 % ice cover was run with only current data, and once with only wind data. The predictions of surface oil spreading for these two scenarios are given in Figure 5.1 and Figure 5.2, respectively. When comparing these two figures with the progressive vector diagrams for the current and the wind in Figure 2.1, it can be seen that the simulated path the oil slick corresponds with the measured current and wind.

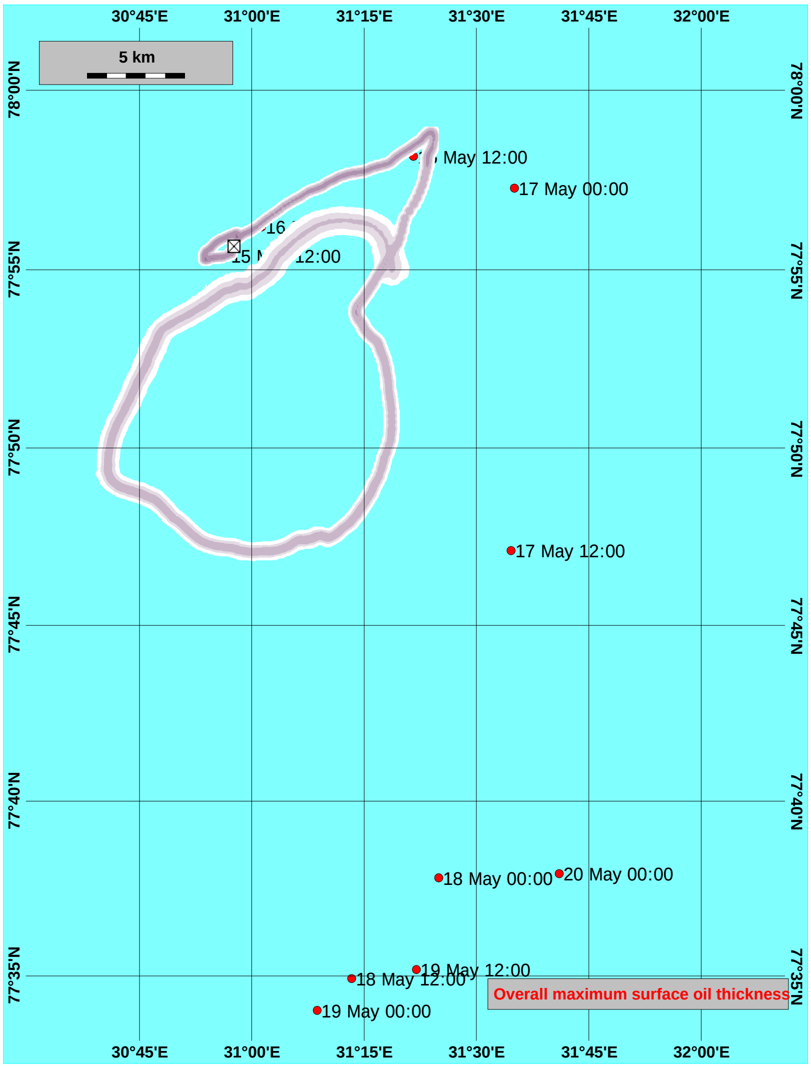

Figure 5.1 Prediction of surface oil spreading with only current data input (no wind at all), given as overall maximum surface thickness

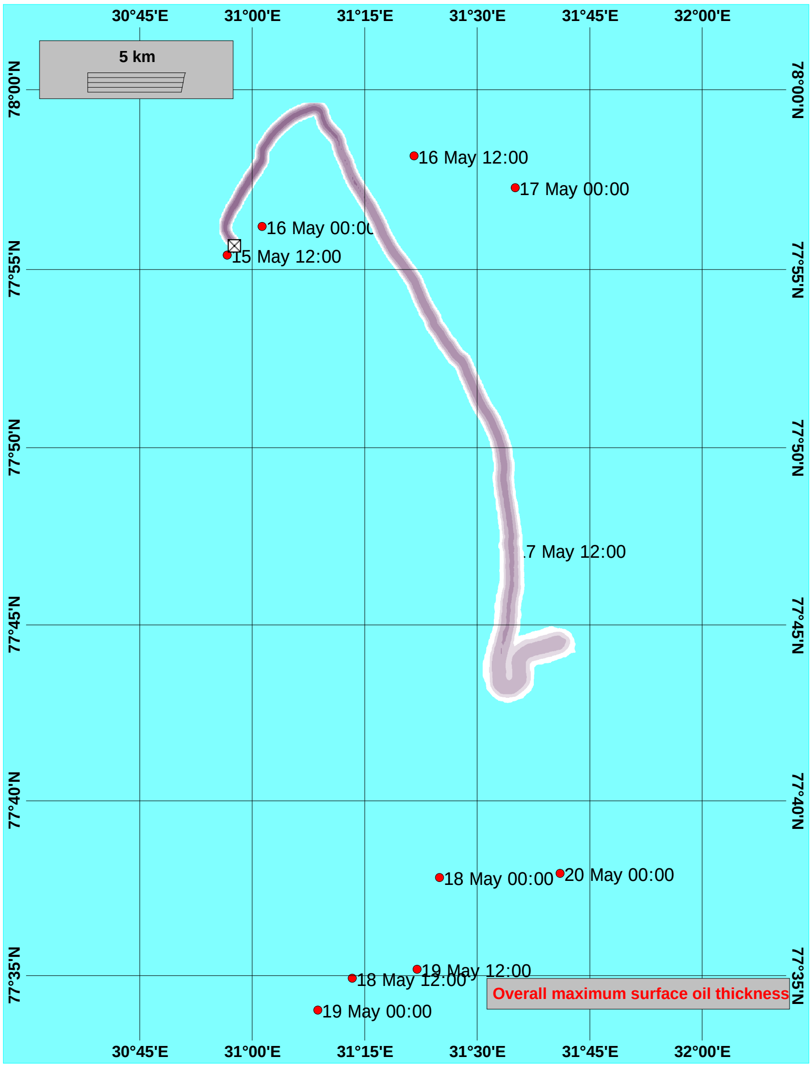

Figure 5.2 Prediction of surface oil spreading with only wind data input (no current at all), given as overall maximum surface thickness

Figure 5.1 and Figure 5.2 show that in order to get good results from the modelling, both good current and wind data from the time of interest is important. Even though the simulation with measured current and wind data showed a good resemblance with the measured ice drift, further field data over longer periods of time is necessary to improve the model.

6 Summary

The OSCAR simulations have been performed, using the MetOcean data from the field experiment as input as well as the chemical composition of the spilled crude oil. The present versions of the SINTEF OSCAR and OWM models take the ice-coverage as an adjusting parameter into the calculations. The ice cover affects weathering, spreading, evaporation of surface oil, as well as drifting of oil with ice. The drift rate has been modified by the Froude number and for the Coriolis' effect on ice in the OSCAR model. However, since the drifting of oil slick with ice has not been understood well due to lack of enough experimental data / observations, the sub-model modifying the drift rate was discarded in these simulations.

When comparing the model results with the field samples, it can be seen that the model gives too high concentration of hydrocarbons in the water column in the beginning of the simulation period, while there was less oil in the water column in the modelled results towards the end of the period. Even so, both the measured concentrations in the water column and the predictions are in the same order of magnitude (approximately 10 ppb). This illustrates that concentrations predicted by OSCAR show the same trend as the measurements in the field.

Surface samples of the oil were collected at least once a day to follow the weathering properties, including the evaporative loss. The simulation shows that the oil slick kept together during simulation period, and that nearly all the oil stayed at the surface during the whole period. This is in agreement with the observations during the field experiment. At the end of the simulation, approximately 10 % of the oil had evaporated. However, the experimental data from FEX2009 indicated an evaporative loss of more than 20 %. The model seems to underestimate the evaporative loss in ice so a further improvement of predictions of evaporative loss at varying ice cover is needed.

It is important to have input data of high quality in order to get the best possible results from a model simulation. The simulation with 80 – 90 % ice coverage has been run with measured current and wind from the same period as the oil spill, and there is a good resemblance between the simulated surface drift of the oil slick and the ice drift logged by GPS.

The verification of the OSCAR model used for oil spills in ice has demonstrated that in order to get good results from the modelling, both good current and wind data from the time of interest is important. Even though the simulation with measured current and wind data showed a good resemblance with the measured ice drift, further field data over longer periods of time is necessary to improve the model. Nevertheless, the data collected during FEX2009 will be used as a test scenario for verification of future versions of the OSCAR model.

7 References

Brandvik, P.J., P.S. Daling, L.G. Faksness, J. Fritt-Rasmussen, R.L. Daae, and F. Leirvik (2010). Experimental oil release in broken ice – a large-scale field verification of results from laboratory studies of oil weathering and ignitability of weathered oil spills. JIP report no. 26. SINTEF A15549, ISBN 978-82-14-04770-7 (32 p).

Daling, P.S., Holumnsnes, A., Rasmussen, C., Brandvik, P.J., Leirvik, F., 2010. Development and field testing of a flexible system for application of dispersants on oil spills in ice, in Proceedings of the 33rd AMOP Seminar on Environmental Contamination and Response, Environment Canada, Ottawa, ON, pp. 787-814

Faksness, L.G., Daae, R.L., Brandvik, P.J., Leirvik, F., Børseth, J.F. 2010. Oil distribution and bioavailability – FEX 2009. JIP report no. 33. SINTEF A16584, ISBN 978-82-14-0512-7 (69 p).

Faksness, L.G.. Brandvik, P.J., Daae, R.L., Leirvik, F., Børseth, J.F., 2011. Large-scale oil-in-ice experiment in the Barents Sea: Monitoring of oil in water and MetOcean interaction. Mar. Poll. Bull. 62: 976-984.

Neff, J.M., Johnsen, S., Frost, T.K., Utvik T.I.R., Durell, G.S., 2006. Oil well produced water discharges to the North Sea. Part II: Comparison of deployed mussels (*Mytilus edulis*) and the DREAM model to predict ecological risk. Marine Environmental Research 62, 224-246.

Reed, M., Aamo, O.M., and Daling, P.S. 1995. Quantitative analysis of alternate oil spill response strategies using OSCAR. Spill Sci. and Tech. Bull. 2, 67-74.

Reed, M., Singsaas, I., Daling, P.S, Faksness, L.G., Brakstad, O.G., Hetland, B.A., and Hokstad, J.N. 2001. Modeling the Water Accommodated Fraction in OSCAR2000. Proceedings of the 2001 Oil Spill Conference, Tampa, Florida. Vol. 2, 1083-1091

Sørstrøm, S.E., Brandvik, P.J., Buist, I., Daling, P., Dickins, D., Faksness, L.G., Potter, S., Fritt-Rasmussen, J., Singsaas, I., 2010. Joint industry program on oil contingency for Arctic and ice-covered waters. Summary report. SINTEF A14181, ISBN-no. 978-82-14-04759-2.

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