A new method for assessing impacts of potential oil spills

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Abstract

Oil drift statistics are computed based on results from a ten member ocean circulation model ensemble. We analyze the results with the aim of quantifying errors that may occur when a traditional deterministic approach is adopted. Trajectories were computed based on results from an eddy-permitting ocean circulation model. In such cases, we find that the oil drift statistics based on a single realization may give rise to errors of the order of 100%. Hence, we recommend the use of ensemble techniques in the present context.

Keywords:

Oil drift statistics, meso-scale processes, environmental impact assessment

1. Introduction

Whenever a new region is considered for oil exploration, an Environmental Impact Assessment (EIA) on the consequences of related activities is produced. The EIA includes a section where consequences of accidental oil spills in selected locations are considered, using statistics from modelled advection and deterioration of oil spills from likely exploration sites. A potential spill is described by simulating particle trajectories that are advected by ocean currents. Each particle initially represents a given mass of oil, which is updated due to deterioration along its path.

The level of detail in the description of the current field has evolved substantially during the past decades. For a long time, the ocean current field was derived from an empirical relation with the surface winds, sometimes modified by background, large scale currents (Melsom, 1993). From the mid-1990s, trajectories were computed based on results from coarse resolution ocean circulation models that do not resolve ocean eddies (Martinsen et al, 1994).

Since around 2000, results from eddy permitting simulations have been used for the present purpose. This was the case with the most recent EIA from the Norwegian sector, see section 8 in Johansen et al. (2003). However, only two years of eddy-permitting results were available, and no attempt to quantify the uncertainty that arises from stochastic meso-scale processes were made. In order to address the latter shortcoming, we here examine results from a 10-member ocean ensemble that covers the period 1986-1995. A description of the ensemble is given by Melsom and Fossum (2008).

2. Traditional method vs. ensemble approach

With the traditional methods for producing oil drift statistics, ocean stochastic processes were not described and the results could be interpreted as a deterministic response to the atmospheric forcing. However, with the advent of eddy-permitting model results this situation changed. Still, Johansen et al. (2003) continued to apply a deterministic approach, probably since the available computer resources at that time did not allow for a probabilistic description of the ocean's response to atmospheric forcing. Here, we examine a probabilistic representation of the ocean circulation in the Lofoten – Barents Sea region, see Section 2 in Melsom and Fossum (2008) for a description of the perturbation technique. The focus here is on the representation of particle advection, and their mass budget is ignored.

Even with the present eddy-permitting model, there are un-resolved features that affect the particle trajectories. We parameterize these processes by adding Gaussian noise to the model results for velocity according to

$$(1) \qquad u^{adv} = u^{mdl} + u' \qquad , \qquad u' \sim N(0, u_0^2)$$

where u^{mdl} is a velocity component from the model results and u' is the Gaussian noise with a standard deviation of u_0. Unfortunately, there was no drifter data available from the simulated period inside the model domain. Hence, in order to estimate the velocity scale u_0 we use drifter data from the summer of 2007, and assume that their dispersion is representative. A good match was achieved with a velocity scale of 0.005 m/s and an e-folding time of 24 h for the perturbation memory, as displayed in Figure 1 below.

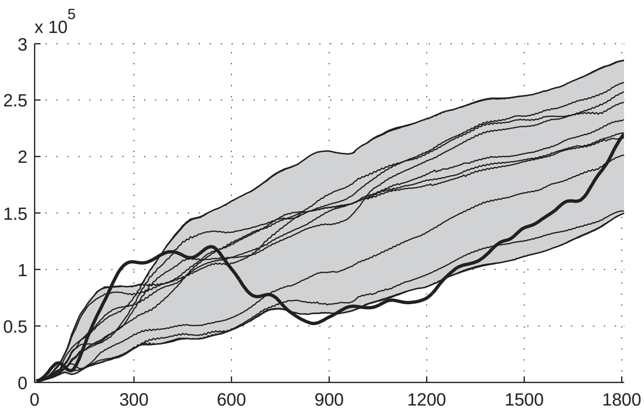

Figure 1: Thick line shows the standard deviation (in m) as a function of time (in h) between four surface drifters that were released simultaneously off Lofoten in June 2007. Thin lines show the corresponding dispersion computed from the ensemble results for 1986 (one line for each of the 10 members). A perturbation scale of u_0=0.005m/s was applied to the modelled trajectories.

3. Results

3.1 Oceanic statistics

Oceanic oil drift statistics may include simple properties like means and maxima of e.g. drift time and oil mass as a function of space. This is sometimes supplemented by descriptions of the composition changes of the oil as a function of time (related to e.g. toxicity), and its vertical distribution in the ocean. Although the drift time to the shoreline is strictly speaking a part of the coastal statistics (see the next subsection), it is usually inferred from maps for the oceanic statistics.

The oceanic oil drift statistics are relevant for a number of environmental issues. While in the ocean, oil may harm life, since it is a toxic substance for fish eggs that are carried by the ocean currents or attached to the ocean bottom. Furthermore, even a low surface concentration of oil impairs the flight of affected sae birds due to feather damaging. Finally, the rate of natural dispersion of oil at sea has an impact on the ability to remove oil by use of chemical dispersants and physically by skimmers.

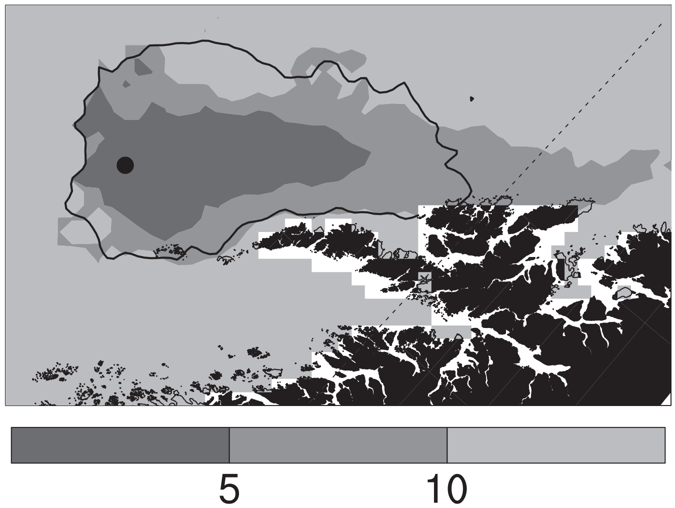

Figure 2: Contour line shows an estimated perimeter of the region that may be impacted after 5 days, based on results for 36.000 trajectories released at the position of the full black circle (4 particles form each ensemble member released every 2 h during 75 days). Gray shades display the minimum drift time based on the ensemble member with slowest drift. Numers on the scale are drift time in days. Dashed line is the 15°E meridian.

Particles were seeded at 10.6°E, 67.6°N, corresponding to the site "Nordland VI" in Johansen et al. (2003). We computed ten sets of trajectories based on the surface currents in the model results, one set for each ensemble member. The ten sets were then merged into a trajectory ensemble, and the minimum drift time was computed as a function of space. The black contour line in Figure 2 is for a drift time of five days.

The procedure of determining the minimum drift time was repeated for each of the ten sets separately. Then, for each position in space the value from the member with the longest minimum drift time was stored, and the result is displayed by the grey shades in Figure 2. We observe that this new field typically has drift times of about 10 days where the minimum drift time in the trajectory composite is 5 days. Thus, if the ensemble approach described in Section 2 gives a good representation of variability related to stochastic processes in the ocean, the use of a single realization with an eddy-permitting ocean circulation model may lead to an over-estimate of the minimum drift time by a factor of two at any given position.

3.2 Coastal statistics

Coastal oil drift statistics provide information that is indicative of how resource demanding cleaning up oil that has encountered the shoreline might be. Quantities that are useful in this context, include the length of the affected coast and the probabilities of various concentrations of oil that may end up on the beaches.

Probabilities of a spill impact exceeding selected lengths of coastline are provided in Table 1, based on simulations of surface spills that last for 5 days. Probabilities were computed separately based on ocean currents from the ten ensemble members. Only the lowest and highest of the ten values are listed in Table 1. We observe that the use of a single realization may have a pronounced influence on the coastal statistics, since e.g. planning for events that have a probability of 0.32 is substantially different from those with a probability of 0.01 (rightmost column in Table 1).

	#affected 8kmx8km coastal grids			
	> 40	**> 80**	**> 120**	**> 150**
Low estimate	1.00	0.85	0.44	0.01
High estimate	1.00	1.00	0.94	0.32

Table 1: Probabilities of exceeding selected limits of coastal grids that become oil infested, based on oil drift statistics. The simulated spill is assumed to have a duration of 5 days, and statistics for each ensemble member is based on 140 such spills. Low and high estimates give the minimum and maximum probabilities of exceeding thresholds in the statistics for the ten members.

4. Concluding remarks

A deterministic approach to eddy-resolving oil spill simulations for EIAs is unsound from a theoretical perspective. In Section 3, we demonstrated that applying a deterministic, single realization technique has a profound impact on the oil drift statistics, particularly for extremes. One example is that estimates of minimum drift time may be off by as much as 100%, another is the statistics for rare events of long stretches of a contaminated coastline. Hence, we recommend that an ensemble approach to eddy-resolving simulations is adopted in EIAs.

Acknowledgements

Financial support was provided by the Norwegian Research Council under contract 173487/S40. The ocean circulation model was run by Dr.s Ana Carrasco and Ingerid Fossum at the Norwegian Meteorological Institute. HPC computer time was allocated by NOTUR (project NN4559K).

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