

# ECMWF Feature article

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**METEOROLOGY**

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Using ECMWF products  
in global marine drift  
forecasting services  
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## Using ECMWF products in global marine drift forecasting services

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As a part of the EU-funded project MERSEA, a global marine drift forecasting system has become operational at the Norwegian Meteorological Institute, hereafter referred to as met.no. The system relies heavily on global forecast products from the ECMWF wave and atmospheric models. In addition, a new wave parameter (the Stokes drift) was implemented for the proper treatment of the surface particle drift. Here, this forecasting system will be presented with emphasis on the use of global products from ECMWF. Also an example of an oil drift forecast will be given.

### Importance of drift forecasts

It is of great societal importance to have safe shipping and oil production at sea. Unfortunately, accidents happen so from time to time there are releases of oil in connection with shipping accidents or discharges from oil rigs. Besides accidental spills, there is also illegal dumping of oil and pollutants for which authorities need back-tracking predictions of the oil spill to find who is responsible. In addition to the tracking of oil spills, there is a vital interest in tracking people lost at sea, drifting ships, containers and other objects.

Today, most countries have one or more authorities responsible for detecting and tracking drifting objects and oil. Observations by satellites, aircraft and ships, as well as drift predictions, are important parts in the complex interplay governing any search and rescue or oil spill recovery action. For instance, in Norway the Joint Rescue Coordination Centres are the operational authority for search and rescue, while for oil spill recovery the responsibility is shared between the Coastal Administration (a government agency) and NOFO (a joint offshore industry enterprise charged with carrying out remedial action at sea). The responsibility of Norwegian authorities covers the Norwegian economic zone, but adjacent waters, such as the Nordic Seas and Arctic, are also of importance. Other countries have similar interests in their national and adjacent waters. However, there is also an interest in being able to monitor and forecast incidents in other waters.

Shipping and marine pollution are truly global and for many areas it is not clear which authority is responsible for remedial action. While there are international agreements ensuring the provision of metocean forecasts in maritime emergencies (MPERSS), there is still a need for drift forecasts at the local level. For example, when a Norwegian ship is involved in an accident, it may be of interest for Norwegian authorities and for the shipping company responsible for the ship in question to obtain monitoring and forecasting information. Therefore, it is an added value to have organizations capable of forecasting the track of oil spills and drifting objects on the global scale.

In many situations there are large uncertainties in the drift forecast that reduce the value of the forecast of, for example, an oil spill. One way to improve the accuracy of the forecast, or for estimating the uncertainty of the forecast, is to use ensemble forecasts. Here it is worth emphasizing that there are two types of ensemble forecasts:

- Traditional ensemble forecast using an ensemble of forcing fields (e.g. different wind forcing).
- An ensemble of different oil drift models.

The latter type of ensemble requires different oil drift models and arrangements to ensure that data from different models is made available. Today, there is much pan-European focus on exchanging data on drift forecasts from various centres through different EU projects (MERSEA, ECOOP, MYOCEAN and a new EU call for downstream services). However, presently these model ensembles are probably not used to their full extent but it is foreseen that this matter may improve as forecasts from different centres become available and the cooperation between European countries intensifies.

## Modelling oil spills

In principle, the drift of various objects at sea follows the same physical principles and are subject to the same geophysical forces (i.e. the drift of an object can be calculated from the forces on the object and its mass). However, different objects (e.g. ships, containers, small boats, wind surfers, icebergs and oil) have very different geometries and rely on diverse parametrizations, and so models have been developed separately for various kinds of drifting objects. This means that in many circumstances very different models are used for different objects. Here, we will describe the drift of oil, but many objects will behave in a rather similar way.

Drifting objects and substances at sea are influenced by:

- Atmospheric winds
- Ocean currents
- Wave drift and wave forces
- Coriolis force

The wind acts directly on a drifting object or oil, forcing it to move with the wind. A classical observation is that an oil slick drifts with typically 2–4% of wind speed with a 0–20° deflection towards the right (north hemisphere). This parametrization provides a simple model for the upper ocean currents: it is simple and easy to implement, but does not cover situations in which wind-drift is not the dominant current component (e.g. in cases with strong tidal currents, density-driven currents or strong swell conditions). Accordingly, if we describe the ocean currents in a better way, we may be able to improve the prediction of those currents and the resulting drift forecasts.

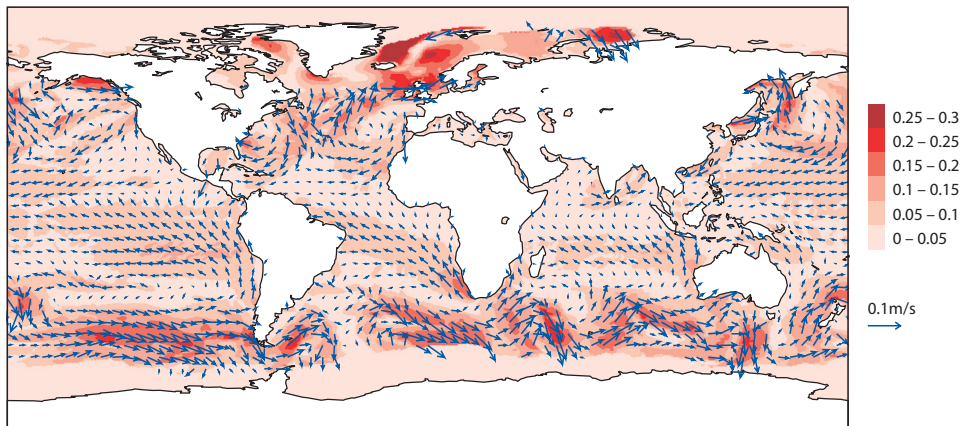
In addition to the ocean current, waves will also affect objects by the wave radiation stress and/or by the Stokes drift. Waves have a certain momentum and when they interact with, for example, a solid body there is an exchange of momentum between the waves and the object; this is called the radiation stress. The Stokes drift is described in Box A.

In operational drift models, the Stokes drift component is often parametrized from the wind speed. However, in some cases, such as the met.no oil drift system (Oil Drift in 3 Dimensions, OD3D), the Stokes drift is taken directly from a wave model. In that case the strength and direction of the Stokes drift can be calculated directly from a two-dimensional wave spectrum provided by an ocean wave model.

Currently, the Stokes drift is not a product routinely delivered by the ECMWF system. Since this is a required component of the met.no marine drift model, the calculation of the global Stokes drift from the ECMWF wave spectra was implemented by met.no under the MERSEA project for use in a global service. To calculate the Stokes drift the full two-dimensional wave spectra are needed. Under met.no's Member State account at ECMWF a routine has been set up that retrieves the wave spectra and performs the calculations. Twice daily, five day forecasts of global 6-hourly Stokes drift are then computed and transmitted to met.no via an automatic ftp routine and provided as forcing to the marine drift forecasting system. It is our opinion that this might be a potentially valuable product for other Member States and therefore we suggest that Stokes drift is introduced as an operational product at ECMWF. Figure 1 shows an example of a global Stokes drift forecast based on the ECMWF wave spectra.

From a forecast/nowcast point of view, atmospheric winds are described with rather good accuracy. This is because there are a variety of atmospheric observations covering the dynamical scales of atmospheric flow. Waves depend essentially on the wind speed: as the wind speed (and direction) is accurately forecast, waves will also be described in a satisfactory way. Due to lack of oceanographic data for constraining the oceanic eddy field, it is generally the forecast of the oceanic current field that is the weakest point in the forecast model for floating objects and oil.

Returning to the question of the Stokes drift, we know that a large part of the drift in the upper ocean is due to the Stokes drift. Also, we expect to have a good forecast of the Stokes drift. It therefore seems to be advantageous to use this forecast together with the currents from the ocean model. However, standard ocean models are not based on a correct separation of the Stokes drift and Eulerian ocean currents (i.e. the momentum flow from the atmosphere is not separated into wave and Eulerian mean momentum in the ocean model), and in principle we would need an improved ocean model to separate ocean currents into Stokes drift and Eulerian mean motion. This has, however, not been done in the present forecast system albeit we are working on developing a more consistent wave-mean flow ocean model system.



**Figure 1** The Stokes drift calculated from the ECMWF forecast on 25 October 2008. We see that the Stokes drift is about 0.1–0.3  $\text{ms}^{-1}$ . To first order there is essentially a linear relation between the Stokes drift and the significant wave height and a Stokes drift of 0.3  $\text{ms}^{-1}$  corresponds to a significant wave height of about 8 metres.

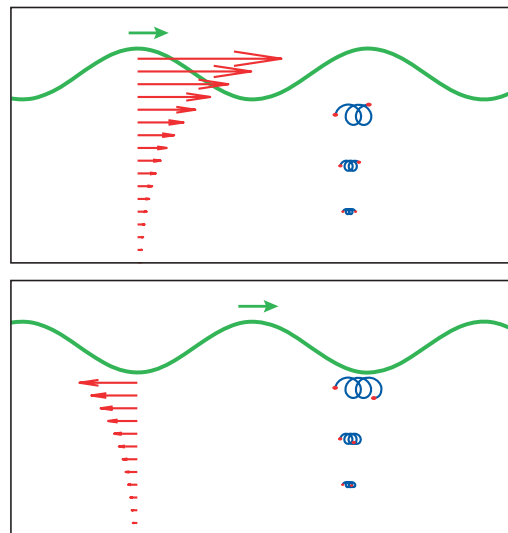
### The Stokes drift

The Stokes drift is the mean velocity of the fluid particles due to the presence of a wave.

If we look at a particle under a wave train, see the figure, it will move faster under the wave crest where the water parcel is higher up in the water column and thus experience stronger positive wave orbital motion than under wave trough where the water parcel is lower in the water column and experience negative and weaker orbital motions. In addition, the particle moves in the direction of the wave propagation under the crest and against it under the trough and is therefore exposed to drift in the wave direction longer. Drifting particles under the action of waves will therefore move in the direction of the wave, and this is called the Stokes Drift.

To further enhance the picture it should be noted that the Stokes drift is an inherently Lagrangian process; particles move but if we take the mean velocity at a fixed position (Eulerian mean) the transport is identically zero (as can be imagined from the figure). In the Eulerian description the wave transport is located between the deepest wave trough and the highest wave crest, while in the Lagrangian description it is distributed as  $\exp(-2kz)$ , where  $k$  is the wave number. However, the deviation between the Lagrangian and the Eulerian description can be resolved by considering the wave-induced motion in between isopycnal layers. This formulation is similar to the estimate of horizontal transport in isopycnal coordinates as is commonly used in atmospheric and oceanic science to describe the transport in an eddy field.

**A**



Motions of particles at different depths (blue lines) due to the passage of an idealized surface wave travelling to the right (green line) for two cases separated by half a wave period. The position of particles during each wave period is shown with the red points indicating the beginning and end positions. The red arrows indicate horizontal velocities.

### An example of an oil drift forecast

On 12 December 2007 there was a large accidental oil spill (4,400 tons) from the Statfjord A platform in the Norwegian Sea (near 61.3°N, 1.9°E). The cause of the accident was a large-diameter loading hose that ruptured during the filling of an oil tanker. On the day of the accident the weather was relatively severe; the Statfjord A platform reported wind speed of 45 knots from the south and a wave height of about 7 metres though the forecast values of wind and wave height were somewhat lower. The heavy seas and strong winds persisted for the following days and caused the oil to separate into drifting streaks (see Figure 2); note that the oil drift is north-eastwards in the direction of the waves.

The severe weather had a strong influence on the oil spill so much of it evaporated very quickly, and the remaining oil dispersed quickly in the horizontal as well as being mixed down in the upper ocean. By 14 December the oil slick had been reduced so much that all remedial action was cancelled by the authorities, and by 16 December the oil spill was no longer detectable from ships or by flight reconnaissance.

met.no was responsible for the initial forecast of the oil drift, and within 30 minutes from the first call a forecast by the OD3D system was delivered to the authorities and NOFO. Figure 3 shows some drift forecasts.

- **met.no Nordic4.** This drift forecast used prognostic forcing data from the in-house atmospheric model HIRLAM, ocean model MIPOM (Meteorological Institute POM model), and the met.no wave model based on the WAM model.

In addition to the standard forecast several alternative forecasts were produced as part of the Mersea Integrated Project ([www.mersea.eu.org](http://www.mersea.eu.org)). These simulations used the ECMWF global forecasts for atmospheric wind and Stokes drift and three different ocean current data sets.

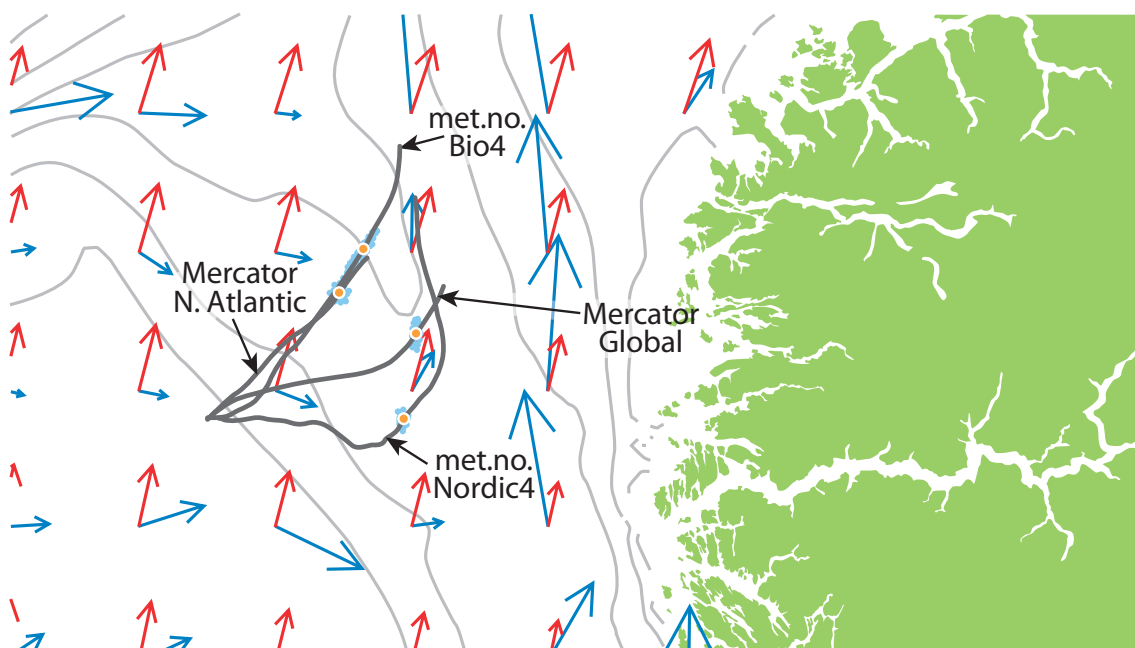
- **Mercator Global.** Forecast using OD3D drift model forced by the global model run by the MERCATOR ocean forecast system ([www.mercator-ocean.fr](http://www.mercator-ocean.fr)).
- **Mercator N. Atlantic.** Forecast using OD3D drift model forced by North Atlantic model run by the MERCATOR ocean forecast system.
- **met.no Bio4.** Forecast using OD3D drift model forced using a second version of MIPOM.



**Figure 2** Aerial photo of the Statfjord A oil slick on 12 December 2008. In the lower left corner is the loading buoy, while the Statfjord A platform is near the centre of the photo. (Photo: Kystverket/Scanpix)

In Figure 3 we see that the net forecast drift is to the east or north-east in all simulations. There were a few observations on the actual movement of the oil slick, and these show that the main oil drift was in the eastward direction with a large dispersion in north-south direction. One interpretation is that the oil at the surface moves north-eastward (due to Stokes drift; note that the oil at the surface moves in the direction of the waves in Figure 2) while the oil dispersed in the water column moved south-eastward with the ocean currents. It is clear that the Stokes drift has a big influence since the Stokes drift is of the same magnitude as the ocean currents at the sea surface. As a final comment we note that the local met.no operational model gave the best results and this is in agreement with the main results from the MERSEA study. However, the ‘imported’ models provided good forecasts and will thus complement the local model; we now have some confidence in using these models outside the domain of the local model.

The differences between the oil drift predictions are mainly due to the use of currents from different models. As the different forecasts give similar results, the OD3D forecast appears to be robust. This proved to be important information for the operator responsible for the forecast, and for the authorities responsible for the action.



**Figure 3** Example of model ensemble forecasts for the Statfjord A incident on 0900 UTC on 12 December, 2007. *met.no Nordic4* is met.no’s drift model in standard configuration (i.e. the local Princeton ocean model with 4 km resolution, a local version of the WAM model for the Stokes drift, and winds from the HIRLAM model); note that this simulation ends at 1200 UTC on 19 December. *met.no Nordic4* is a version of Nordic 4 that uses winds and waves from the ECMWF global operational forecast. *Mercator Global* and *Mercator N. Atlantic* are  $1/4^\circ$  and  $1/15^\circ$  MERCATOR operational models that use winds and Stokes drift taken from the ECMWF global forecast. Grey curves show the mean trajectories up to 0000 UTC on 17 December (1200 UTC on December 19 for Nordic 4). Clouds of purple dots (the model is set up using many particles that are advected with currents and also describes a random walk) represent the oil slicks at 1600 UTC on 16 December (about 3.5 days after the spill). Red dots are the mean position of oil particles at the same time as the purple clouds. Blue arrows are examples of surface currents from the Mercator N.Atl model. Red arrows are the Stokes drift from the ECMWF WAM model.

## Discussion

In this short communication we have described some new developments that have taken place within the European community regarding the drift of objects and oil at sea. The development focuses on (a) sharing forecasts made at different national centres to provide an ensemble forecast and (b) a widening of the forecast product range to include areas beyond the national responsibility. One challenge is to go to the global scale; another challenge is to be able to use a variety of data from different forecast centres and to find the most reliable model for a given region. It is clear that major atmospheric centres such as the ECMWF will play a crucial role for such developments as they can provide atmospheric and wave forecast data for regions where national centres do not operate.

We also point to the 'new' product for calculating the Stokes drift provided by ECMWF. This is not routinely incorporated into drift models, but we advocate using the Stokes drift as it is a reliable forecast product that will probably enhance the forecast of drifting objects and substances. At present, the basic spectral data used to calculate the Stokes drift are only available up to day 5 of the forecast. Since all other the global forcing data sets applied in this study extend to at least day 10, it is the availability of wave data that limits the forecast period for global marine drift forecasting to five days.

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