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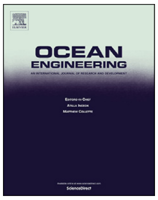

Oil drift modeling in pack ice – Sensitivity to oil-in-ice parameters

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ABSTRACT

An improved oil-in-ice parameterization has been implemented in the Seatrack Web oil spill model, tested using data from the Runner 4 oil spill accident, which occurred in high ice concentrations in the Gulf of Finland on 5 March 2006. The model is able to describe the observed transport and spreading of oil reasonably well. The sensitivity of the results towards oil-in-ice parameters and hydrodynamic forcing models has been investigated. Both the mean oil trajectory and the oil spreading are sensitive to a threshold velocity for the withdrawal of oil from below ice floes, and the oil spreading is highly sensitive to the size of the floes. The trajectories for the ice drift and for the water current drift set the limits of the oil drift, and these are in turn highly dependent on the hydrodynamic forcing and the assimilation of ice conditions. In future development of oil spill modeling in ice it is therefore important to focus not only on the ice parameterization but also on the ability to model ice drift, ice floe sizes, and the currents below the ice.

1. Introduction

Oil spills in ice covered regions provide an increasing threat to Arctic and sub-Arctic ecosystems, as vessel traffic in ice covered regions increases and exploration of oil and gas reserves in the Arctic becomes feasible (Drozdowski et al., 2011; Lee et al., 2015; Afenyo et al., 2016b). Oil spill trajectory modeling is an important tool for risk management of oil-related activities, i.e., to estimate environmental risks, plan oil spill response measures, and to provide operational information about the location of actual spills (Afenyo et al., 2016b). However, there are large gaps in our knowledge about the behavior of oil when it enters cold, ice-covered waters, and thus research on crude oil spills in Arctic waters, improved risk assessments, improved models of oil-in-ice effects, and improved quantification of model uncertainties have been identified as high-priority research areas by a Royal Society of Canada expert panel (Lee et al., 2015).

Here we will focus on oil spills in the Baltic Sea, which is a heavily trafficked semi-enclosed sea in northern Europe. The Baltic Sea is partially ice covered during the winter season, and will continue to be so in a future climate, even though the ice will become thinner and more mobile, the ice season will become shorter, and inter-annual variations will be large (Höglund et al., 2017). The risk of vessel accidents in the northern Baltic has been studied in Valdez Banda et al. (2015, 2016) and Goerlandt et al. (2017), and the outflow of oil from damaged vessels has been studied in Kollo et al. (2017) and Sergejeva et al. (2017). As a next step in a full risk analysis it is important to determine the fate of the oil spill, and the present work on oil spill modeling in ice-covered water aims to support this endeavor.

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 (Drozdowski et al., 2011; Afenyo et al., 2016a,b). Early trajectory models were based mainly on wind data from atmospheric models (ASCE, 1996), but present model systems also include wave conditions from wave models, and current, turbulence, and ice conditions from oceanographic models to predict the trajectories. One such system is Seatrack Web (Liungman and Mattsson, 2011; Ambjörn et al., 2014; Ambjörn and Mattsson, 2006), which is a web-based oil spill trajectory model used by about 80 stakeholders and agencies around the Baltic Sea. It 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

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Environment Institute (FMI). In the present work we study how an improved parameterization of the interaction between oil and ice influences the Seatrack Web model results.

Present knowledge about how the interaction with ice modifies the transport and weathering of an oil spill is based on a limited number of laboratory experiments and experimental releases in the 70s - 90s (see Fingas and Hollebone, 2003 for a review), but more recent field experiments have also been performed (Brandvik and Faksness, 2009; Faksness et al., 2016). A recent review of oil spill modeling in ice covered waters is given in Afenyo et al. (2016b). The presence of cold conditions and ice significantly complicates an already complicated problem by modifying the properties of the oil, as well as providing a number of additional states in which the oil can be transported (see Fig. 5 in Afenyo et al., 2016b), e.g., under the ice, on top of ice mixed with snow or in meltwater pools, encapsulated in the ice, propagating up brine channels, etc.

The ice in the Baltic Sea consists only of first year ice, and the heavy vessel traffic and ice breaker activity in the region modifies the ice conditions when compared to, e.g., remote Arctic regions. Hence, some Arctic results may not be directly applicable in the Baltic. In addition, there are few datasets available for model validation in the Baltic Sea. Of the few reported accidental spills in ice, we have only found one case where a large fraction of spilled oil was tracked for a longer period. On 5 March 2006 the Dominican-registered cargo ship Runner 4 collided with the Malta-registered cargo ship Svjatoi Apostol Andrey in heavy ice conditions in the Gulf of Finland, and sank (Wang et al., 2008). The ship carried 102 tonnes of heavy fuel oil, 35 tonnes of light fuel oil, and 600 L of lubricant. Between 5th and 15th March there are few observations of the oil patch, but between the 15th and 19th March large oil patches were observed and combated north-east to north-west of Tallinn, before the oil-ice mixture moved into the shallow waters around Tallinn (Fig. 1). Ice drift modeling presented in Wang et al. (2008) was unable to explain the drift from the collision site to Tallinn. The same problem was experienced with Seatrack Web simulations of the oil spill, but improved descriptions of air-ice and ice-water drag, as well as assimilation of satellite derived ice products, in an updated version of Seatrack Web yielded a stronger ice drift that enabled the simulated ice and oil trajectories to reach Tallinn (Raudsepp et al., 2010). The spreading of the oil patch in the model was much smaller than what had been observed, but by assuming a continuous oil release between the 5th and 10th March a reasonable spreading of the oil patch was obtained. Stanovoy et al. (2012) proposed a more advanced oil spreading model for use in the Gulf of Finland, where oil is allowed to spread under ice, and where the advection, diffusion and spreading of ice on the surface is dependent of ice concentration, c. They did, however, not present any validation of the model against real spills, e.g., the Runner 4 case.

Here we will present the results of implementing a more advanced oil-in-ice parameterization in the Seatrack Web code and how this influences the advection and spreading in the Runner 4 case. The main aims are to identify some important parameters in the oil-in-ice parameterization, and to study the sensitivity of the results to these parameters as well as to the forcing fields. The implementation largely follows the suggestions of Venkatesh et al. (1990) where the oil behavior changes between three ice concentration regimes;

- $c < 30\%$ where oil moves as if there is no ice,
- $30\% < c < 80\%$ where oil spreading is influenced by ice floes, some of the oil may be situated below ice floes, and oil at the surface may either be moving without being influenced by the ice or with the ice drift, and
- $c > 80\%$ where a large part of the oil is under the ice and the oil in leads is prevented from spreading further.

The remaining parts of this paper are structured as follows. First we will present the details of the oil trajectory model, including the old and the new description of oil in ice. In section 3 we present the runs performed with the model, and the atmospheric and ocean forcing fields used to produce the results. The results are presented in Section 4 and discussed in Section 5. Finally, Section 6 summarizes the results and states the conclusions.

2. Description of Seatrack Web

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 will be described in detail below. The forcing interface part provides 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. Until January 2017 the Seatrack Web user could choose between three different operational configurations of Hiromb (Funkquist and Kleine, 2007; Axell, 2013). The first, BS01, was a one nautical mile resolution setup covering the Baltic Sea with an open boundary in Skagerak and forced by the operational HIRLAM atmospheric model (Dahlgren et al., 2014). The second configuration, NS03, was a three nautical mile resolution setup covering the Baltic Sea and the North Sea, also forced with the operational HIRLAM. These two setups produced 60 h forecasts, four times per day. The third configuration, sometimes referred to as NS03 long, had a three nautical mile resolution covering the Baltic Sea and the North Sea and was forced by forecasts from ECMWF producing 10 day forecasts once per day. Since February 2017 the forcing input is provided by the operational two nautical mile version of Nemo-Nordic

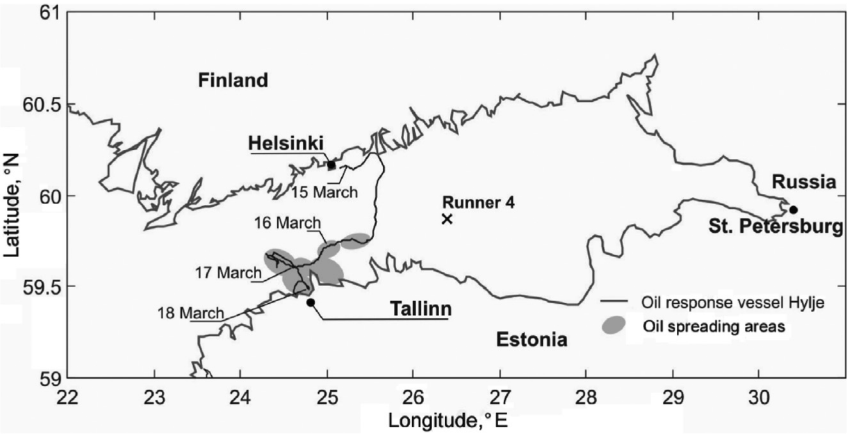

Fig. 1. Sketch of oil spreading between 15 and 18 March as observed from oil combattting vessel Hylje (reproduced from Wang et al., 2008 with permission from the author).