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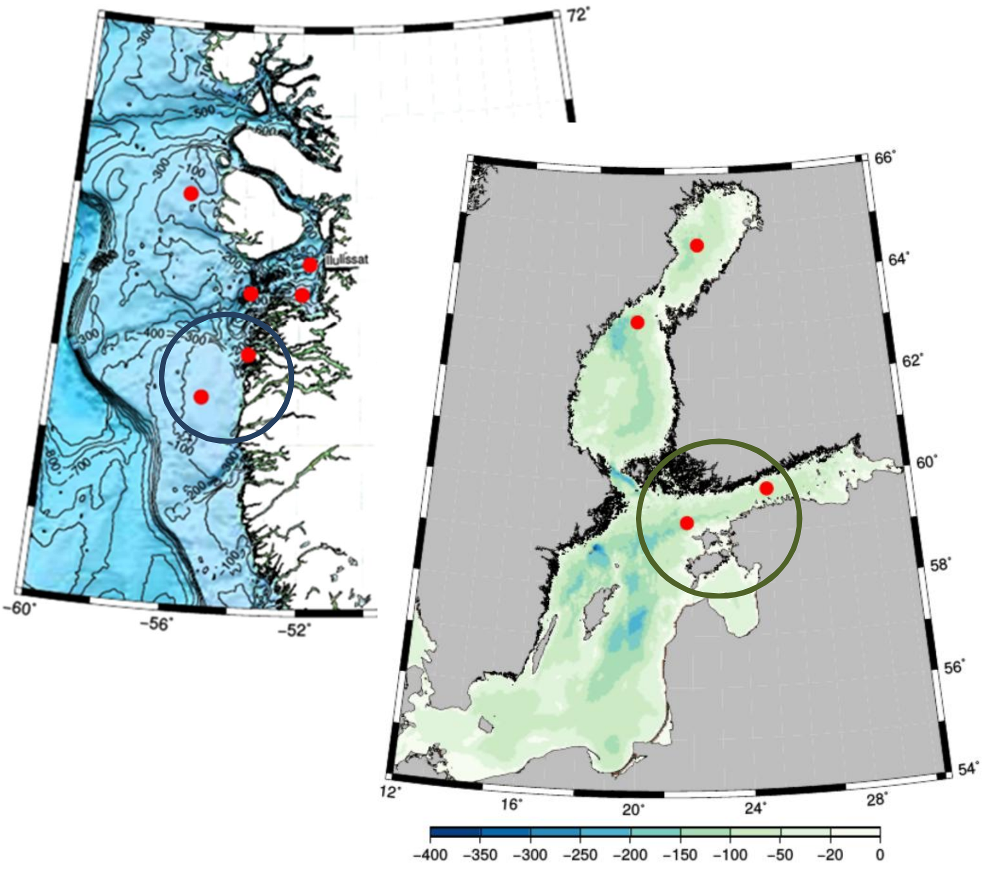


# Oil spill trajectory simulations report

D5.3

WP5: Strategic Net Environmental Benefit Analysis (sNEBA)

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**Table of Content**

## Executive Summary

Oil spill trajectory modeling is an important tool for oil spill response in an acute oil spill situation and operation. The modelled drift of the oil slick tells the response teams which counter measures to use and where to prioritize the actions to optimize the environmental (and economic) benefit from the operation. Hence, oil spill trajectory modelling is essential, when performing a Net Environmental Benefit Analysis (NEBA) and/or a strategic NEBA with respect to the biology at risk from the oil spill.

Oil spill trajectory modeling calculates how an oil spill is transported, spread out, and weathered under the influence of winds, waves, currents, turbulence, gravity, surface tension, and viscosity. Seatrack Web, present used model system, include wave conditions from wave models, and current, turbulence, and ice conditions from oceanographic models to predict the trajectories.

For running simulations, several parameters regarding location, oil spill volume, rate and type, and simulation duration can be selected for model entrance of 1) oil slick observed on sea surface or for 2) continuous oil spill. For WP5 scenarios, continuous oil spill entrance is selected. Furthermore, as the model uses a 10 days weather forecast for forcing or has a weather data archive of 10 days back in time, date for simulation start must be designated.

From a simulation example in the Gulf of Finland, it can be shown from the mean trajectory of the drift of a heavy fuel oil spill that the oil after 2 days would reach shore in the Finnish archipelago. From the data output of the simulation it can be seen that there is no natural dispersion of the oil, it does not evaporate but takes up 60% of water. Furthermore, it is shown that the properties of the oil with respect to viscosity and density does not chance much during the simulation run. In addition, the underlying forcing is presented; current speed and direction as well as wind speed and direction.

Due to the relative short weather archive in the model, a programme for running simulations has been developed. Data from the simulation runs will be ready for the analyses and assessments expected to be performed during 2018 for the scenario cases (Baffin Bay and Baltic Sea) to the sNEBA tool (D. 5.11).

Hence, the programme and input to simulations includes simulations for oil spill volumes of 1000 tonnes with a duration of 24 hours for two scenarios in the Baffin Bay and two scenarios in the Baltic Sea. Duration of the simulations will be 7 days and weather forcing selected for 3 different seasons; autumn, winter and spring covering calm weather (m/s <5) and harsh weather (m/s >15) for three different oil types; a Heavy Fuel Oil, a crude oil and a diesel oil.

## Background

Oil spill trajectory modeling is an important tool for oil spill response in an acute oil spill situation and operation. The modelled drift of the oil slick tells the response teams which counter measures to use and where to prioritize the actions to optimize the environmental (and economic) benefit from the operation. Hence, oil spill trajectory simulations are essential, when performing a Net Environmental Benefit Analysis (NEBA) with respect to the biology at risk from the oil spill.

Also when performing a strategic NEBA (sNEBA), oil spill trajectory simulations are essential. The sNEBA includes an analysis, which is based on oil spill scenarios, including oil dispersion and drift simulations. Furthermore, the sNEBA includes published as well as expert knowledge on the environment in the area in question. The environmental knowledge included in the sNEBA, to achieve the overall environmental optimal oil spill combating strategy, is biodiversity (on sea surface, in sea and sea bed, and seasonality), biology, ecotoxicology of oil (naturally and chemically dispersed as well as oil burning residues). The sNEBA is hence a planning tool, and thus a desktop exercise performed for theoretic oil spills, to support decision making regarding development of oil spill contingency plans (national, international and activity based) and response strategy as well as assessing oil spill combating potential for optimal environmental benefit.

Oil spill trajectory modeling calculates how an oil spill is transported, spread out, and weathered under the influence of winds, waves, currents, turbulence, gravity, surface tension, viscosity, and, if present, ice.

Present used model system, Seatrack Web (Liungman and Mattsson 2011, Ambjörn et al. 2014, Ambjörn and Mattsson 2006) include wave conditions from wave models, and current, turbulence, and ice conditions from oceanographic models to predict the trajectories. Seatrack Web, which is a web-based oil spill trajectory model used by about 80 stakeholders and agencies around the Baltic Sea is co-developed by SMHI in Sweden, the Danish Maritime Safety Administration (presently the Defence Centre for Operational Oceanography, FCOO), Bundesamt fur Seeshiffart und Hafen (BSH), and the Finnish Meteorological Institute (FMI).

Weather archive for simulations goes 10 days back, and hence simulation runs has to be run at times when weather forecast is in favour of harsh weather for weather worst case scenarios and calm weather for best case or current driven trajectory.

## Description of SeaTrackWeb

Seatrack Web (Liungman and Mattsson 2011) is an oil spill trajectory system that can be run with a user-friendly web-based interface. Seatrack Web consists of a forcing interface part, a user interface part, and a trajectory calculation part. The trajectory calculation part of Seatrack Web is called PADM (PArticle Dispersion Model), and is described in details in Arneborg et al. (2017), however, see below regarding included oil weathering processes.

Arneborg et al. (2017) also describe the input to the forcing interface part, which is input of currents, winds, temperatures, ice conditions, etc., from atmospheric and oceanographic models. Interfaces are available for several models. In the Baltic, the system is run in operational mode with input from regional operational models. The forcing input, when running the simulations from DCOO, is based on the hydrodynamic cores, the General Estuarine Transport Model (GETM, www.getm.eu), for open ocean dynamics to small coastal embayments, and the High Resolution Limited Area Model (HIRLAM) obtained the Danish Meteorological Institute (DMI).

### Oil types and weathering

Arnborg et al. (2017) describe the model, that includes algorithms on oil particle advection, Stokes drift and turbulence, gravitational spreading, dispersion and buoyancy, as well as oil weathering (see below).

In the model, oil is represented by a cloud of particles that have a number of properties, including position, volume, mass, thickness, etc. These are advected by the three-dimensional flow field predicted by the hydrodynamic (HD) model, as well as the Stokes drift, dispersion, and random displacements caused by turbulence, as described in more detail below. When the oil particles are located on the surface, each particle is represented as a circular disc of oil of a certain thickness and radius. The radius increases and the thickness decreases with time to represent the gravitational spreading of the oil. In addition, oil may be dispersed into the water column as a cloud of small droplets due to the action of breaking waves on a surface slick, and oil below the surface may move vertically due to buoyancy forces. This is described in further details in Arnborg et al. (2017).

A strong and very useful feature of the Seatrack Web, with respect to data output of the simulations, is the inclusion of oil weathering processes in PADM. Arneborg et al. (2017) describe the weathering processes included in PADM, as oil is weathered over time due to evaporation, emulsification, dissolution, biodegradation, and photooxidation. In PADM, the two most significant weathering processes for short-term simulations are included: evaporation and emulsification, as these modify the mass, the density and the viscosity of the oil, as well as the mass of water in the case of a water-in-oil emulsion. For oil weathering calculations, PADM can use two types of algorithms; the first uses a two-component approach where the oil is assumed to consist of a volatile and a non-volatile component, where the evaporation of the volatile component is calculated according to logarithmic expressions and the rate of emulsification is a function 250 of the wind speed; the second type uses oil proprietary empirical formulae developed by SINTEF based on a large set of experimental data on oil types. Both types of weathering algorithms rely on databases of chemical and physical properties for all oils to be considered. For further details on weathering calculations, see Liungman and Mattsson (2011).

## Simulation input

For running simulations, several parameters regarding location, oil spill volume, rate and type, and simulation duration can be selected (Table 1) for model entrance of 1) oil slick observed on sea surface or for 2) continuous oil spill. For WP5 scenarios, continuous oil spill entrance is selected. Furthermore, as the model uses a 10 days weather forecast for forcing or has a weather data archive of 10 days back in time, date for simulation start must be designated.

Table. 1. Input parameters for simulations in Seatrack Web, and parameter options to be selected.

| Parameter | Options<br>1 | 2 | 3 |
|---|---|---|---|
| ***Oil spill locality*** | Mark at map | Coordinates | |
| ***Simulation start date*** | Real time | 10 days forward (weather forecast) | 10 days hincast |
| ***Duration of oil spill*** | Hours | | |
| ***Oil type*** | Oil class | Specific oil type, e.g., IF380, Statfjord A, Light Diesel Fuel | |
| ***Oil spill volume*** | Total amount | Rate (e.g., m3/hour, tonnes/day) | |
| ***Duration of simulation run*** | Hours | Days | |

For the cases included in WP5, Disko Bay and Baltic Sea, locations and oil spill volume as well as spill duration have been selected to correspond to the scenarios selected for oil dispersion simulation as described in WP5 Deliverable 5.2 by ClimateLab (Table 2). From both types of simulations oil drift and dispersed oil concentrations can be obtained for the environmental assessment for the different spatial compartments (e.g., sea surface, water column).

Table 2. Scenario locations, oil spill volume and duration of oil spill and simulation run time. BB=Baffin Bay, Greenland; BS= Baltic Sea.

| ID | Longitude | Latitude | Total load (Tonnes) | Duration (hours) | Simulation time (days) |
|---|---|---|---|---|---|
| BB-S1 | 55.15 ◦W | 67.54◦N | 1000 | 24 | 30 |
| BB-S6 | 51.66 ◦W | 69.20◦N | 1000 | 24 | 30 |
| BS-S3 | 21.85 ◦E | 59.20◦N | 1000 | 24 | 7 |
| BS-S4 | 24.94 ◦E | 59.82◦N | 1000 | 24 | 7 |

## Data from simulations

The simulation can be run showing the oil slick as it spreads on the sea surface. When simulations are finalized, the mean trajectory of the oil spill from the selected scenario location will be indicated on map. Besides trajectories, data on forcing as well as oil fate and weathering can be obtained (Table 3).

From the trajectory data oil impacted sea surface will be calculated by drawing polygons from oil slick dots and calculate polygon area.

Table 3. Forcing information and data obtained from simulations in Seatrack Web

| Forcing | Data |
|---|---|
| Currents and wind | Speed and direction |
| Oil fate | evaporation, dispersion, shore |
| Oil weathering | water content, viscosity, density |

## Simulation run example

Present simulation examples is based on following scenario input:

- Coordinates for BS-S4
- Total oil spill volume of 1000 tons HFO for
- 24 hours
- Simulation ran for 7 days
- Max wind speed reached 14 m/s in the beginning of the simulation run period
- Wind direction from South

Mean trajectory for the drift of the oil spill, from outlet (black dot) to reach shore in the Finnish archipelago (red dot) (Figure 1). The figure shows only the mean trajectory, which is the mean value of the oil particles spreading. In the interactive interface, the more detailed trajectory of oil particles can be observed in the simulation sequence.

Figure 2 shows the vertical distribution of oil in the water column. From the upper figure it can be seen that after 2 days the oil is reaching shore and the volume and fraction of the oil goes from all oil being present at the sea surface (pink line) to all oil reaching shore (turquoise line). The vertical grid lines indicates days of simulation run (7 grid lines = 7 days). From the lower graphs, it can be seen that there is no dispersion of the oil, it does not evaporate but takes up 60% of water.

IF-380 is a very heavy fuel oil (HFO), and in HFOs the natural dispersion is found to be low (Fritt-Rasmussen et al., in prep), which also can be observed from Figure 2.

Evaporation will lead to increased viscosity, pour point, density and flash point. The SINTEF weathering modelling (OWM) and laboratory analysis predict that HFO will remain long time on the water surface and uptake of water (emulsification) also stabilise the oil to stay on the water surface (Fritt-Rasmussen et al. in prep.). In Figure 3, it is shown that the properties of the oil with respect to viscosity and density does not chance much during the simulation run, which may be due to no evaporation but maybe also the oil reaching the shore, but also that it stays on the surface with 60% uptake of water until it reaches shore.

In Figure 4, current speed and direction is illustrated. The lowest graph shows that at the time when the oil is reaching shore after 2 days, the current shifts from having an East bound direction to a North bound. The mean oil spill trajectory has, in general, a North bound direction (Figure 1).

Although weather forecast showed max. 9 m/s for the simulation run periods (figure 5, upper; from https://www.timeanddate.com/weather/finland/helsinki/historic?month=11&year=2017), the actual wind data input of was 14 m/s in the beginning of the simulation run period (Figure 5, lower). Both forecast and simulation data, showed a prevailing wind direction from South, which again explains the general North bound direction of the oil spill trajectory (Figure 1).

Figure 1. Simulated mean trajectory for the drift of an oil spill during the 7-day simulation run.

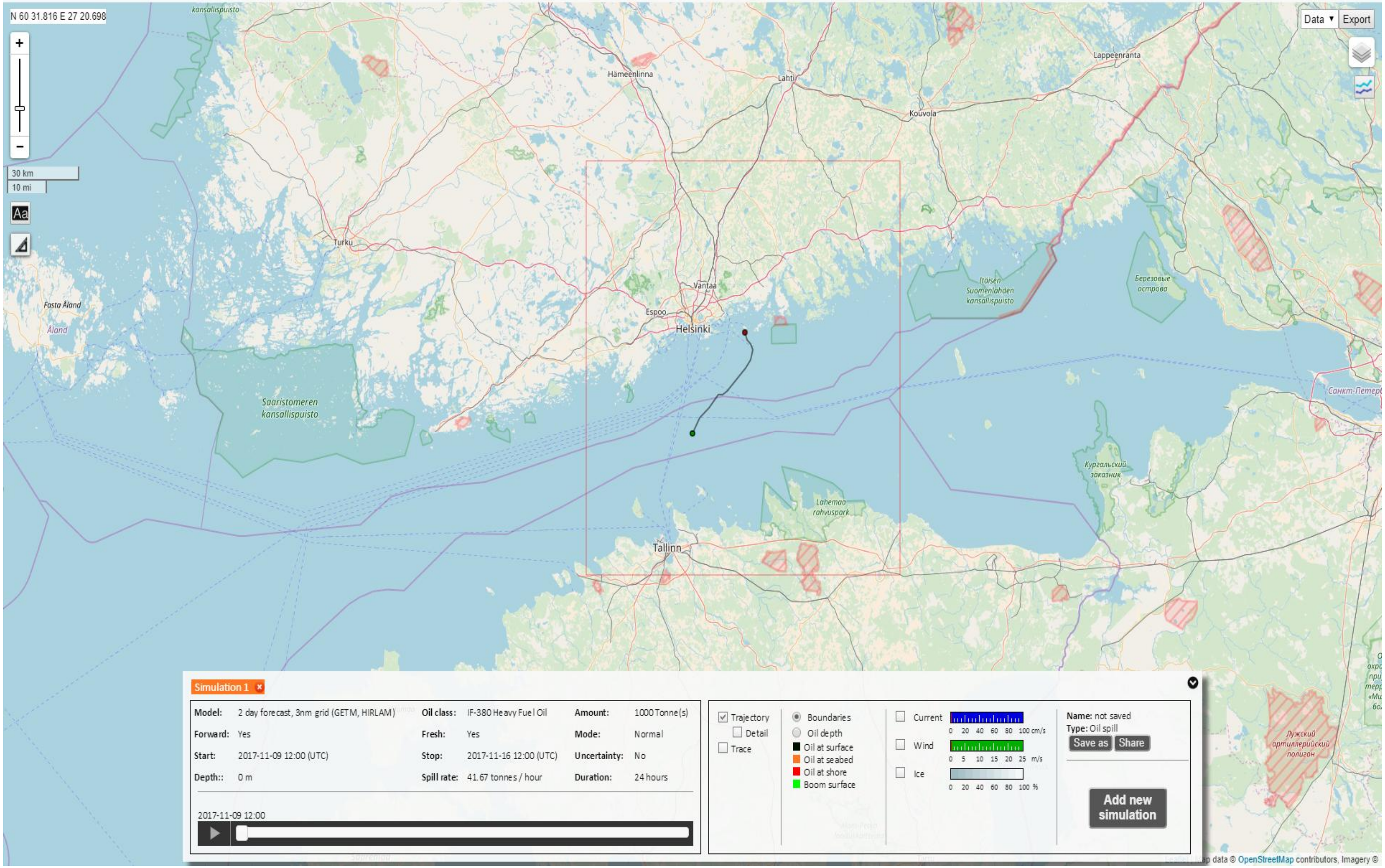


Figure 2. Simulated vertical distribution of oil in the water column during the 7-day simulation run.

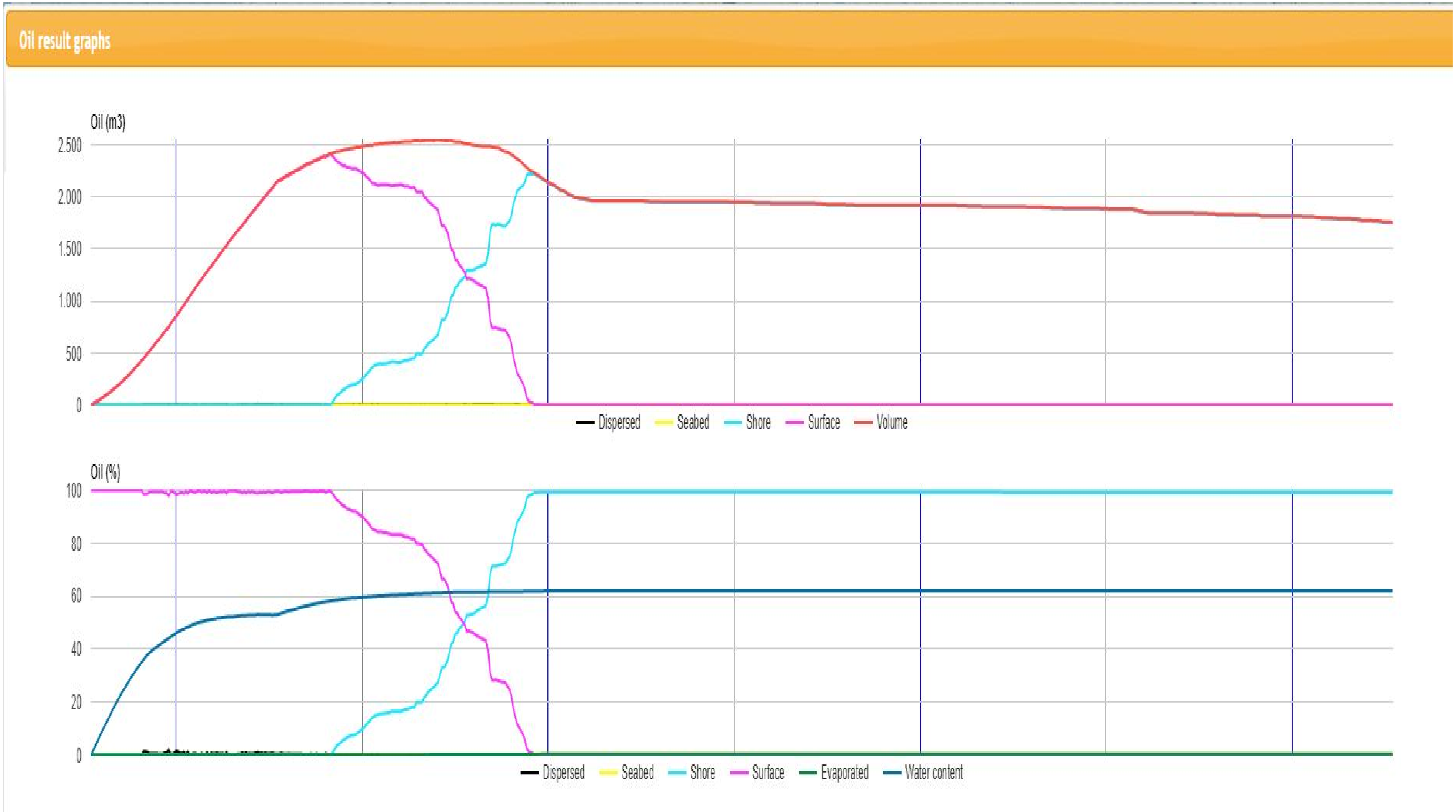


Figure 3. Simulated oil viscosity and density during the 7-day simulation run.

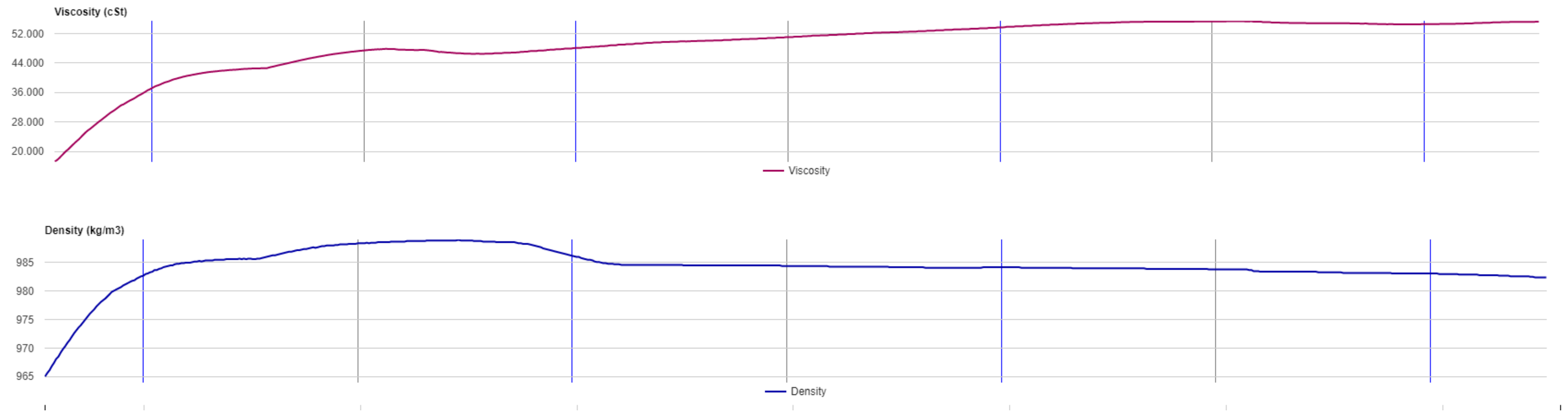



Figure 4. Simulated current speed and direction of the soil slick during the 7-day simulation run.

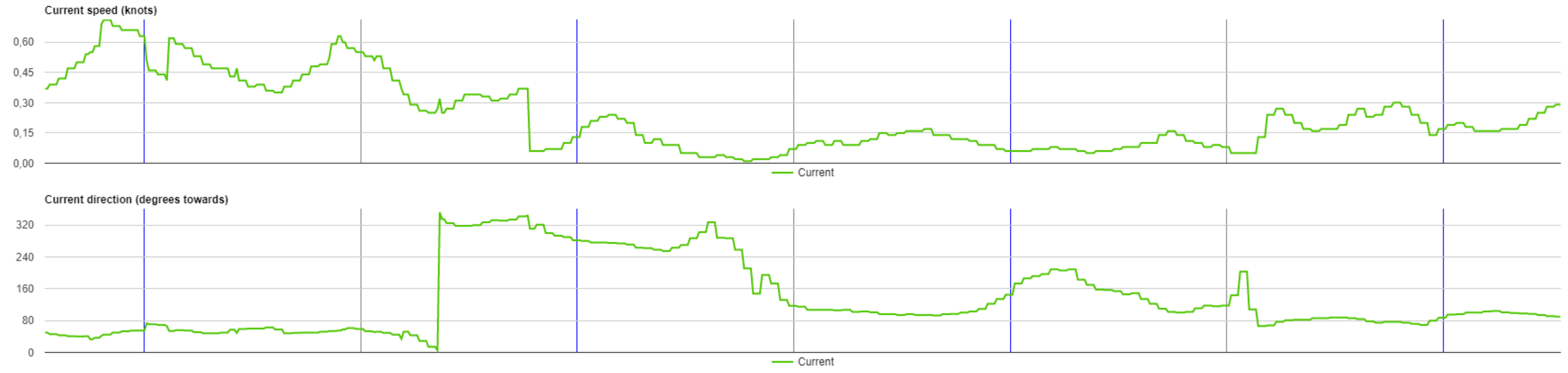
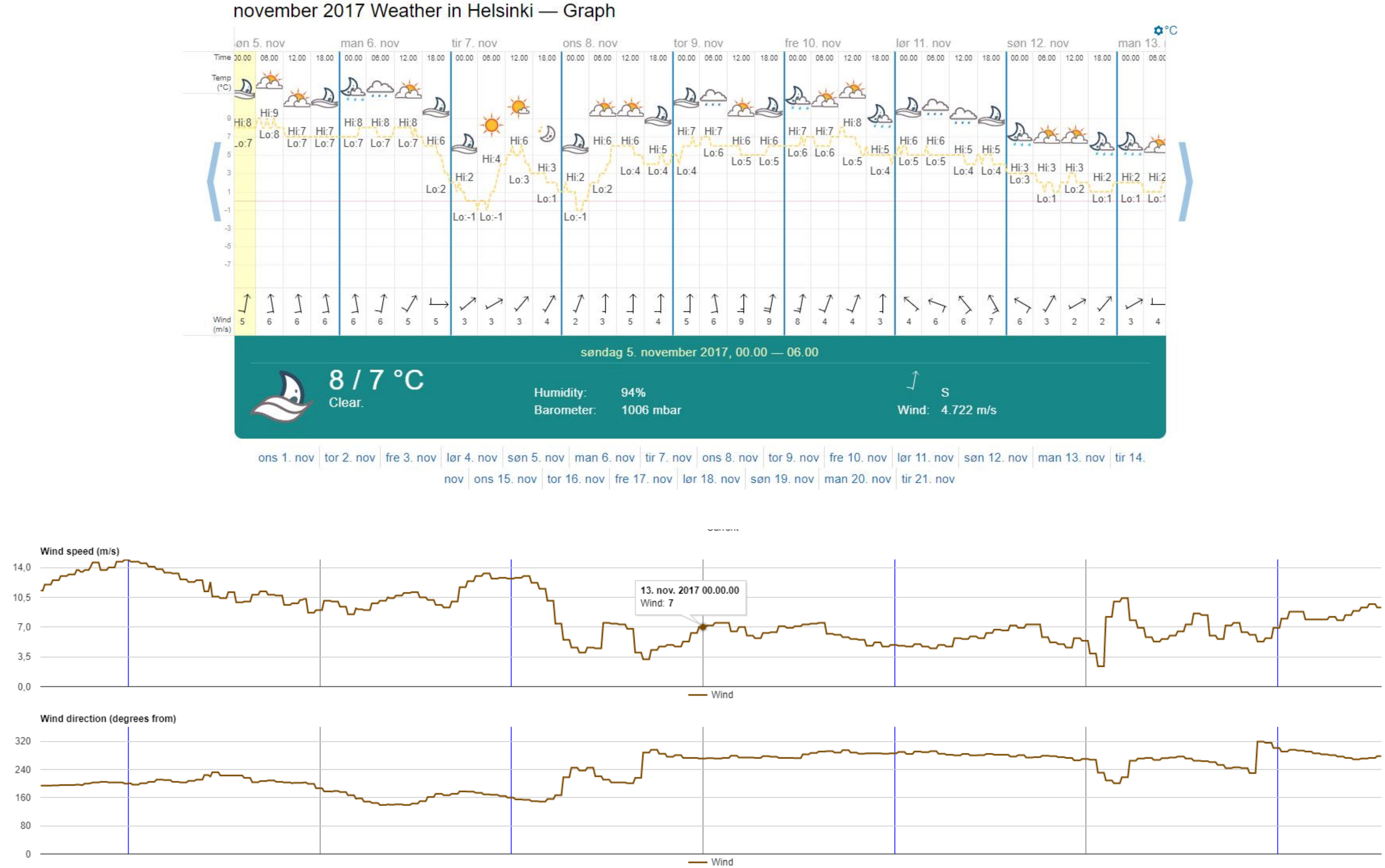


Figure 5. Weather forecast and simulated weather input data during the 7-day simulation run.



## Simulation runs programme

Due to the relative short weather hincast in the model, a programme for running simulations has been developed. By following weather forecast through autumn 2017, winter 2017/2018 and spring 2018, data for harsh and calm weather, as well as data from different current and wind speed and directions is expected to be obtained. These data will then be ready for the analyses and assessments expected to be performed during 2018 for the scenario cases (Baffin Bay and Baltic Sea) to the sNEBA tool (D. 5.11).

Hence, the programme and input to simulations are as follows:

- Oil spill volume at surface: 1000 t with a duration of 24 hours
- Localities: Baltic Sea S3 and S4; Greenland S1 and S6
- Duration of simulation: 7 days
- Seasons:
  - *Disko* - October 2017, May 2018, July 2018
  - *Baltic Sea* - October 2017, February 2018, July 2018
- Weather conditions: calm (m/s <5) and harsh (m/s >15)
- Three oil types:
  - *IF-380* (Heavy Fuel Oil)
  - *Statfjord A / Rebco* (crude oils)
  - *Light Diesel Fuel* (852,5 kg/m3)

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