Chapter 23

# FORECASTING THE DRIFT OF OBJECTS AND SUBSTANCES IN THE OCEAN

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**Abstract** Forecasting the drift of floating objects, ships and oil spills is an important ocean application. Most nations support services for ship safety, oil spill combatment and search-and-rescue, all of which may benefit from drift forecasts. Examples from Norwegian services are discussed. The models for drifting things themselves are founded on hydrodynamic principles (ship drift), empirical parameterizations (floating objects) and oil-water chemistry. An overview of these models is given. All the drift models share a crucial reliance on geophysical forcing data. In operational services, these data are obtained from weather, wave and ocean forecast models. Currently, ocean forecasts are the component with greatest scope for improvement. Effective interfacing of drift forecasting services to the users - the emergency response services - is vital for obtaining optimal benefit from the forecasts.

**Keywords:** Oil spill, search and rescue, ship drift, ocean forecasting.

## 1. Introduction

Ocean forecasting is founded on the operational prediction of the prognostic variables in hydrodynamic models: water level, temperature, salinity and currents. While these variables are essential for describing the state of the ocean, they are in themselves of limited interest outside of the scientific community. Most people are not concerned with, for example, tomorrow's forecast for surface current 2 km out to sea - even those who reside on the coast. Of more interest to public is how these physical variables affect other things in the ocean. In the case of currents, there is considerable interest in how various things in the ocean are transported from place to place and how they are altered along the way. The transport of objects and substances by currents is commonly referred to as *drift*, and is the subject of this paper.

There are a number of drifting objects and substances in the ocean that are of concern or interest to us, most important of which are the nutrients and phytoplankton that form the basis for life in the ocean. However, in this work we will focus on a special class of drifting things: those that derive from human activities and have potentially serious consequences for human activities and the marine ecosystem. Specifically, we will look at (large) floating objects and oil spills. These are quite different things, but in the present context of ocean forecasting, they share a dependence on knowledge of the physical conditions in the ocean, chiefly currents. Furthermore, they share a potential for negative impact sufficient to warrant the development of services, including the prediction of their drift and fate, to mitigate those impacts.

In the case of drifting objects, we are concerned with objects of great value in themselves, such as a human body, and those that (also) pose a threat to maritime safety, such as a floating container. The task at hand is either to find and recover a lost object (search-and-rescue, or SAR) or to track a known object until remedial action can be taken. Many countries have established national SAR services for handling emergency situations, and some also run trajectory models to aid in the search. The objects that are of interest in this type of service range from smaller than a human (debris from a wreck) to large ships, although the scope and administrative organization of the services vary from country to country. In this work, we will focus on examples for SAR and ship drift.

Oil spills are quite different inasmuch as the object is a fluid that spreads and can change properties quite dramatically once it is spilled into the ocean. The source of the oil may be on the surface (a ship) or subsurface (an offshore wellhead blowout). Also, oil on the surface can be mixed down into the water column by wave action and be transported by subsurface currents. Oil spills fall generally into two classes: small spills from ships, typically from illicit flushing of ballast tanks, and large catastrophic spills, either from tanker accidents or from offshore installations. Small spills from shipping are so numerous that they account for the bulk of the worldwide input of oil to the sea, but it is the large accidents that are responsible for the most dramatic damage to the environment. In most countries, detection and combatment of oil spill incidents is a national service that includes a drift forecast component.

In the following, we will look at current practises in forecasting the drift of floating objects and oil spill fate, using examples from operational services in Norway. Two aspects of these services will be addressed: the scientific basis for the forecast numerical models used and the information infrastructure required for operational service. Since the theme of the Summer School is ocean forecasting, we will only briefly describe the modeled processes and concentrate more on the practical implementation and operational aspects. Indeed, models for drifting objects, ship drift and (especially) oil fate are quite complex and a fuller understanding of the modeled processes is beyond the scope of this summer school. However, some insight into the workings of these models is necessary to understand the operational data input and dissemination requirements. The sections 2 and 3 will introduce modeling of floating objects and oil spills, including typical methods for implementing them. It will become apparent that the geophysical data needed to drive these models in an operational service are quite similar. Therefore, section 4 will deal with the structure of operational services for both floating objects and oil.

## 2. Drift of floating objects

The motion of a drifting object on the sea surface is the net result of several forces acting upon its surface (water currents, atmospheric wind, wave motion, and wave induced currents), and its center of mass (the gravitational force and the buoyancy force). It is possible to estimate the trajectory given information on the local wind, surface current, and the shape and buoyancy of the object.

The position of a floating object is computed by numerically integrating the total drift velocity $\mathrm{V}_{drift}$ of the object, given by

$$\mathbf{V}_{drift} = \mathbf{V}_{curr} + \mathbf{V}_{rel}, \tag{1}$$

where $\mathbf{V}_{curr}$ denotes the ocean current velocity relative to the earth, and $\mathbf{V}_{rel}$ denotes the object drift velocity relative to the ambient water. The ocean current is made up of two components: the surface current, which includes the Ekman drift, baroclinic motion, tidal and inertial currents, and the Stokes drift induced by waves. $\mathbf{V}_{curr}$ is assumed to influence all floating objects in the same manner. It is typically equated with the (near-)surface current obtained from a numerical ocean model, a parameterization on the wind velocity and/or local observations. $\mathbf{V}_{rel}$ results from the wind and wave forces acting on the object, and is strongly dependent on the characteristics of the object.

The basic model in eq. 1 may be separated into two modules, based on the forces that determine $\mathbf{V}_{rel}$. A well-known result from hydrodynamics is that wave effects are small when the length scale of the object is smaller than the wave length and increase dramatically when the lengths are about the same (Grue and Biberg, 1993, Hodgins and Hodgins, 1998). Thus, one module is for relatively small objects (in practise, less than some 10's of meters), where wave forces may be ignored and wind forces are of variable importance, depending on the overwater structure of the object. Objects in this class include wreckage, bodies, rafts, small craft, etc. Drift due to wind forces is commonly referred to as *leeway* drift, also called the windage. The other module is for larger objects - conveniently lumped together under the heading of "ships" - where both wind and wave forces on the object must be taken into account.

## 2.1 Leeway drift

The maritime term *leeway* refers to an object's motion relative to the wind. It is well known that, due to the asymmetry of almost any floating object, there will be a net side force causing the object to drift at a certain angle to the wind. Thus, we can decompose the leeway drift velocity vector into two components: a downwind and a crosswind leeway component, as shown in Figure 1. The concept of leeway drift is an empirical approach to the very difficult problem of determining the net force on a drifting object. Compounding the difficulty is the wide range of objects (size, form) that we may want to track. Thus, empirical studies of actual objects have so far been the most fruitful method. Allen, 1999 reports field experiments carried out to determine how different classes of objects respond to the wind. The DWL and CWL components for each class of object are recovered from linear regressions on the windspeed. The standard deviations about the DWL and CWL coefficients are identified as "error bars" on the drift properties, and must be interpreted as the total error associated with the wind and current measurements as well as the inherent variation in leeway properties of two ideally identical objects.

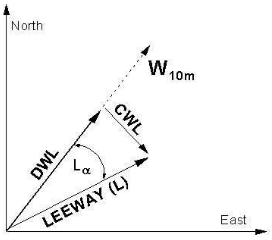


*Figure 1.* Relationship between leeway drift velocity vector (**L**) and wind velocity vector $\mathbf{W}_{10m}$. DWL = *downwind leeway* component, CWL = *crosswind leeway* component, $L_\alpha$ = *leeway angle* (measured positive for leeway to the right of the wind direction).

Allen and Plourde, 1999 have assembled tables of the leeway parameters for 63 leeway categories of floating object. These tables consist of the linear regression coefficients, and their standard deviations, for each of the 63 categories. They are mainly based on observations and field experiments, although some of the values have been extracted by converting values derived from other ways of calculating the off-wind drift of a floating object.

In implementing the leeway drift in the **met.no** operational service, the DWL and CWL components are calculated in a straightforward manner from the linear regression formulae as functions of the wind speed, once the object type is specified. The standard deviations are used in estimating the uncertainty in the drift speed and direction. An interesting result of the field experiments is that both positive and negative values of the CWL component can occur for a given category of objects. Apparently, small differences in the initial orientation of the object relative to the wind can result in the object drifting either to the left or to the right of the wind direction, with about the same likelihood. The initial orientation is normally unknown, so the prediction is obliged to account for both possibilities.

## 2.2 Ship drift

The drift of ships has been approached in a different, more analytical manner, based on knowledge from marine architecture and hydrodynamics. The ship drift model at **met.no** is based on work at Det norske Veritas (DnV), reported by Sørgård and Vada, 1998 in which estimates of the wind and wave-generated forces acting on the vessel, rather than empirical regressions, are used to calculate the velocity relative to the water ($\mathbf{V}_{rel}$). The advantage of this approach is, of course, that knowledge of the object may be reduced to a few key parameters.

Case studies by Sørgård and Vada, 1998 show that the relative drift speed of the ship will increase rapidly (in a matter of 2-10 minutes) towards a stationary solution. Therefore it is not necessary to integrate the acceleration over time when the relative drift speed is calculated for simulations over several hours or more; the stationary solution may be applied to good approximation. This means among other things that it is not necessary to know the mass of the ship.

The balance of forces acting on the ship may be written

$$\mathbf{F}_{wind} + \mathbf{F}_{wave} + \mathbf{f}_{form} + \mathbf{f}_{wave} = 0. \qquad (2)$$

$\mathbf{F}_{wind}$ is the wind drift force acting on the vessel; it depends on the vessel length, the keel-to-deck height, the momentary draft and the lateral area of the superstructure. It may be formulated in the well-known form

$$\mathbf{F}_{wind} = \frac{1}{2}\rho_a(A_h + A_s)C_d\|\mathbf{U}_w\|\mathbf{U}_w, \tag{3}$$

where $\rho_a$ is the density of air, $A_s$ is the superstructure area, $A_h$ is the wind-exposed hull area, $C_d$ is a drag coefficient and $\mathbf{U}_w$ is the wind velocity. $\mathbf{f}_{form}$ in eq. 2 is the form drag or damping force exerted by the water on the hull due to the relative motion; it depends on the wet lateral area of the hull, i.e., the length and draft. $\mathbf{F}_{wave}$ is the wave drift force acting on the hull, while $\mathbf{f}_{wave}$ is the wave damping a counterforce that occurs as the moving hull generates its own wave field. Much research has been done to determine the wave drift and damping. Numerical simulations of individual tanker hulls and idealized objects at DnV have shown that representing hulls with a simple rectangular box of similar dimensions is a fair approximation. Thus, a ship may be parameterized using just the length, beam and draft. The wave forces on a given hull are calculated as functions of the wave spectrum. DnV have tabulated transfer functions in wave frequency space for both the wave drift and wave damping forces, for a range of box hull dimensions. The forces for a particular ship may then be estimated by interpolation in the database.

Figure 2 sketches the forces acting on a drifting ship. Usually, the wind and wave forces will act in about the same direction, but for the sake of generality they are given different directions. Observations ( Sørgård and Vada, 1998) have revealed a difference in drift direction depending on whether the wave (and wind) direction is towards the port or starboard side of the ship. Due to limited data it was not possible from those observations to separate the wind and wave effects. However, the correlation with wave direction was observed to be the more significant. In the **met.no**/DnV model, this modification is included by altering the wave drag force direction by an empirically determined angle.

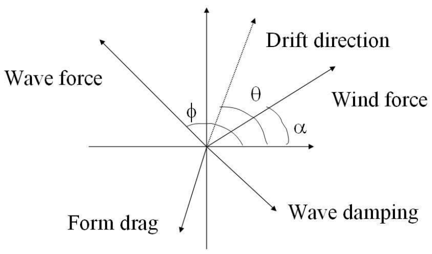


*Figure 2.* Forces acting on a drifting ship.

## 2.3 Stochastic approach to drift prediction

In predicting the drift of objects on the sea surface, we are faced with the challenge of accounting for uncertainties in almost all aspects of the task. We have already seen that the models for drift of objects and ships utilize empirical parameterizations (or empirically calibrated formulae) and imperfect approximations to the hydrodynamical laws. In addition, we often lack information about the object itself and where it is (or was at some time). And even if we did have this information, there is still the unavoidable uncertainty in the wind, wave and current data we use to drive the drift models. Accounting for uncertainty is most readily approached in a probabilistic framework. By assigning probabilities to the relevant parameters, an ensemble of numerical integrations can be performed where the various parameters are perturbed in a stochastic fashion. The perturbations are dictated by the pertinent probability distributions. Thus, we get a cloud of "candidate" positions for the drifting object. This cloud is itself a measure of search object's most probable location. Such a technique is known as a Monte Carlo integration and has been extensively used across many scientific disciplines (see e.g., Press et al., 1993).

*The last known position.* The first task in any real SAR or tracking operation is to determine the last known position (LKP). For SAR, this is a critical step, since the accuracy of this information is decisive for the outcome of the search. In the case of ship drift, the position at any time is often known very accurately. In the stochastic approach, an uncertainty is then assigned to the LKP, both in space and time. If the LKP is assumed to be very precise (e.g., a distress call is received from a ship with a GPS unit), a small radius may be assigned to the datum and all candidate objects (ensemble members) can be released at the same point in time. In the other extreme - a situation where little is known about the time and location of the accident - then a wide radius and a long period of time must be used. This will result in a cloud of possible initial positions scattered over a large portion of the sea surface released over an extended period of time. Thus, the various members of the ensemble will meet very different fates under the influence of differing current, wind and wave conditions. Obviously, the choice of initial distribution of ensemble members will affect the future search area seriously. It is the task of the Rescue Coordinator to estimate the LKP and its distribution.

*Uncertainties in forcing fields and drift properties.* In addition to the uncertainty assigned to the LKP, we also need to address the uncertainties present in the forcing data that are used and the drift properties of the object. The spread of the ensemble is thus a function of perturbations to the time-invariant leeway coefficients (accounting for experimental variance) and time-varying perturbations to the wind field. The latter represent a random walk perturbation. A discussion of more advanced stochastic methods can be found in Griffa, 1996 and Berloff and McWilliams, 2002. Particularly the random flight model is useful when studying surface drift. However, for SAR purposes, it suffices to observe that the random walk will represent an upper bound on the inflation of search areas as it represents the maximum dispersion of particles in a given flow. Using random walk means erring on the side of caution in the sense that the size of the search areas is not underestimated. As search areas should be conservative (rather too large than too small), this makes sense with an operational SAR model.

*The orientation of a drifting object.* A final random factor is the orientation of the object with regard to the local wind direction. As the leeway drift for most objects contains a substantial cross wind component, there will be a significant discrepancy between the downwind direction and the direction of propagation of the object. Whether the object drifts to the left or to the right of the wind cannot be known in advance and unless more is known about the object we must assign equal probability to the two outcomes. Search areas are thus naturally bimodal, meaning that there will be two disjoint areas of high probability.

Furthermore, one could even "perturb" the object class if nothing is known about the object. In practice, however, this is done by running several integrations from the same initial conditions, once for, say, a person in water (PIW), then for a life raft, then for a swamped boat, etc. Overlaying the different trajectories will give a total search area.

*Implementation of stochastic initial positions.* The ensemble is O(500) and all members are positioned using a 2D normal distribution with a standard deviation equal to half the radius input by the user. The mean position of the particle cloud is a great circle arc and the release time varies linearly throughout the ensemble. This approach is flexible: it allows on one hand for point release in space and time and, in the other extreme, a contiuous release in space and time in a "trumpet" shaped area with one radius in one end and another radius in the other end of the seeding area (see figure).

## 3. Oil spill fate modeling

Oil spill fate models tend to be considerably more complicated than the models for surface objects, due to the range of oil types and the complex chemical processes that oil undergoes in the ocean (weathering). We will in the following outline the types of models in use and the processes that they include. For a fuller review of the state of oil spill modeling, see Reed et al., 1999.

## 3.1 Oil and weathering processes

Oil spilled into the ocean ranges from unrefined crude oil to heavily refined products, with a corresponding wide range of chemical composition. In accidents, there can be several types of oil product spilled, for example crude oil cargo and diesel fuel. The chemical composition of the particular oil type and how it is spilled into the ocean determine to a large degree how weathering processes will transform the spill (Daling et al., 2003) and, consequently, what kind of remedial action can be considered.

The main weathering processes are evaporation, emulsification and natural dispersion:

*Evaporation.* For some oil types high in volatile fractions (e.g., many crude oils), evaporation from the surface slick removes a significant portion of the total mass within a short time, while other types (e.g., heavy fuel oils) lose relatively little to evaporation. Evaporation algorithms depend on the boiling point of the oil components, the ambient temperature, wind speed, film thickness and exposure time, although there is debate as to which parameters are important. The algorithms in use vary widely in computational expense and interpolation into empirical databases is a common practical approach.

*Emulsification and natural dispersion.* The uptake of water into the oil forms an emulsion, which may differ dramatically in drift behavior from the pure oil. Natural dispersion is the uptake of oil droplets of diminishing size into the water until they are no longer part of the oil slick in any practical sense. These two processes, illustrated in Figure 3, are competitors inasmuch as each reduces the rate of the other. In particular, the rate of natural dispersion is reduced with emulsion formation and, consequently, the lifetime of the slick is extended. Changes in the slick lifetime, in turn, affect the choice of response and possibility for environmental impact. All algorithms currently used for modeling emulsification and natural dispersion are curve fits to empirical data. Oil spill models must also track changes in the basic physical properties of the oil, such as density and viscosity, under the weathering process. These calculations are typically based on empirical tables. Inaccuracies can have important ramifications for the drift prediction. For example, the density of oil is close to that of water, and slight increases can result in increased downward mixing under the action of waves.

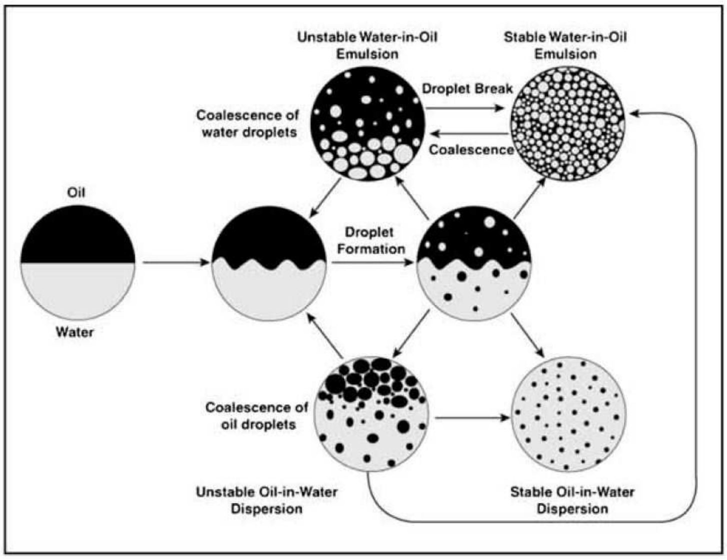


*Figure 3.* Illustration of emulsification and natural dispersion processes active when oil is spilled onto seawater. The action of waves initiates a complex mixing of oil droplets into water and water droplets into oil, resulting in stable emulsion and dispersion. From Daling et al., 2003

At present, setting up algorithms to determine the properties of weathered oil starting from various oil products still relies heavily on field or laboratory experiments. These are time-consuming and expensive, and a methodology for parameterizing these properties on, say, basic petroleum assay data would be a valuable aid.

## 3.2 Transport processes: spreading and advection

By spreading we mean the spread of the oil from its source as a light fluid on top of a more dense fluid (water). This process may be described by fundamental gravity-viscous equations. Spreading affects the weathering processes since it influences film thickness. Reciprocally, evaporation and emulsification change the viscosity and density of the oil, thereby altering the spreading. At some point, the spreading process ceases. For most crude oils, this occurs quite early in the spill. Thereafter, the movement of the oil is dominated by the geophysical advective forces: currents, wind, waves and associated turbulence. During this initial phase, advective processes at scales of 10's to 100's of m are important, and it is believed that Langmuir cells play a central role. These scales are smaller than those typically covered by the hydrodynamic forecast models used to drive oil spill models; these sub-gridscale effects must be parameterized from the available hydrodynamic data. Advection at scales larger than 1 km can be estimated from the hydrodynamic model data.

Spreading and advection of oil are also strongly influenced by the release conditions. So far, we have implicitly assumed a spill on the surface, or near enough that the oil rises to the surface unaltered. Deep, underwater releases may result in quite different initial surface slick conditions. The oil may be transformed during its rise to the surface and it will be advected by subsurface currents. In the case of a wellhead blowout, the oil may be accompanied by gas, which forms gas hydrates in contact with the water. Some oil spill model systems include special initialization modules for deep sources (Johansen, 1998, Wettre et al., 2001).

## 3.3 Model implementation

Representing an oil slick on the surface of the ocean and accounting for its motion, deformation and tendency to break up into smaller slicks, not to mention the changes due to weathering described above, is a formidable task. Over the years, several concepts have been introduced, ranging from simple center-of-mass trajectories to complex polygon representations. Perhaps the most popular type of model today treats the oil as a collection of discrete particles, each representing a certain mass of oil. The model currently in use at **met.no** is of this type, and we will explore it as an example. The main advantages of the particle representation are that it is inherently Lagrangian, it is amenable to a probabalistic approach and it reduces to a series of independent particle integrations. The disadvantage is that the results don't look much like an oil slick.

The **met.no** model OD3D has been developed together with SINTEF Applied Chemistry, who develops the weathering algorithms. An oil spill is described by a position, time of start, duration, spill rate, oil type, plus other optional parameters. Given this information, a prescribed number of particles is added (seeded) every time step (typically 1 hour) for the spill duration. The mass of each particle is determined by the flow rate, and remains constant throughout the simulation; mass loss due to evaporation and dispersion is effectuated by removing particles. Advective and weathering processes are applied on a particle-by-particle basis. The model is forced by atmosphere, ocean and wave data from a selection of sources, ranging from manually entered values to hindcast and forecast model data. Particle information is output to a history file at hourly intervals for analysis and graphical rendering.

The particle based model described here is very similar to the probabalistic approach used in the SAR model described above. In both cases, a cloud of particles is spread and advected by geophysical forces. Aside from some differences in the seeding strategy, the real difference lies in the peculiarities of the particles and how we interpret the results; floating object particles are robust but have very special drift characteristics, while oil particles are fairly simple drifters but with complicated lifelines. The particle approach can be (and is) utilized in models of other things in the ocean, such as fish eggs and larvae.

## 4. Operational services

We have seen that, despite the fact that life rafts, tankers and oil are quite different things in the ocean, the models that are used to predict their drift have much in common. Primarily, they share a reliance on the same kinds of geophysical forcing data. When these models are to be implemented in an emergency service for real-time response to incidents, immediate access to prognostic forcing data is essential. The need is especially acute for SAR services, where minutes saved can mean lives saved. Consequently, forecast services for SAR, ship and oil drift are closely allied to operational centers for weather and ocean forecasting. Forcing data not only need to be available quickly, but also in the form of products suitable for the drift models. This requires preparation and testing of the full data production chain. The various drift models also share a need for efficient interfacing with the users - the crisis response teams in the field. Attaining optimal performance of the services is dependent on end-to-end testing and validation of the systems through regular exercises.

In order to facilitate rapid and reliable national response services for emergency drift episodes, Norway has implemented drift models for SAR, ship and oil drift at **met.no**. These models are directly interfaced to the operational forecast models for the atmosphere, ocean and waves. Many countries have similar arrangements. The responsibility for action in an emergency lies with the Joint Rescue Coordination Centres of Norway (JRCC) for SAR and ship drift, and with the Norwegian Coastal Authority for oil spills; they will request drift forecasts based on information at hand. A cardinal rule for these services is that a forecast should always be returned to the requesting party, even if the best available data basis is uncertain. Thus, backup alternatives to operational forecast model data are required, and uncertainty assessment is an essential part of the forecast information returned.

## 4.1 Geophysical forcing data access

An important task for the operational implementation is accessing the best possible forcing data at a given time and location. This can be a complicated task. In a SAR case, for example, the LKP may be many hours, even days old. At **met.no**, forcing data sets covering the last 7 days are maintained for rapid retrieval to meet such an eventuality. Furthermore, there may be several candidate forecast models, with different horizontal extent and resolution, capable of supplying the same type of forcing data (Figure 4). The choice of model data set to use for a drift forecast will in principle depend on the location and the presumed forecast accuracy of the data. However, in practical implementation, the choice is limited to models that are considered "officially operational" in the sense of established quality and robustness (e.g., supported by automatic backup systems, computer redundancy, archiving, etc.). In a typical national service, there will be a small number (1-2) of *operational* models for weather, ocean and wave forecasting, together with several *pre-operational* models being tested in the daily routine with the aim of replacing or supplementing the existing operational models. At **met.no**, the drift services currently obtain their atmosphere and wave forcing data from a selection of operational models, including **met.no**, ECMWF and UK Met Office, while ocean data are obtained from one operational model at **met.no**. The default is the **met.no** *operational* models (cf. Figure 4). In the event of total failure to obtain model forecast data, an operator may enter uniform values of wind, wave and current manually.

Recent developments in global ocean modeling and, not least, data exchange capability (e.g., the European Mersea project) are making it feasible to access adequate ocean forcing data from other operational forecasting centers. Thus, there is potentially a wide range of alternative data sets available. The **met.no** drift forecast service is being extended to allow selective access to a fuller range of forcing data sets, from local, high resolution in-house models to global data sets obtained from external sources.

The challenge of this approach is devising methods to determine which forcing data sets are best for a given emergency situation. For external data sets, one must ensure that they are reliably available and archived (e.g., for post mortem reruns), as well as make the necessary agreements on formats, data product requirements and delivery sched-

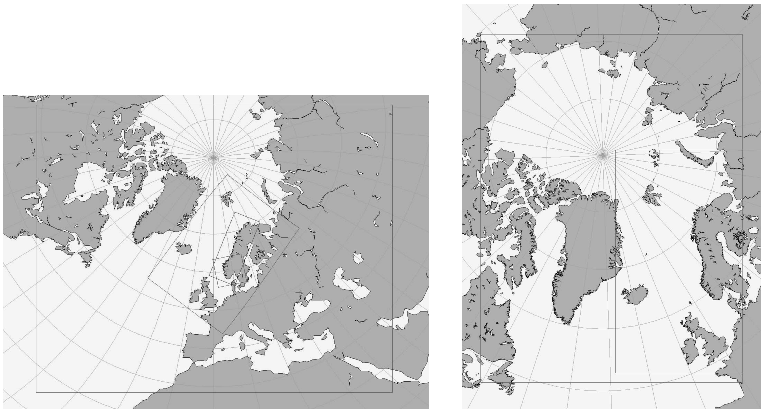


*Figure 4.* Geographical extent of operational models at **met.no**. Left: numerical weather prediction models. The largest rectangle is operational HIRLAM at 20 km resolution. The smaller domains are nested pre-operational models at resolutions of 10, 5 and 4 km. Right: ocean models. The largest rectangle is a pre-operational coupled ocean-ice model at 20 km resolution. The inset covering the Nordic Seas is the operational model at 4 km resolution.

ules. These issues have been solved for atmospheric and wave data, through WMO (World Meteorological Organization) data exchange conventions. The situation for ocean forecast data is less mature, but is being vigorously addressed in several international initiatives (e.g., GODAE, GOOS, Mersea). Furthermore, the drift forecasting services need to find the optimal method of utilizing external data sets. Two options are: applying the external data directly to the drift model, and nesting local in-house models. Nesting may be done on a routine basis, as is typically done in weather forecasting (e.g., European national weather services nest limited area models in ECMWF global model data), or on a case-by-case basis using so-called “relocatable” models. Each method has advantages and difficulties, and the local drift forecasting service must judge what is best. Given the increasing number of forcing data options, it is imperative that the drift forecast services offer the right balance of forecast alternatives and simple, easily understood drift information to the field teams. This can only be done through comparative testing and validation of the alternatives. At present, skill assessment of drift forecasts is not well-established.

## 4.2 User interface

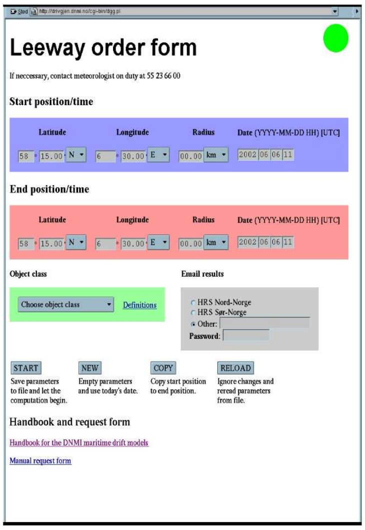
In the Norwegian emergency drift response services, a request is typically made by the duty officer to a meteorologist on watch at **met.no**, who, in turn, starts a forecast run of the relevant model; the drift forecast information is then sent back to the requesting officer in an agreed form. Since services for SAR, ship and oil drift have developed more or less independently over the years, the interface between **met.no** and the user has been somewhat different. However, the current development is moving away from manual operation and towards an automated production via similar web-page request forms for user input. The returned forecast information, on the other hand, is tailored to the needs of the particular emergency agency. Typically, the user will require some graphical products for quick assessment, but also forecast data to feed into their own crisis management tools, such as GIS. The Leeway user interface may serve as an example.

Figure 5 shows the Leeway request form that is filled out in a web browser by the duty officer at JRCC in the event of a SAR emergency or exercise. The request results in an automatic run of the Leeway model using the default operational atmosphere and ocean model forcing data (cf. Figure 4). Forecast data are returned as a compressed data file via email. The file is formatted so as to be readable by JRCC's SAR management tool. This tool has features tailored specifically to the JRCC's operations, such as overlaying on digital sea charts and calculating polygonal search areas. **met.no** maintains an in-house capability for graphical rendition of the forecast results; this serves both as a backup for the JRCC tool and as a development tool.

## 5. Outlook

Forecasting the drift of oil, ships and other floating objects have become standard ocean applications that address a clear demand from society. Modeling techniques have advanced considerably over the past 30 years, from rule-of-thumb models ("3% of wind speed and $15^o$ to the right") to complex numerical and empirical models. The models governing the fate of the drifting things - ship hydrodynamics, small object taxonomies and oil chemistry - are capable of giving increasingly detailed information on their specific behavior in the sea. There are still, however, significant deficiencies in these models; for example, object taxonomies need to be expanded to cover more object classes.

Improvements in drift forecast skill are currently being sought in the geophysical forecast data used to drive the drift models. Wind and wave forecasts are generally considered to be of good quality in the drift fore-



Leeway order form

If neccessary, contact meteorologist on duty at 55 23 66 00

Start position/time

| Latitude | Longitude | Radius | Date (YYYY-MM-DD HH) [UTC] |
|---|---|---|---|
| 58 ° 15.00 ' N | 6 ° 30.00 ' E | 00.00 km | 2002 06 06 11 |

End position/time

| Latitude | Longitude | Radius | Date (YYYY-MM-DD HH) [UTC] |
|---|---|---|---|
| 58 ° 15.00 ' N | 6 ° 30.00 ' E | 00.00 km | 2002 06 06 11 |

Object class

Choose object class
Definitions

Email results

○ HRS Nord-Norge
○ HRS Sør-Norge
● Other:
Password:

| START | NEW | COPY | RELOAD |
|---|---|---|---|
| Save parameters to file and let the computation begin. | Empty parameters and use today's date. | Copy start position to end position. | Ignore changes and reread parameters from file. |

Handbook and request form

Handbook for the DNMI maritime drift models

Manual request form

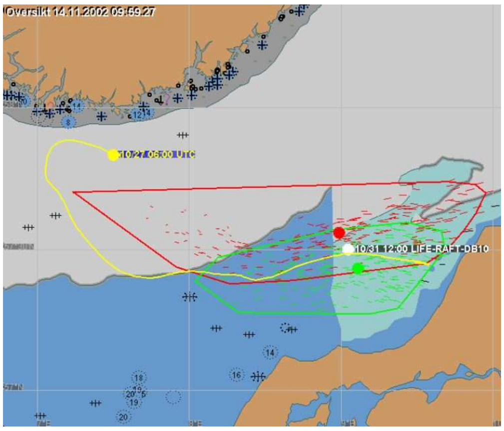


*Figure 5.* Example of a user interface to a SAR forecast service: **met.no** Leeway interfaced to Joint Rescue Coordination Centres of Norway (JRCC). Left: Snapshot of web browser request form. Sending the request starts a model forecast run. Results are returned JRCC by email. Right: Snapshot of drift forecast data presented in JRCC's management tool (SARA). Short line segments show particle paths over 1 hour: red = leeway to the left, green = leeway to the right (see text). Large red and green spots indicate centroid of corresponding particle clouds; white spot is centroid for all particles. Red and green polygons enclose corresponding particle clouds, indicating possible search areas. Yellow line is quick estimate of path of centroid for all particles. Data are overlaid on digital sea chart.

casting context, at least out to a day or two. The situation is less satisfactory for ocean currents and hydrography, which reflects the fact that ocean models exhibit variable forecast skill at the small scales that often are important in drift emergencies. However, the skill of ocean models is steadily increasing with improvements in computing capacity, observations and assimilation methods. An important aspect is the emerging capacity for global ocean forecasting, which is expected to give two benefits to drift forecasting services. One is an improvement in regional and local ocean forecasts via nesting of hydrodynamic models. The other is a capability for drift forecasting anywhere in the global ocean with improved skill. At the other end of the spatial scale, local operational ocean models are moving to higher resolution, giving increasingly improved definition of coastlines and topography, and consequently small scale dynamics. Since most SAR operations occur within 5 km of the coast, this is an important development.

Finally, the interaction of forecast providers with the people responsible for taking emergency action in the field needs to be maintained and enhanced. The task for drift forecast services is helping the response teams to use the forecasts and use them intelligently. This means making forecast products that are quickly understandable in a crisis situation; it also means attacking the difficult problem of estimating forecast accuracy. Education of response teams needs to be complemented by feedback from regular field exercises and post-crisis assessments.

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