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Modelling the transport of oil after a proposed oil spill accident in Barents Sea and its environmental impact on Alke species

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Abstract. Accidental oil spills can have significant effect on the coastal and marine environment. As the oil extraction and exploration activities increase in the Barents Sea, it is of increasingly importance to investigate the potential oil spill incidents associated with these activities. In this study, the transport and fate of oil after a proposed oil spill incident in Barents Sea was modelled by oil spill contingency and response model OSCAR. The possibility that the spilled oil reach the open sea and the strand area was calculated respectively. The influence area of the incident was calculated by combining the results from 200 simulations. The possibility that the spilled oil reach Alke species, a vulnerable species and on the National Red List of birds in Barents Sea, was analyzed by combining oil spill modelling results and the Alke species distribution data. The results showed that oil is dominated with a probability of 70-100% in the open sea to reach an area in a radius of 20km from the release location after 14 days of release. The probability reduces with the increasing distances from the release location. It is higher possibility that the spilled oil will reach the Alke species in the strand area than in the open sea in the summer. The total influence area of the release is 11 429 km^2 for the surface water and 1528 km^2 for the coastal area.

1. Introduction

Among the different types of marine pollution, oil is a major threat to the sea ecosystems [1]. Accidental oil spills to the marine environment has received great concern due to their potential impacts on the marine ecosystems and marine activities [1, 2]. There are serious consequences associated with an acute discharge, when large amounts of oil suddenly released into the natural environment and reach the vulnerable ecosystem. Examples of accidental oil spills involve vessels that come in distress or collide, oil well blowouts, pipeline ruptures, and explosions at storage facilities etc. [3]. This has happened several times in history. Historically, the largest accidental oil spill worldwide was a blowout at the Ixtoc-1 well that released 480000 tons crude oil into the Gulf of Mexico over a 10-month period from June 1979 to February 1980 [3]. The Prestige sank in northwestern Spain on 19 November 2002 and contaminated the Galician coastline with 60000 tons of oil [4]. The incident caused serious ecological damage along 900 km of coastline, from northern Portugal to southern France, and some areas of the coast are still not yet fully clean after two years of the incident happened [4]. A total of 12,700 cubic meters of oil suddenly released into the environment in an uncontrolled blowout accident happened in Ekofisk field in 1977 [5], which got high international attention, and became the basis for the strict environmental requirements on the Norwegian continental shelf [6].

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Another acute oil spill incident from the grounded oil tanker "Exxon Valdez" outside Alaska in 1989, resulted in a sudden spill of 42 000 cubic meters of oil to the environment and 23 species and habitats were affected. After 25 years there were only 13 species that could be considered fully recovered [7]. The Deepwater Horizon drill rig explosion and subsequent sinking in 2010 resulted in the largest offshore oil spill in US history. This spill lasted for 3 months, and resulted in serious consequences to the Gulf of Mexico, its coastal zone and living marine resources [8-10].

As oil extraction and exploration activities increase in the Barents Sea, the probability for an acute oil spill incident increases thereby. Since accidental oil spills can cause serious consequences to the recipient environment and the ecosystems living in the recipient environment, an environmental risk assessment is of great importance for oil companies in the planning and implementation of various activities. Modelling the transport and fate of oil after the oil spill incident is an important step in evaluating the potential risk to the exposed ecosystems.

In this study, the transport and fate of oil after a proposed oil spill incident in Barents Sea was modelled with OSCAR model. The possibility that oil will reach the open sea and shoreline and the influence area following the oil spill accident was investigated. The possibility that the spilled oil will reach Alke, an important species in Barents Sea, was also investigated.

2. Methodology

2.1. Oil spill transport model-OSCAR

The OSCAR (Oil Spill Contingency and Response) model is developed by SINTEF in Norway and is a state of the art, 3-dimensional dynamic simulation tool for planning and response for oil spill. OSCAR model can simulate the transport, fate and effects of oil from an oil spill incident. OSCAR system has several key components: OWM (SINTEF's data-based oil weathering model), FATES (a three-dimensional oil trajectory and chemical fates model) and an oil spill COMBAT model, and exposure model for fish and ichthyic plankton, birds and marine mammals (figure 1) [11]. FATES model calculates both the total and the dissolved concentration of oil in the water column and in the sediment, and the total area of the sea and strand area that is contaminated by oil. Therefore this model needs the sea data and wind data as input parameters. The exposure model is able to analyze which sensitive areas will be affected by oil spill and how the species in the water will be affected [12].

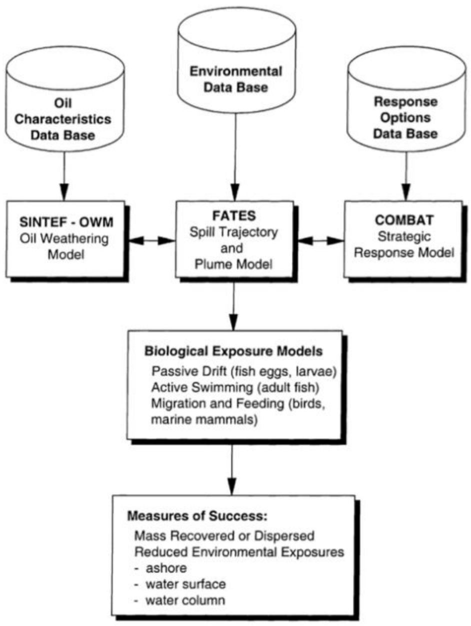

Figure 1. Overview of the OSCAR model [11].

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OSCAR model can support both 2D and 3D modelling. The 2D modeling is for surface release. 3D modelling can be used to investigate the oil concentrations, amount of oil in the sediment and in the strand. OSCAR employs surface spreading, advection, entrainment, emulsification, and volatilization algorithms to determine transport and fate at the surface.

OSCAR model can also be used to perform stochastic simulations. The scenario can be simulated hundreds or thousands of times. Afterwards the software can export several factors linked to oil release, for example average oil amount, shortest arrival time and possibility to reach the area, to the user defined grid. The software support GIS. Different data set with geographical information can be imported into the software, such as the bird and fish species data in the context of an oil spill. The analysis results can also export as GIS supported format.

2.2. Python

Python is an interpreted, interactive, object-oriented programming language [13]. The programming was designed by Guido van Rossum, and first published in February 1991. Python is an open software and can be used to treat large amounts of data [13].

In this study, Python version 3.5.0 is used to link the stochastic data from OSCAR and bird population data. The exported data from OSCAR contains 74218 rows, which is time consuming to connect each cell of this data with the corresponding cell for bird population manually. The stochastic data from OSCAR was linked to the data from bird population by their common parameter IDCell. By this way, each cell with different oil spill amount in the scenario is linked together with the corresponding number of Alke species (figure 2).

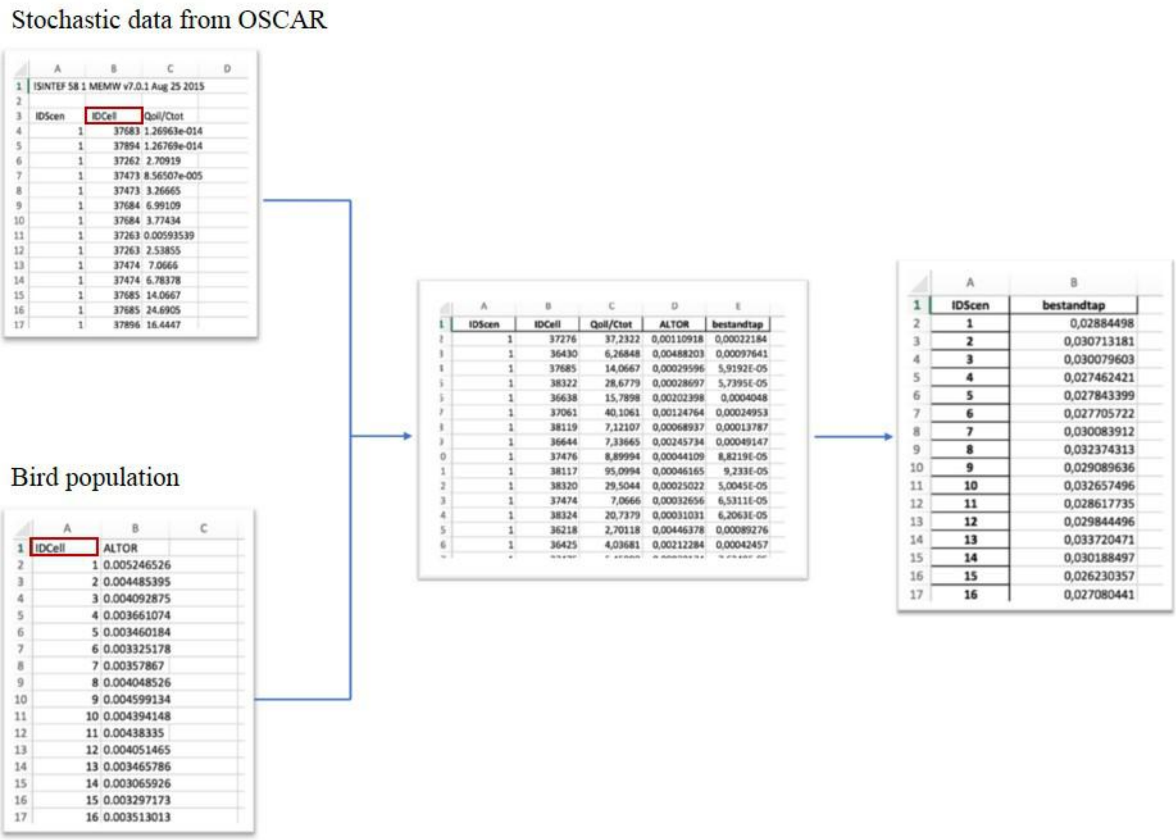

Figure 2. Simplified interpretation on link the data from OSCAR and data from species population.

2.3. ArcGIS
ArcGIS is a geographic information system (GIS) software that deals with maps and other geographic information. It is developed by ESRI (Environmental Systems Research Institute). ArcGIS can be used to make and present map, to put together different geographic data, to analyze and maintain geographic information in the databases.

In this study, ArcGIS version 10.0 is used to present the results from oil disperse modelling and combine the Alke species data with oil disperse modelling results.

3. Methodology

3.1. Location for oil disperse modelling
Area PL 764 is selected as the study area. It is relatively close to the shore. Therefore, it is higher possibility for the oil to reach the strand area in case of an accidental oil spill. The assumed location of oil spill in the current study is 70.80°N, 19.67°E as shown in figure 3. The shortest distance to the shore from the location is 57 km.

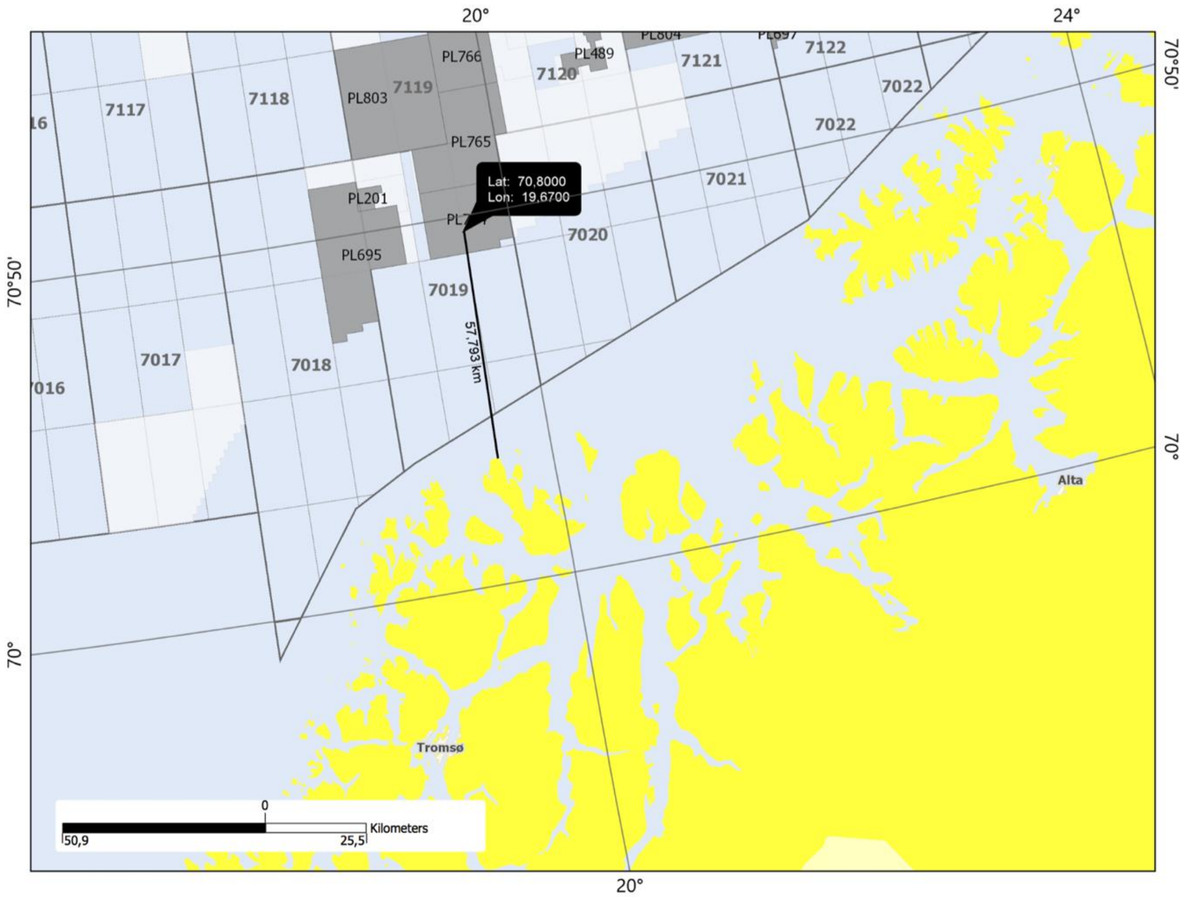

Figure 3. Location of oil spill incident.

3.2. Spilled oil types used in the model
PL 764 is an area that hasn't started the test drilling. There is no previous data about what types of oil exist there. Due to its relatively short distance to Goliat-field, the oil type Goliat Blend was selected first. However, Goliat Blend oil doesn't exist in the OSCAR system. Therefore another oil type Alpine, which has similar properties as Goliat Blend oil, was selected in this study to do the simulation.

Alpine is a paraffinic crude oil. It contains large amounts of light molecular compounds. In case of an oil spill, about 25% of the total volume of spilled oil will be evaporated within 24 hours, either during the summer season or during the winter season. The oil has a pour point of -18°C. At a wind speed of 10 m/s, the pour point increases significantly to 10°C in winter and 15°C in summer with weathering [14].

3.3. Data collection

3.3.1. Ocean current. Ocean current data is collected from Institute of Marine Research and modelled with NorKyst-800 model. NorKyst-800 (Norwegian Coast 800 m) is a numerical ocean modelling system suitable for reproduction of physical variables as sea level, temperature, salinity, and currents for all coastal areas in Norway and adjacent seas [15]. The full NorKyst-800 bathymetric grid consists of 2600×900 grid cells with each cell having an area of 800×800 m [15].

The modelled data from 01.05.2010 to 31.07.2010 was collected. This will be sufficient to cover an oil dispersion duration of 70 days. Figure 4 shows the area modelled in NorKyst-800.

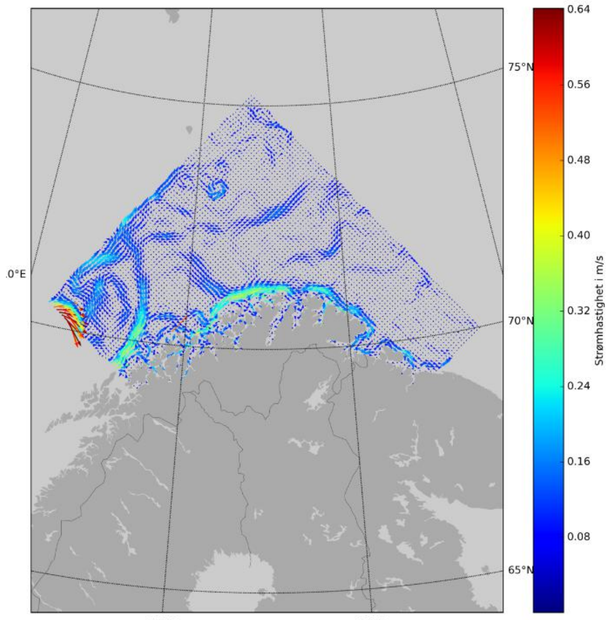

Figure 4. Average value for ocean current in the modelling period.

In oil dispersion modelling, the data used have a time resolution of one hour. Therefore the ocean data is modelled for each hour in the period. Sakshaug et al mentioned that the currents in the Barents Sea is low compared with the upstream speed of the Norwegian Sea, which is between 0.5-1 m/s [16]. The Norwegian coastal current has a near-coastal speed in excess of 0.25 m/s [16]. Our current data (figure 4) is in consistent with their study.

3.3.2. Wind. The wind data is collected from the Meteorological Institute. The data is Hindcast over that area. Hindcast data is generated by running the numerical model with the historical data. In contrast to weather observation stations, the Hindcast model can cover a much bigger area than individual observations. In such a way, the wind data for the area without monitoring stations can also be generated, for example the Barents Sea [17].

The wind data is from HIRLAM10 model, the High Resolution Limited Area Model. The model has a resolution of 10-11 km. HIRLAM10 atmospheric downscaling and wave hindcast is performed based on the ERA40 reanalysis covering the Norwegian Sea, the North Sea and the Barents Sea [17].

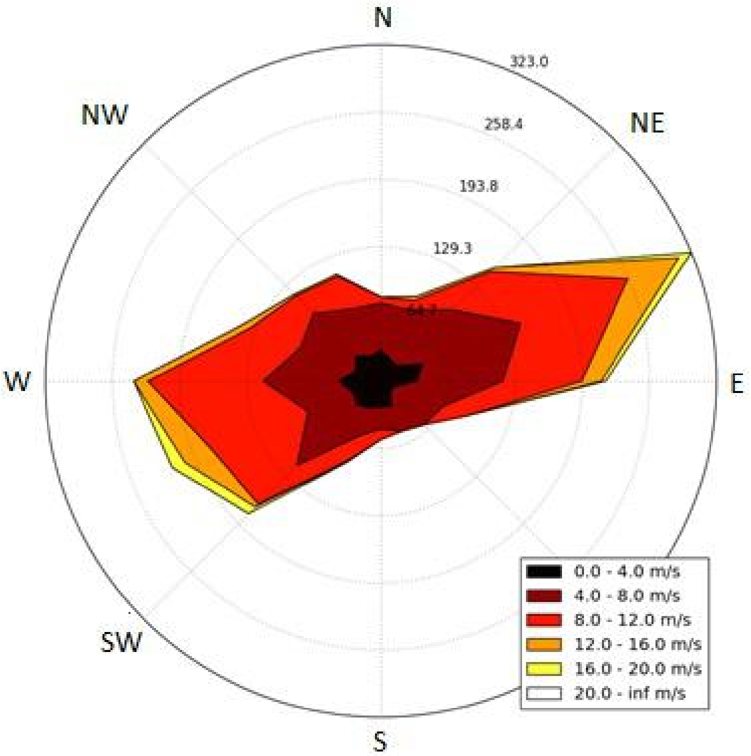

Figure 5. Wind rose from 70.81°N, 19.75°E in the period 2010.05.01 to 2010.07.31 with HIRLAM10-wind data.

Wind data for the corresponding period and the same time resolution as the ocean currents is used (figure 5). Figure 5 shows that the dominating wind direction in the study area is from southwest, west and between east and northeast. The numbers in figure 5 are the number of measurements made on the wind speed and wind direction. The size of the areas with different colors indicates the number of measurements made at the corresponding wind speed. The bigger the area is, the more measurements that has been made at that wind speed category. The data set consists of 2208 measurements at different wind directions. The average wind speed is 7.07 m/s.

3.3.3. Bird Species. Data for bird species is collected from SEAPOP. SEAPOP is organized and carried out by personnel from the Norwegian Institute for nature research (NINA), Norwegian Polar Institute (NP) and Tromsø Museum, University Museum (TMU).

Alke is a pelagic diving seabird. It can dive down to 100 meters. According to the estimates in 2013, the population of Alke species in Norway was just under 55,000 [18]. This represents 5% of the total population in Europe. Of these, it is estimated that just under 45,000 couples living in the Barents Sea. Alke is on the National Red List of birds that are highly endangered (EN). Since the species has had a 50-80% reduction in the last three generations, it is now classified as highly endangered [19]. Since Alke is a very vulnerable and sensitive species in the study area, Alke is selected in this study to investigate the impact on it from the proposed oil spill incident.

The Alke species data in the summer is collected from SEAPOP. The definition of summer period in SEAPOP is between 1st April and31st July. This is consistent with the time period for the ocean current data and wind data. The number of each species is modelled and presented in a 10×10 km network. The distribution of the Alke species in the open sea and along the coast is analyzed.

- The distribution of Alke at open sea

The distribution of Alke at open sea is shown in figure 6. From figure 6, the number of alke species at open sea is quite low.

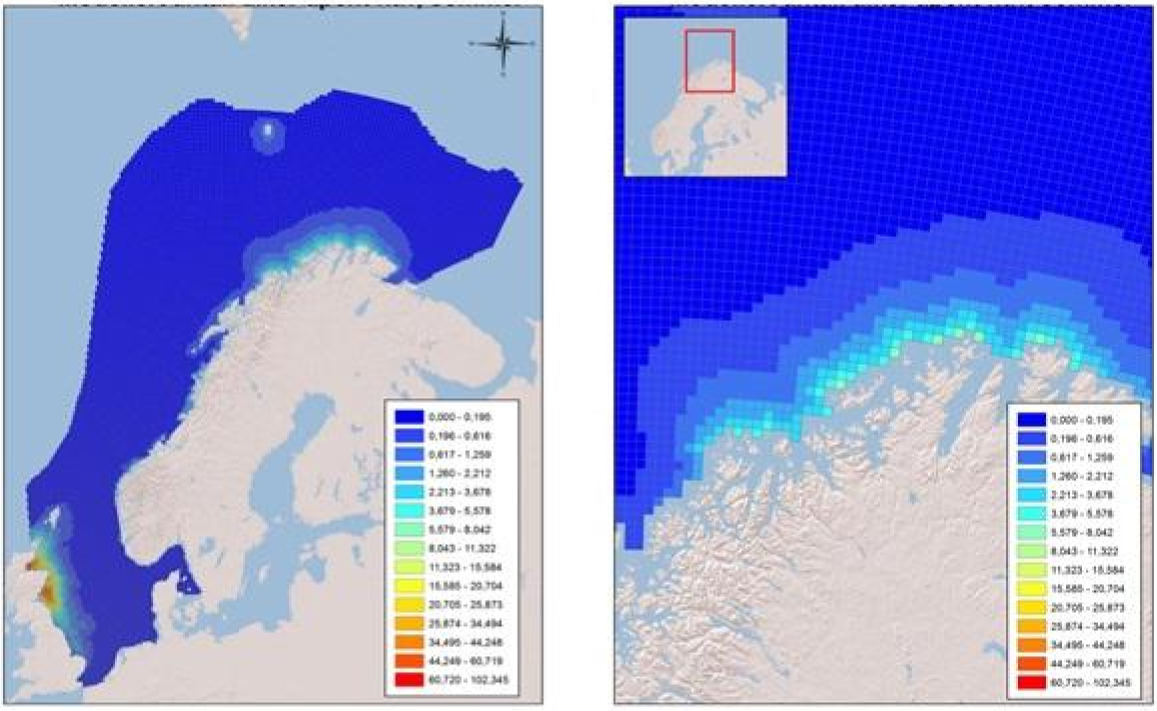

Figure 6. Distribution of Alke species at open sea.

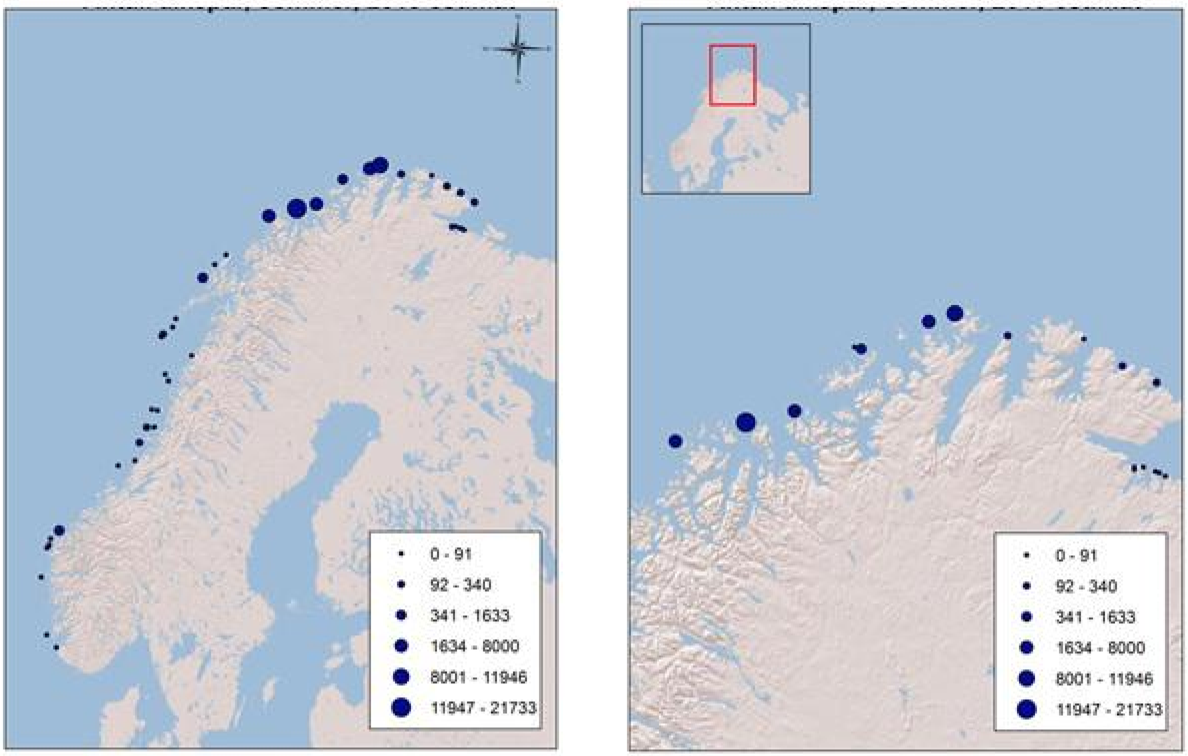

Figure 7. Estimated Alke species in summer 2013 along the coast.

- The distribution of Alke along the coast

The population size of Alke species along the coast in the breeding period is mapped. The number is calculated by counting the number of breeding couples from flight, boat and from land [20]. The localities that SEAPOP count on are distributed at different locations in Norway as shown in figure 7. In our study for the coastal area, we used the estimated number of Alke couples in the summer period in 2013, as shown in figure 7.

4. Results

4.1. Probability that oil reach open sea and the strand area at an accidental oil spill in Barents Sea

The probability that oil will reach the strand area and the open sea 14 days after the accidental spill is simulated with the OSCAR model. The results are combined with estimated Alke species number in summer 2013 and shown in figures 8 and 9 with the help of ArcGIS.

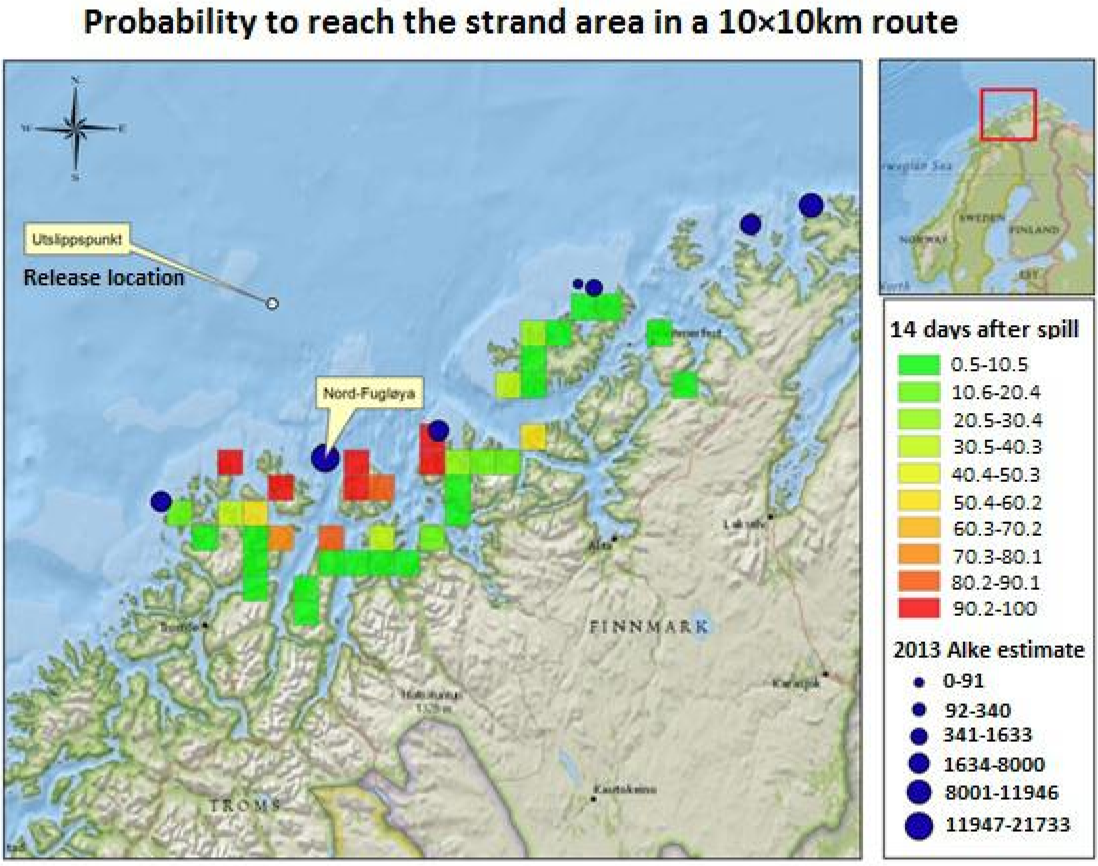

Figure 8. The probability that oil reach the strand area.

As it is shown in the figures, it is much higher number of Alke species in the strand than in the open sea in our analysis period. The breeding of Alke species is ongoing in the summer season. Therefore the population distribution of Alke species corresponding to this period dominates in the strand area since Alke reside in the strand during their breeding. The probability that the spilled oil will reach the Alke species is higher in the strand area than in the open sea.

Oil is dominated with a probability of 70-100% in the open sea to reach an area in a radius of 20km from the release location after 14 days of release. However the probability to reach the strand varies between 1-20%, with the exception of some points with 90-100% probability. The probability reduces with the increasing distances from the release location.

Nord-Fugløya is estimated to be the largest breeding place for Alke. It is zero probability that the spilled oil will reach this place. Reason to this maybe the resolution of the model is too low. However, it is very high probability that oil will reach the surrounding area of this place (figure 8). More modelling with high resolution is needed therefore.

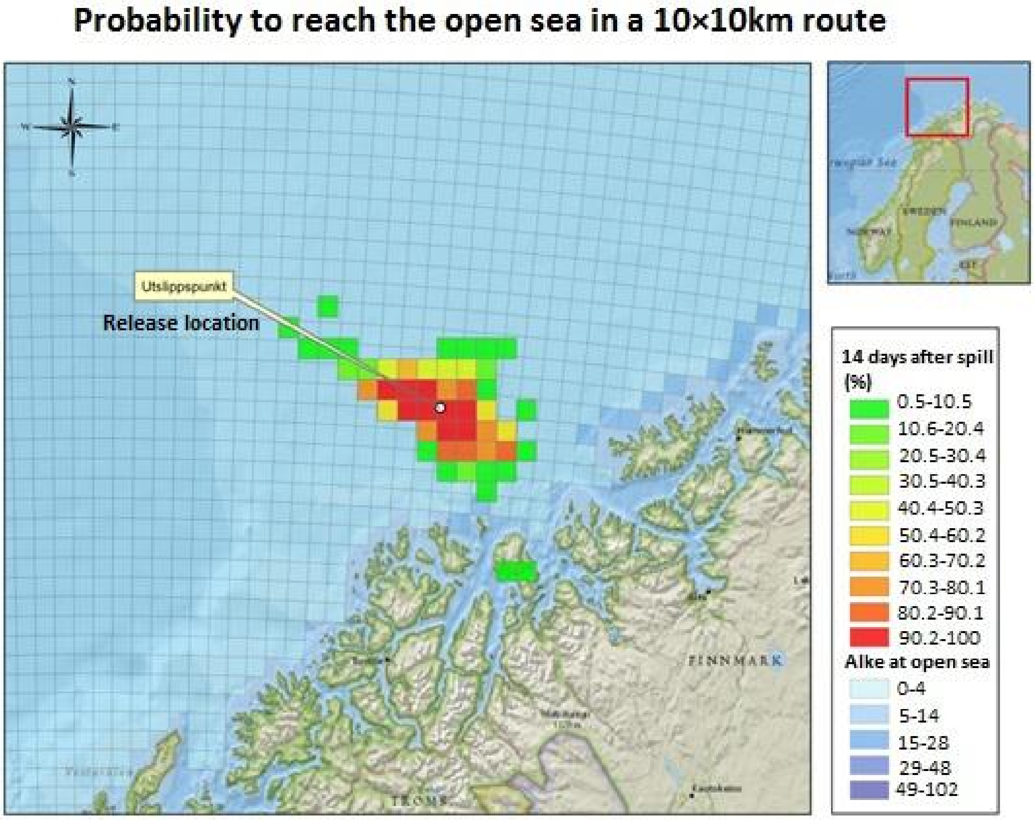

Figure 9. Probability that oil reach open sea.

4.2. The influence areas following the accidental oil spill

To illustrate how the influence area is calculated, single simulation during our modelling period is shown. By looking at three simulations at different times with identical parameters, the influence of the wind and current data on the scope of oil dispersion is analyzed.

Simulated oil release on 1st May:

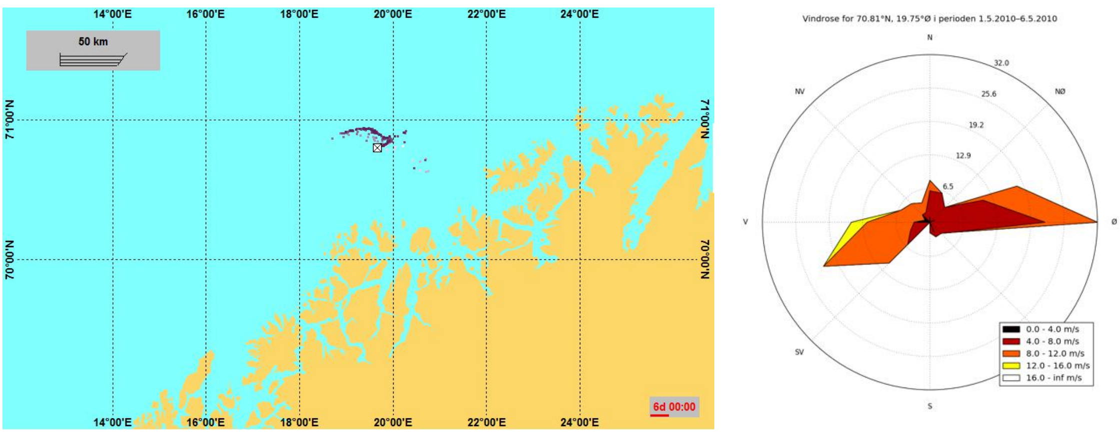

Figure 10. Simulated oil disperse after six days of release, and the corresponding wind rose.

Simulated oil release on 1st June:

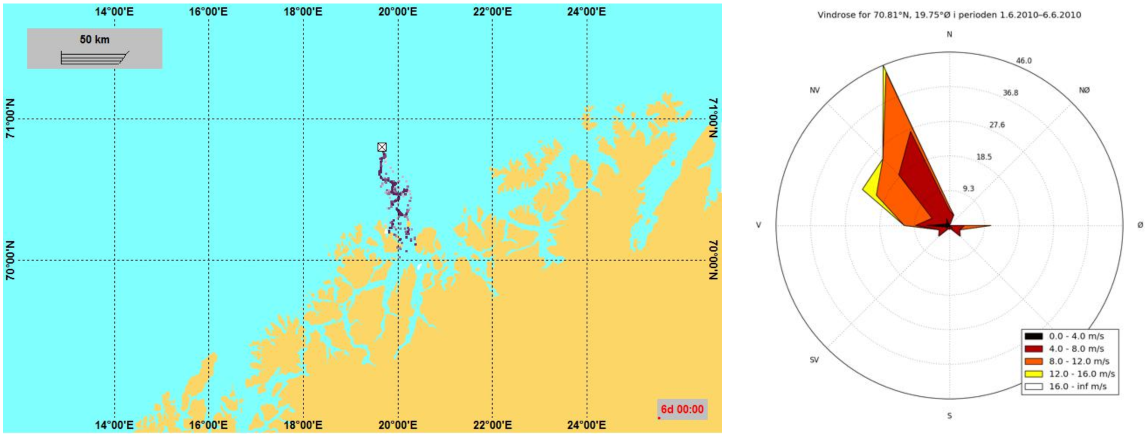

Figure 11. Simulated oil disperse after six days of release, and the corresponding wind rose.

Simulated oil release on 1st July:

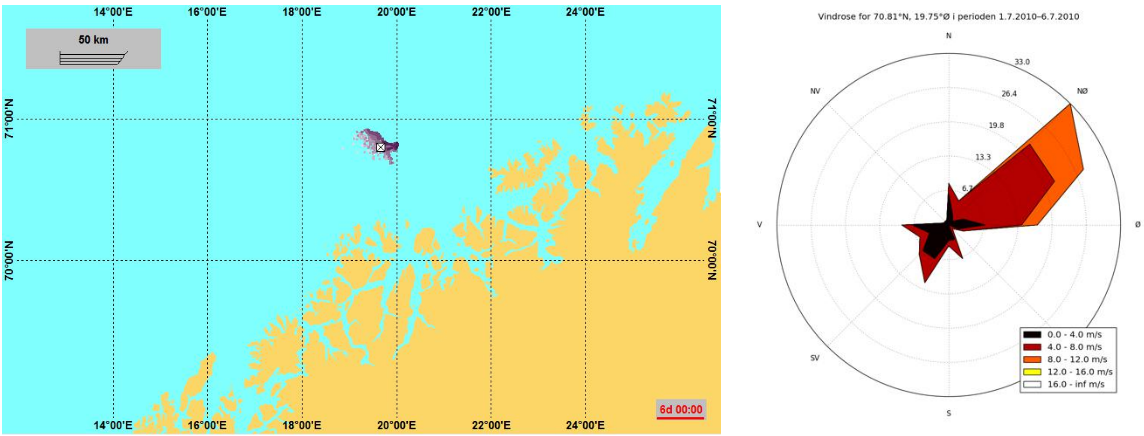

Figure 12. Simulated oil disperse after six days of release, and the corresponding wind rose.

Results from the single simulations are compared with the corresponding wind rose for the same period. Figures 10-12 illustrates how the oil on the sea surface will be affected by the dominating wind direction. The figures showed how the current and wind direction will affect the transportation of the spilled oil. In addition, the influence of currents counteracts the spread of oil from the prevailing wind direction is shown in figure 12.

The potential influence area of the release in this study is calculated by combining the results of all the 200 simulations to one total risk picture (figure 13). Oil dispersion calculations by OSCAR formed the basis for the influence area.

The total influence area of the release is 11 429 km^2 for the surface water and 1528 km^2 for the coastal area.

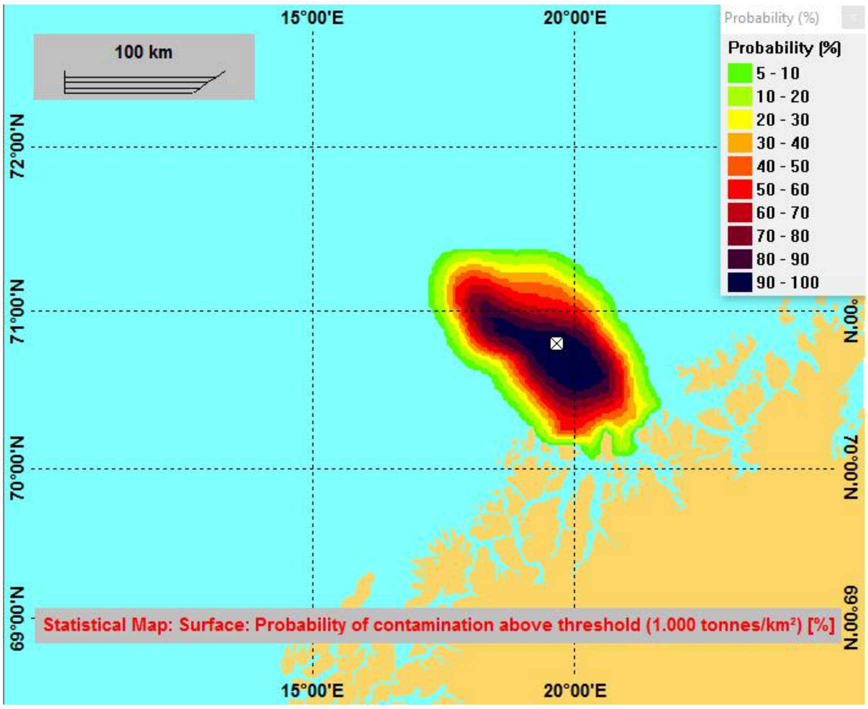

Figure 13. Influence area for our release.

5. Discussions

After an oil spill incident, the spilled oil will float on the surface of the water. Therefore species living at the surface of the water is most vulnerable to oil spill. The bird species must regularly pass through the air-water interface to breathe, are particularly vulnerable to oil exposure [21].

There are more Alke species reside in the strand area in the summer. So it is high possibility that the spilled oil will reach the species in the strand area than in the sea. The species are more affected in the places with high oil coverage on the shoreline. The shoreline surveillance on the environmental impact of the Exxon Valdez oil spill also indicated that high local mortality of species occurred at the place where oil coverage exceeded 90% [22].

The dominating wind direction has a significant effect on the transportation of fate of spilled oil. The effects of wind on the advection of a parcel of oil floating on the sea surface have been studied extensively [23]. Al-rabeh A.H. estimated the wind-induced surface oil spill speed and computed the associated deflection angle suitable for the Arabian Gulf [23].

Several data bases used in our study are based on the operations in Nordsjøen and Norwegian sea [24, 25]. Therefore it will be certain degree of uncertainty linked to them when we use these data to analyze an oil spill incident at Barents Sea.

6. Conclusions

The transportation and fate of oil in case of a proposed oil spill incident in Barents Sea is modelled with oil spill contingency and response model OSCAR. The results showed that it is higher probability that oil will reach the open sea than the strand. Oil is dominated with a probability of 70-100% in the open sea and between 1-20% probabilities to reach the strand. There are more Alke species distributed in the strand than that in the open sea in the summer. Therefore it is higher probability that the spilled oil will reach the Alke in strand than in the open sea. More Alke species will be affected in the strand than in the open sea. The total influence area of the release is 11 429 km^2 for the surface water and 1528 km^2 for the coastal area. More emergency response and management strategies should be developed for the strand area to counteract the potential oil spill accidents in the Barents Sea.

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