APP4SEA
Report on existing oil spill response models
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Norwegian Meteorological Institute
Oceanography & Marine Meteorology
Bergen, Norway

APP4SEA

ARCTIC PREPAREDNESS PLATFORM
FOR OIL SPILL AND OTHER ENVIRONMENTAL ACCIDENTS

Best Practices of Computer Modelling in Oil Spill Response

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The 21st century brought unprecedented interest in the Arctic resources, turning the region from the world's unknown periphery into the center of global attention.

Within the next 50 years, local coastal communities, their habitual environment and traditional lifestyle will undergo severe changes, starting from climatic perturbations and ending with petroleum industrial intervention and increased shipping presence.

The APP4SEA project, financed by the Northern Periphery and Arctic Programme will contribute to environmental protection of the Arctic waters and saving the habitual lifestyle of the local communities. It will improve oil spill preparedness of local authorities and public awareness about potential oil tanker accidents at sea.

SYKE | Norwegian Meteorological Institute | KYSTVERKET
University of Iceland | eri environmental research institute | Scottish Natural Heritage – All of nature for all of Scotland
marine scotland | Scottish Government gov.scot | University of Oulu

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Summary

This report provides a brief description of three oil spill modelling tools that are developed and in use in the Northern Periphery and Arctic region countries – Seatrack Web, OSCAR and OpenDrift. The report also gives some examples how these applications can be used.

Introduction

In oil spill response operations, the more information you possess, the higher chances of successful outcomes are. There are three main stages of situational development with oil spill accidents:

- DETECTION. Firstly, one needs to know for sure, whether an oil spill accident occurred or not. If it did, then - where, when and how it happened? What is scale of it, volume, oil type, slick dimensions on water surface, and direction of the slick movement?

- LOCALIZATION. Secondly, once the position and the scale of the spill are set, containment of the slick in one place is required. The slick needs to be localized. No movement towards shorelines, natural parks, closest population centres should progress substantially from the place of accident. This is one of the most crucial actions for saving the environment and people. Another reason, why localisation is also important, but this time mostly from operational point of view – by containing the slick, the oil, as a substance, is kept preserved and with sufficient level of thickness. No matter what Oil Spill Response (OSR) method is going to be used, the fresher the slick and the thicker it is, the better it is for operations.

- RESPONSE. After the slick has been stopped and contained in one place, it is time to remove it from water or use some treatment measures to "help" the ocean to clean itself. This is the stage, when thermal, chemical, mechanical, physical and biological technologies are applied to combat the environmental contamination.

This report focuses only on the first step - detection. Boom installation and response operations are the main part of oil spill response. However, there should be a great deal of information collected beforehand. The following ten pages will offer your attention everything about applied models and information they need and produce.

There is a list of questions responders have to reply before localisation and response stages:

- What kind of oil do we deal with: type, viscosity, density, volume, surface area, film thickness, freshness, ignitability?

- What type of the environment the oil slick is surrounded with: air conditions – temperature, wind patterns, solar radiation, day light availability, precipitation, visibility, and water state – temperature, salinity, wave height, sea currents, ice coverage?

Once OSR team is aware of all needed parameters about the spilled oil and the environment it is in, and profound planning and preparations are completed, operations can commence.

Computers visualize this data into animation format. The scope of this report lies only within Nordic countries: Finland, Norway, Sweden, Norway, Iceland and Scotland, which are part of Northern Periphery and Arctic Programme area. Geographically, it is from the North Sea to the Baltic Sea west to east, and from the Baltic Sea to the Barents Sea south to north.

To the best of our knowledge, there are three oil spill models developed an in operational use in those countries – Seatrack Web, OSCAR and OpenDrift. Some of them are commercial access only. Only one of the three is available openly. It has been written as open source code. In addition the US developed model GNOME is in use in Scotland. Within this report, we will provide a brief description of the three models. A case study with instructions will be offered you in the end of the report: where you can play with OpenDrift and simulate your own oil spill study. Enjoy your reading!

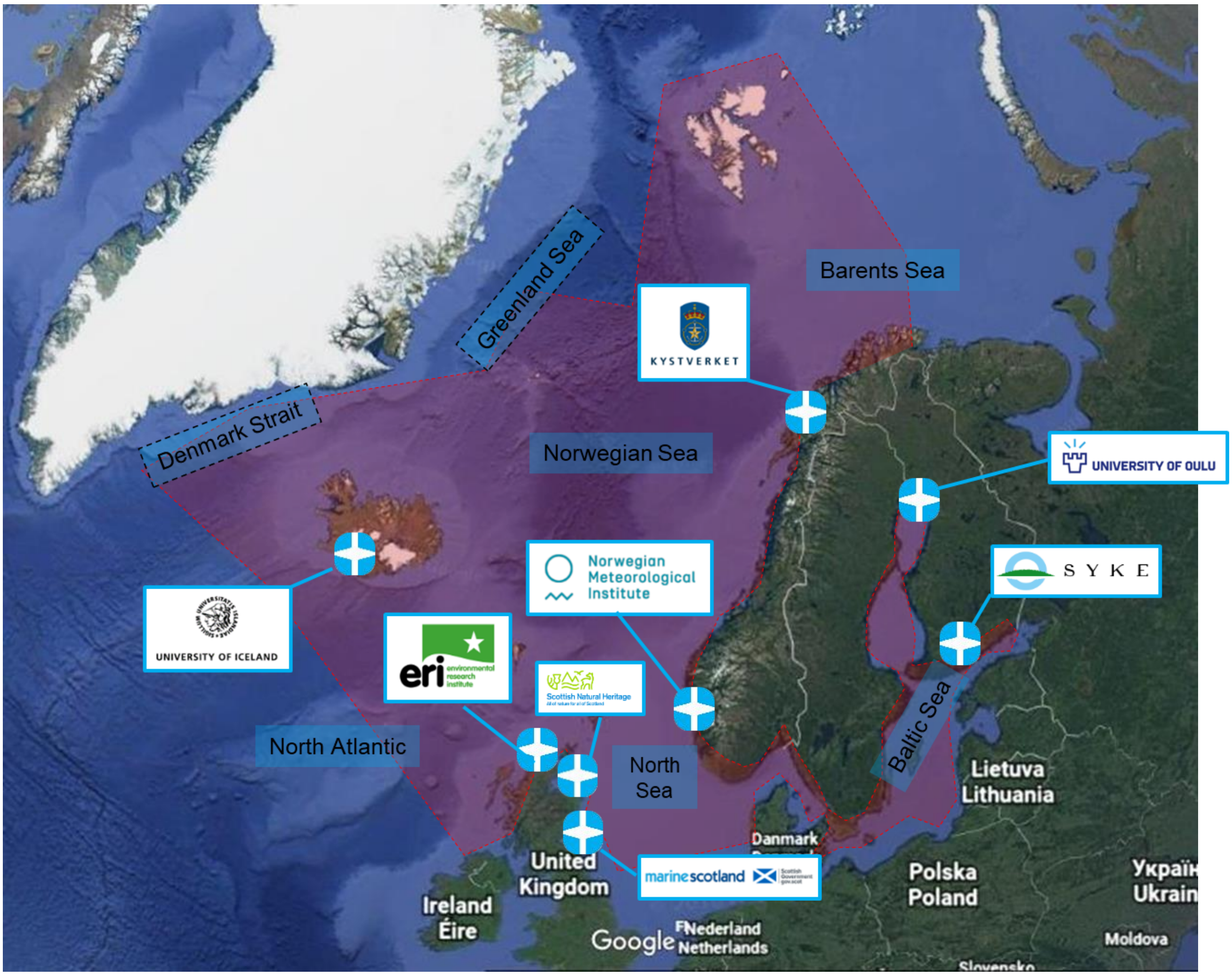

Figure 1 –APP4SEA project partners located on the map and the main sea areas addressed in the project

This report has been done as part of the Arctic Preparedness Platform for Oil Spill and other Environmental Accidents (APP4SEA) project financed by the Northern Periphery and Arctic Programme (NPA) during 2014-2020. NPA is a European Regional Development Funding instrument and it involves remote communities of Northern Europe and aims to facilitate its sustainable development with related social, economic and environmental benefits. Figure 1 illustrates four countries, where the represented project partners originate from: Finland, Norway, Iceland and Scotland. The list of the partners consists of University of Oulu & Finnish Environment Institute (Oulu & Helsinki, Finland); Norwegian Meteorological Institute & Norwegian Coastal Administration (Bergen & Tromso, Norway); University of Iceland (Reykjavik, Iceland); North Highland College, Scottish Natural Heritage & Marine Scotland (Thurso, Inverness, & Aberdeen, Scotland). The lead partner is the University of Oulu (Oulu, Finland).

Oil spill modelling tools

Background

Oil drift models are used to predict the behaviour and fate of oil in water. They can make oil spill recovery operations more efficient by predicting where the oil will move and mitigate the damage on wildlife and beaches (Fig. 1).

An oil drift model depends on *forcing data* from atmospheric (wind and air temperature), ocean (current, temperature and salinity) and surface wave (wave height and period) models. The quality of the output obviously depends heavily on the quality of the forcing data. The forcing models need to be updated daily with fresh forecasts in order to provide realistic scenarios.

Figure 2 – Oil drift models can be used to minimize the damage from oil spills by providing more efficient recovery of oil.

Transport models in atmosphere and ocean can be divided into two categories: Eulerian and Lagrangian. A Eulerian model describes the transport medium as a grid and follows the tracer of interest (here: the oil) from grid cell to grid cell. In a Lagrangian model, the tracer is represented as a number of individual particles which are followed over time. Each particle has its own properties and may lose mass due to evaporation, natural dispersion (due to wave action) etc. A Lagrangian model is less computationally demanding and the three models described here are all of this category.

When oil is spilled in water, it will quickly change properties (Fig. 2). The behaviour and fate of the oil depends much on oil type. The mixture between oil and water is called emulsion (Fig. 3). The emulsion is generally more viscous than the original oil. Oils are normally divided into light, medium and heavy oils. If the oil contains a high fraction of light components, much of the oil will evaporate. Up to 50% of the mass can be lost in 24h (Fig. 4). Viscosity is another property which varies significantly between oils, and is important when it comes to how fast the oil is split into smaller droplets which have lower buoyancy than larger droplets, and which will not reappear at the surface.

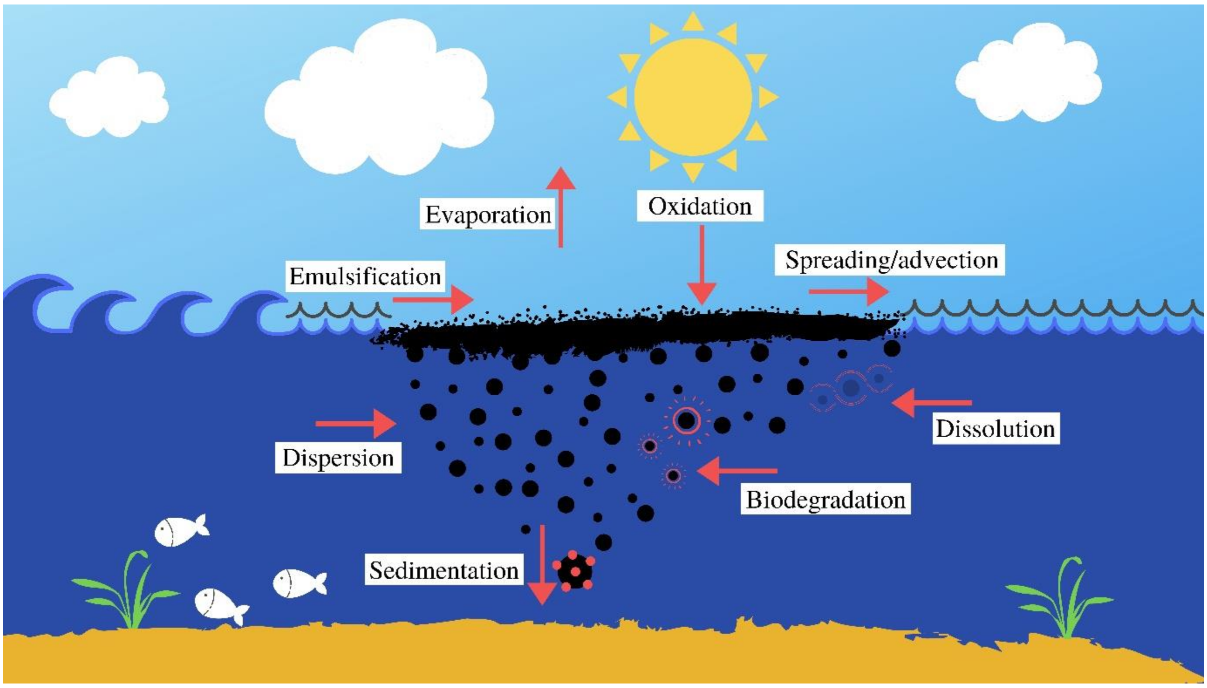

Figure 3 – Oil weathering processes

Figure 4 – The mixture of oil and water is called emulsification, and often has much higher viscosity than the original oil. This means that it flows slower, like dense syrup, and is more "sticky".

As seen in Figure 5, the amount of oil at the surface varies a lot with time. When the wind speed is above about 5 m/s, the surface wave will start to break (form whitecaps), and the oil will be split into droplets and mixed vertically in the water masses. This process is called natural dispersion. When the droplets are really small (below about 50 micrometers), they will stay in the water mass and never reappear at the surface.

An oil drift model can in principle be set up anywhere in the world, depending on forcing data available. To the best of our knowledge, there are three oil spill models developed in the APR countries which are currently in active use, namely SeaTrack Web, OSCAR and OpenDrift. Only the latter model is available as open source code. Here we will provide a brief description of the three models. This is not meant as an evaluation or inter comparison of the models.

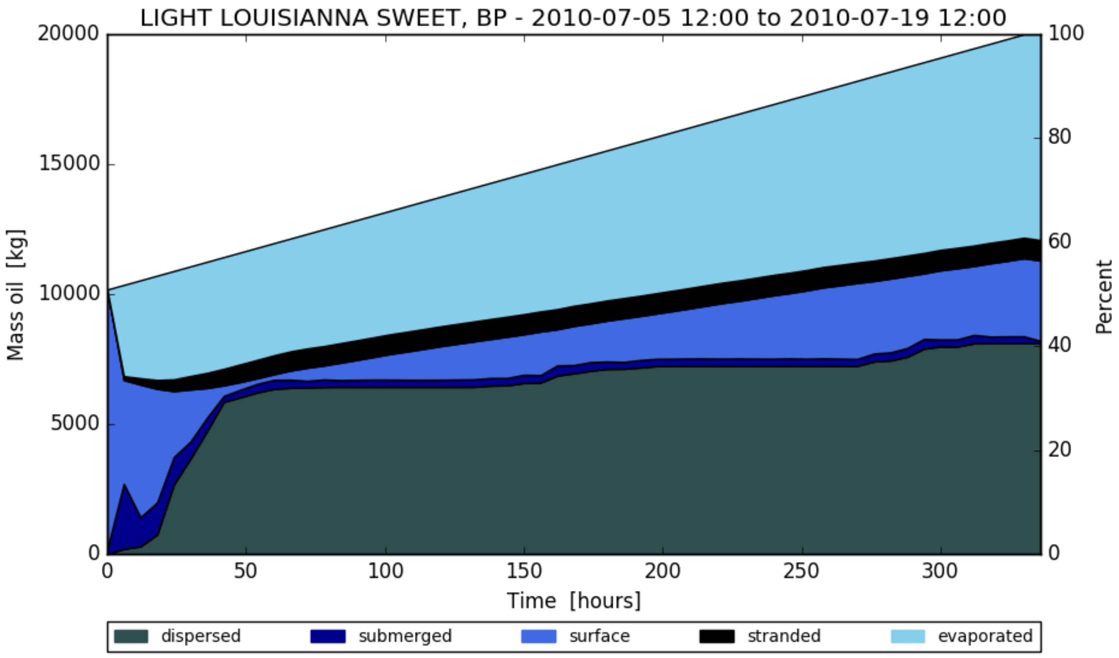

Figure 5 – Mass balance of a continuous oil spill in the Gulf of Mexico, based on a simulation with the OpenDrift model. At the end of the two week simulation, about 17% of the oil is present at the surface, while about 40% is evaporated. About 40% is naturally dispersed due to wave breaking, which means that the oil is split into tiny droplets which will not reappear at the surface.

What do models do?

Models help responders to envision, where the slick will move and what changes oil will undergo after certain time of it floating in open seas. The model cannot provide 100% accurate predictions, since there are several limitations. OSR models are rather advanced, but none of them can tell you the "truth" about oil spill behaviour in Arctic conditions, which are quite harsh and unpredictable.

In any case, for any model to simulate any results, initial data inputs are required. This is where all possible information about oil spill accident is needed. Examples of input dataset can be the following:

- **oil data**: geographical location of the spill accident, start time of the accident, volume of spilled oil, proximity to the closest OSR center, oil type with corresponding physical and chemical properties, dimensional parameters of the slick;
- **environmental data**: time of the year, seasonal climate peculiarities, forecasts of wind, temperature, waves, ocean currents, temperature, salinity and perhaps sea ice;

Once all these inputs are done, simulation can take place. Thanks to modern supercomputer power, the process can be prompt.

What questions can OSR model answer us, if you we imagine ourselves as oil spill responders:

1. Where is this slick moving?
2. What the state of oil can we expect at the place, where we respond to the accident?
3. What would be the recommended OSR method for this particular case?

SEATRACK WEB. Seatrack Web is another oil drift calculation system to support OSR operations. It is a Swedish development, Swedish Meteorological and Hydrological Institute (SMHI). It is mostly applied in the area of responsibility of Baltic coastal states – the Baltic Sea.

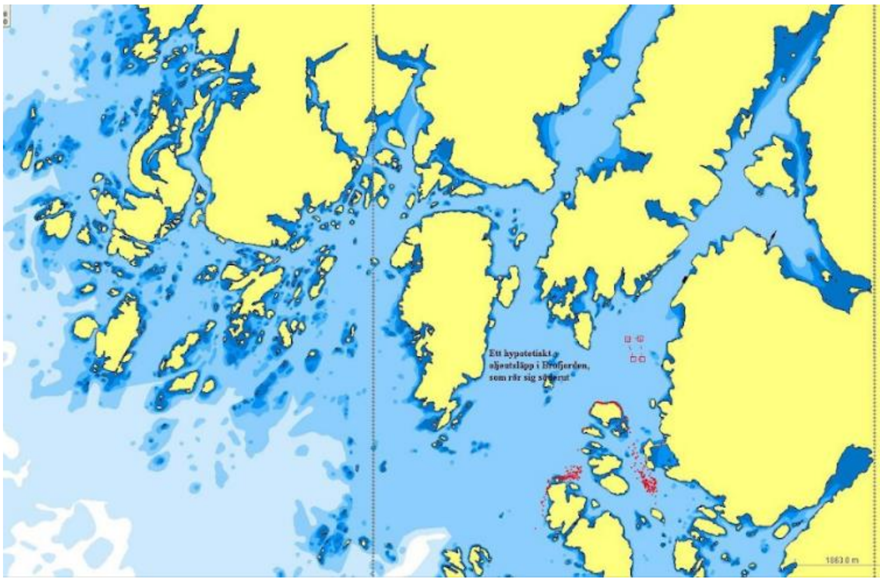

Figure 6 – Seatrack Web. Source: https://goo.gl/9TNWoJ

Country of development: Sweden
Year of development: 1990s
Area of application: Baltic Sea
Access: Swedish Meteorological and Hydrological Institute (SMHI)

The system consists of three main parts: forcing in the form of forecasted ocean, wave and wind fields, and an oil drift model with a graphical user interface (https://stw.smhi.se/). The oil drift model PADM has been jointly developed by SMHI and the Danish Maritime Safety Administration (DAMSA). It is executed, whenever a Seatrack Web user requests a simulation. The graphical user interface has been developed at SMHI and is based on open source GIS-server technology, i.e. the user interacts with georeferenced data in a map.

The area covered by the Seatrack Web HELCOM system is the Baltic Sea, the sounds between Sweden and Denmark, the Kattegat and the Skagerrak, and the North Sea to about longitude 3° east. The forcing fields for Seatrack Web HELCOM are presently provided by the weather model HIRLAM and the ocean model HIROMB. These are run operationally and form the basis for weather and ocean forecasts at SMHI. For longer forecasts forcing fields from the European Centre for Medium-Range Weather replace those from HIRLAM.

Seatrack web can be run through a web interface. Licence is required.

OSCAR. Oil spill contingency and response, or OSCAR, is a Norwegian model for planning and response in case of oil spill accidents.

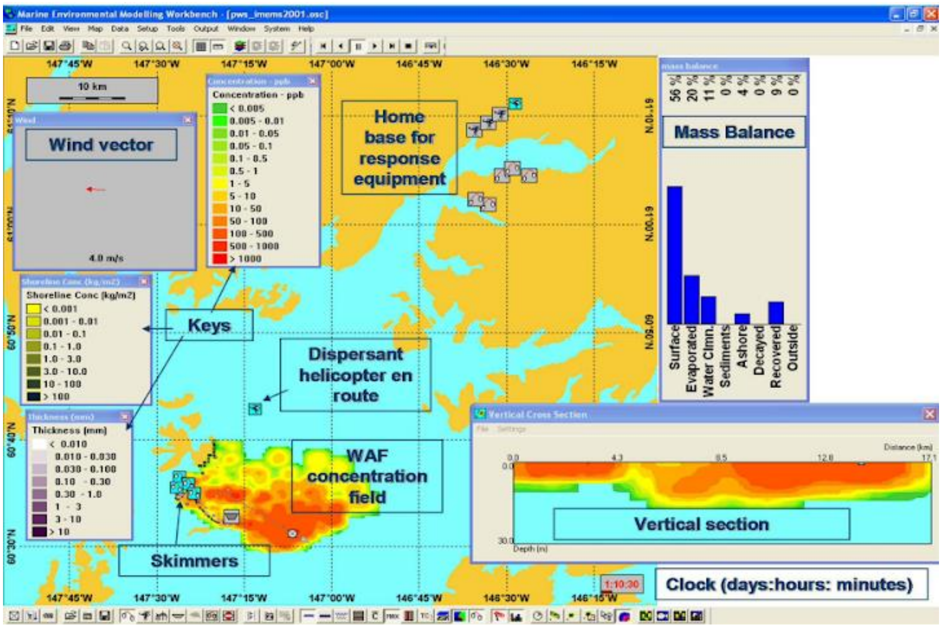

Figure 7 – OSCAR. Source: https://goo.gl/9TNWoJ

Country of development: Norway
Year of development: 1990s
Area of application: Global
Access: SINTEF

OSCAR provides insight in the behaviour of oil during an accident and captures the effects of contingency and response, allowing for contingency analysis and planning as well as hind- and forecasting https://www.sintef.no/programvare/oscar-oil-spill-contingency-and-response/ .

The model accounts for weathering, the physical, biological and chemical processes affecting oil at sea. Many of these processes are strongly coupled with laboratory activities at SINTEF on oil weathering. Contingency and response strategies provided ranges from mechanical collection of oil to dispersant application on surface and in water. OSCAR has been involved in and is still in use for planning, hind- and forecasting of accidental releases in locations such as the Northern and Baltic Sea, Gulf of Mexico and the Mediterranean Sea.

OSCAR is continuously updated and actively developed with the industry in order to improve the existing model and applying the model software to new problem areas.
The model software contains several sub-models which also exist as separate model products:

- Oil Weathering Model describes with both first principles and experimental results the weathering processes of oil on the sea.

- DeepBlow describes the spreading of oil from a subsea release, describing the multiphase plume trajectory including oil and gas.

OSCAR also supports doing statistical or stochastic modelling, providing insight in how a typical oil spill scenario behaves under a wide range of weather or seasonal conditions.

OSCAR is mainly run through a windows program and a licence is required.

OpenDrift. OpenDrift is another Norwegian model, developed at the Norwegian Meteorological Institute.

Country of development: Norway
Year of development: Since 2013
Area of application: Global
Access: https://github.com/OpenDrift/opendrift

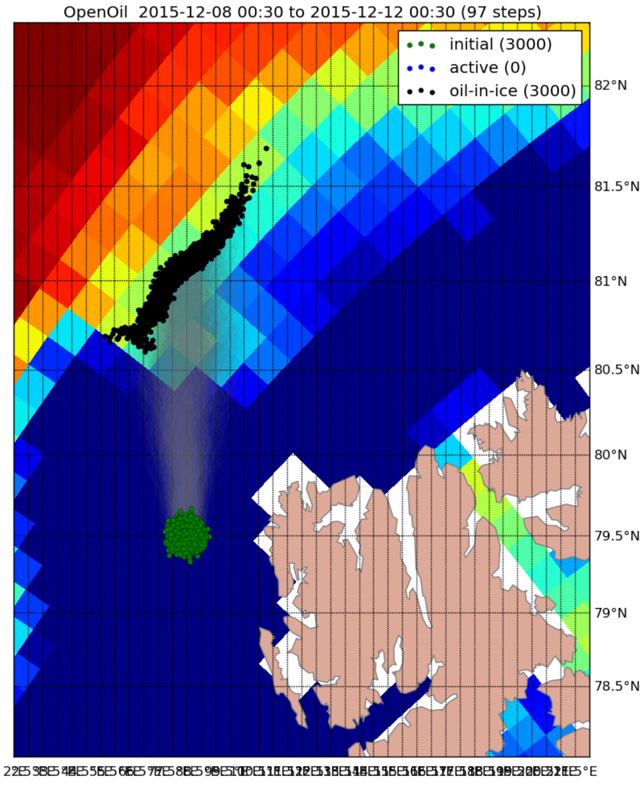

Figure 8 – OpenDrift simulation NorthWest of Svalbard- particles reaching the ice edge. Background colour is ice density in the Arctic20 ocean model. Source: https://github.com/opendrift/opendrift/wiki

It is coded entirely in Python and is available at https://github.com/OpenDrift/opendrift . It contains several modules for search and rescue, icebergs, plastics and biology (larvae, parasites, fish eggs, etc.). The oil drift module (OpenOil) is coupled to the NOAA oil chemistry database with nearly 1000 oil types and OpenDrift is now the main model for oil spill preparedness and search and rescue operations in Norway. It has previously been evaluated against drifter and oil slick observations in the North Sea. The framework is highly generic and modular, and is designed to be used for any type of drift calculations in the ocean or atmosphere. The framework allows for the ingestion of an unspecified number of forcing fields (scalar and vectorial) from various sources, including Eulerian ocean, atmosphere and wave models, but also measurements or subjective estimates of 10 the same variables. A basic backtracking mechanism is inherent, using sign reversal of the total displacement vector and negative time stepping. OpenDrift is fast and simple to set up and use on Linux, Mac and Windows environments, and can be used with minimal or no Python experience. It is designed for flexibility, and researchers may easily adapt or write modules for their specific purpose. OpenDrift is also designed for performance, and simulations with millions of particles may be performed on a laptop.

The OpenOil module is a full-fledged oil drift model, bundled within the OpenDrift framework. As a model it has been developed from scratch, but is based on a selection of parameterisations of oil drift as found in the open research literature. With regard to horizontal drift, three processes are considered: – Any element, whether submerged or at the surface, drifts along with the ocean current. – Elements are subject to Stokes drift corresponding to their actual depth. Surface Stokes drift is normally obtained from a wave model. Oil elements at the ocean surface are moved with an additional factor of 2% (configurable) of the wind. Together with the Stokes drift (typically 1.5% of the wind at the surface), this sums up to the commonly found empirical value of 3.5% of the wind. Biological degradation has recently been implemented.

OpenDrift can be run through python scripts, a simple graphical user interface, or a website for official users (halo.met.no).

Do it yourself: step-by-step simulation example

Instructions for OpenDrift simulations:

Step 1. Open this link: https://github.com/opendrift.

Step 2. Manual on how to install and use it in practice with an imaginary case. The goal is to show OpenDrift at work.

Conclusion

Here we have provided a brief description of the three most well-known oil drift models developed and in use in the Nordic countries. Other open source models such as GNOME from US NOAA can also potentially be used in this region and is in operational use at Marine Scotland Science. Below is a comparison of a Seatrack Web simulation and an OpenDrift simulation in a region, where the Seatrack Web region overlap with the Norwegian high resolution NorKyst800 ocean model domain (Figs. 2 and 3). In this case, the two simulations reveal similar drifting directions and distance within 48 hrs. This is not meant as a quantitative comparison. The main features of the models are listed in Table 1. While Seatrack Web has a limited geographical extent, Opendrift can be used globally by using forcing data on Thredds servers. OSCAR's geographical coverage depends on the forcing data available. All models include sophisticated oil chemistry and backtracking opportunities. Only OpenDrift is freely available as open source code, while the two others require a licence.

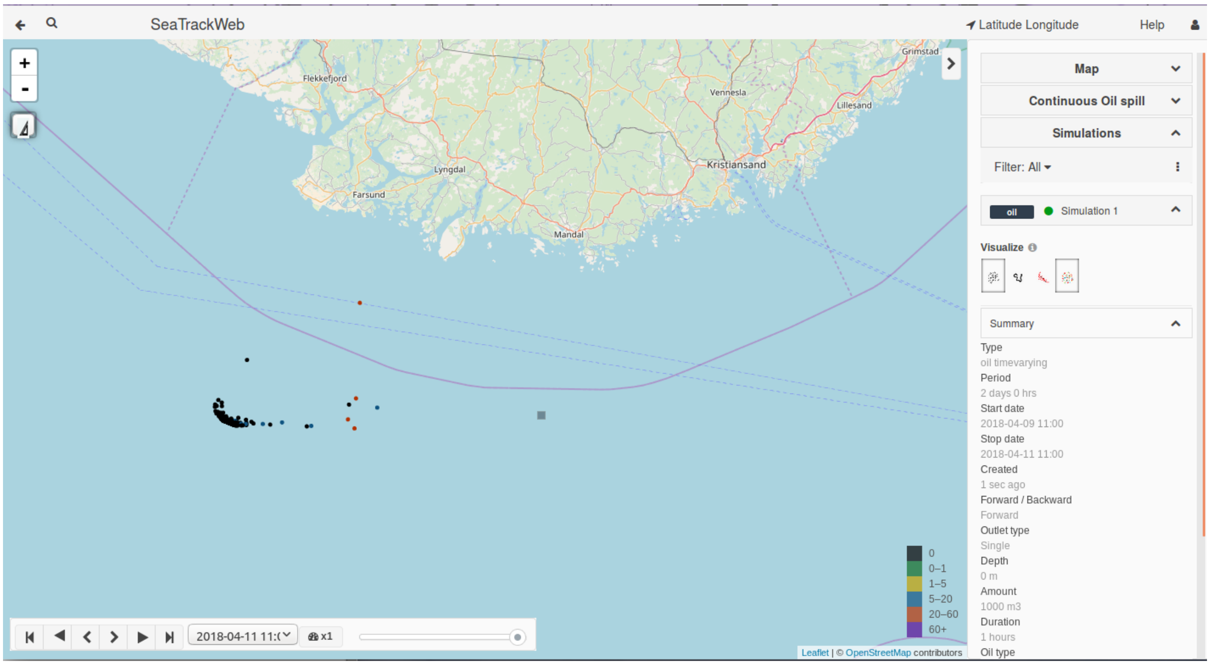

Figure 8 - Seatrack Web simulation starting at 9 April 2018 at 1100 UTC and running for 48 hrs. Starting location is 57.72N / 7.36084E (S of Norway) and the spill lasts for one hour. Oil type is "heavy" (>1000 cSt) and calculation accuracy is high

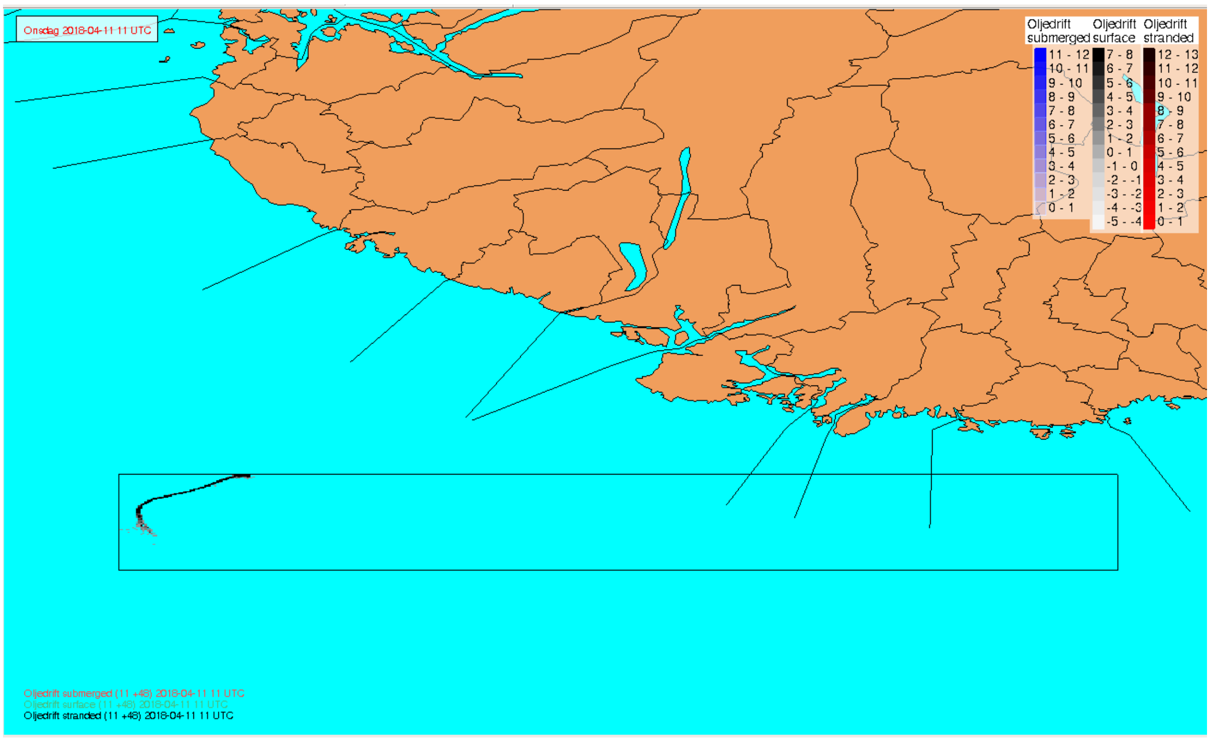

Figure 9 – Same as above, but using OpenDrift

Table 1 - Summary of the main features of the three models described here

	Setrack Web	**OSCAR**	**OpenDrift**
Advanced oil chemistry	x	x	x
Global coverage		(x)	x
Open Source code			x
Backtracking	x	x	x
Flexibility in forcing data		(x)	x
Contingency and response		x	

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