Leeway model documentation v2.5

Leeway is a Monte Carlo-based stochastic ensemble trajectory model that calculates the motion of objects on the sea surface under the influence of wind (reference height 10m) and surface currents (ideally the average over 0.3-1.0m below sea surface). The output is an approximation of the time-evolving probability distribution (search area) in the form of an ensemble of particle positions. Drifting objects are divided into classes, e.g., a person in water (PIW), various classes of life rafts, small motor boats, etc. A list of the different SAR objects is available in Appendix 2. The model reads current and wind fields in GRIB format in regular latitude-longitude (plate-carree), rotated spherical and the polar-stereographic projection. The model is described in detail in Breivik and Allen (2008).

Stochastic approach to search and rescue

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 centre 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.

In searching for drifting objects on the sea surface, we are invariably faced with the challenge of reducing a number of unknowns. This is most easily expressed 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 over the past few years (see *e.g*. Press *et al,* 1992).

Determining a last known position

The first task in a search and rescue (SAR) operation is to determine the datum, or last known position (LKP). Once this is done, it is up to the Rescue Coordination Centre (RCC) to predict the drift of the object at large. A stochastic approach allows a precision to be 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, take 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 LKP's scattered over a large portion of the sea surface released over an extended period of time. Thus, the various members of the ensemble will endure very different fates due to changing tidal currents, passing weather systems, and geographicallyrestricted ocean currents (e.g., the Norwegian Coastal Current). It is intuitively obvious that the choice of initial distrbution of ensemble members will affect the future search area seriously. It is the task of the Rescue Coordinator to make these decisions.

Uncertainties in forcing fields and drift properties

In addition to the uncertainty assigned to the LKP in space and time, we also need to address the uncertainties present in the underlying data that are available. The force acting on the object on the sea surface is a sum of surface and body forces and must be estimated in order to make a forecast of its future position. The surface forces contributing to the object's motion include surface currents, winds (typically taken at 10 m above the sea surface), the wave motion, and wave induced currents (Stokes drift, see e.g. Kundu 1990). The body forces acting on its centre of mass are the gravitational force and the buoyancy force. The net force is exceedingly difficult to compute due to the irregular geometry of real-world objects. It should by now be obvious that there are a number of uncertainties that need to be addressed even if a last known position in space and time is given with high precision. Our ensemble of candidate drifting objects need to take these uncertainties into account. Hence, we need to perturb not only the initial position in space and time, but also the direction and magnitude of the forces acting upon the object.

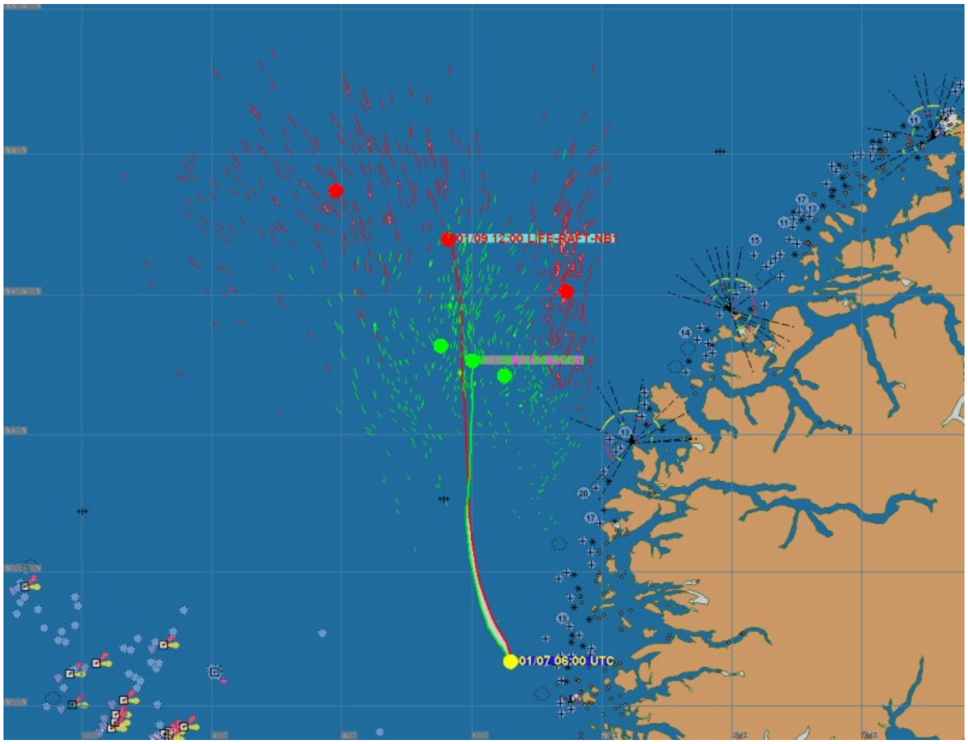
The leeway of a drifting object

The leeway of a drifting object is defined as its motion due to wind and waves relative to the ambient current between 0.3 and 1.0m below the sea surface. It is decomposed into downwind leeway and crosswind leeway (DWL and CWL). Field studies have been carried out to determine how different classes of objects respond to the wind (Allen, 2005). It turns out that objects have various magnitudes of DWL and CWL, which is to be expected as the objects studied have vastly different shapes and buoyancy characteristics. The crosswind and downwind components are given as linear regressions on the downwind speed. The standard deviations about the DWL and CWL coefficients have also been determined. These are "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.

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 often be two disjoint areas of high probability. The orientation (left and right of wind) is initially distributed equally. The perturbations in leeway properties (DWL and CWL) are supposed to cater for the properties unique to the object (e.g., is this a less than normally loaded life-raft?, does the raft sag?, etc). If the time-invariant perturbations were left out, the search area would be much smaller as adding zero-mean perturbations to otherwise identical forcing fields will eventually average out.

Shown below is an example of the different drift properties of two typical SAR objects; a person in water (PIW), moving mostly with the surface current and a life raft with no ballast system, moving at a considerable fraction of the wind in addition to the current. There is a small but significant probability that a drifting object will change its orientation relative to the wind. This is referred to as "jibing". An hourly probability of 4% is assumed by default in the model. This leads ensemble members to change their tack at irregular intervals. Jibing causes the search area to "fill in" the middle between the two high-probability regions associated with the two stable drift directions. 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. The yellow dot indicates the initial search area (particle release position) determined by the user. The red and green big dots indicate the average position of the left and right halves of the two ensembles right now as well as their total average. The lines represent the average trajectory of the two ensembles over time. The red and green "specks" show the instantaneous position and motion of the individual ensemble members (particles). The response of the life raft to the wind is almost twice that of the submerged person in water. However, present near the coast is a strong north-flowing current which affects both objects equally strongly. The strong current shear is hinted at by the way in which the particles closer to shore spread out in a long, thin band (apparent for the right-drifting life rafts). What is also obvious is that the life raft presented here displays a greater divergence from the wind direction than the PIW. This results in a greater separation between the two halves of the ensemble of life-rafts.



Defining initial search areas

In order to properly define an incident it is necessary to define both a geographical area and a period in which the accident may have happened. These "start" and "stop" parameters define the earliest and latest times that the accident may have occured. The ensemble members (particles) are then released in the area and throughout the period. A total of 500 particles is usually released, but this number is user-specified. The individual particles may be released in an entirely random manner, but a simplified seeder is included for the most common cases.

Simplified seeder

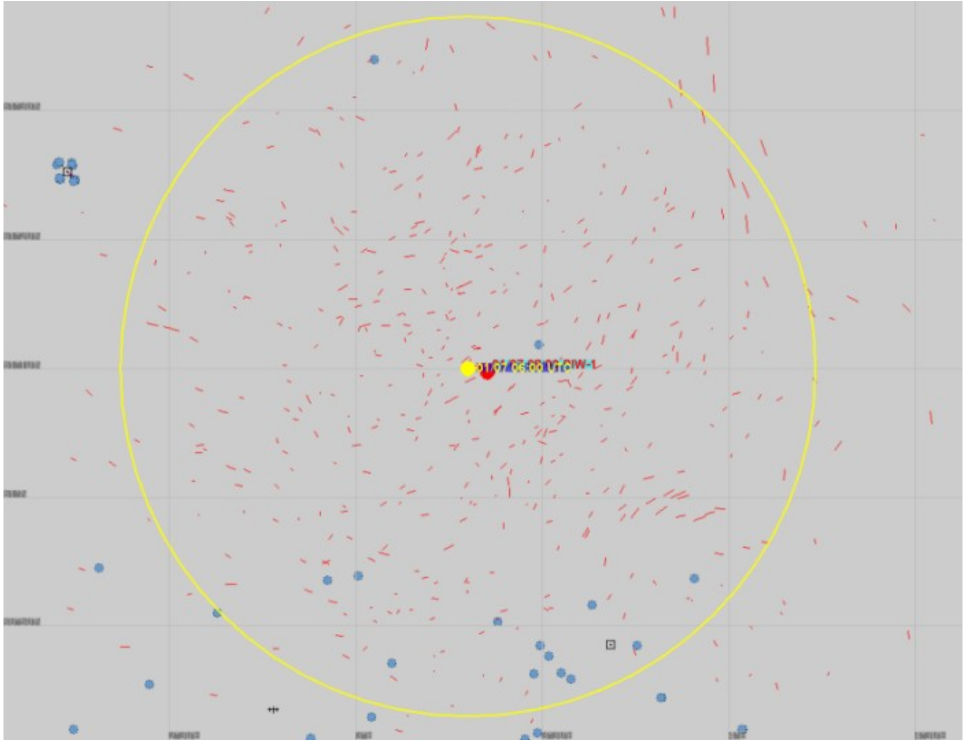
Using the simplified seeder, an input file is prepared in the following manner. All members are positioned using a 2D normal (Gaussian) distribution with a standard deviation equal to half the radius input by the user. Two radii of uncertainty allow the user to assign a certain precision to the guess. The radius of uncertainty is influenced several factors, among them the quality of the positional fix, *i.e.*, does the position stem from a GPS device or is it inferred in some other, less precise, way.

A total of eight degrees of freedom must be set in order to properly define the initial search area. These are defined by the user through the web request form:

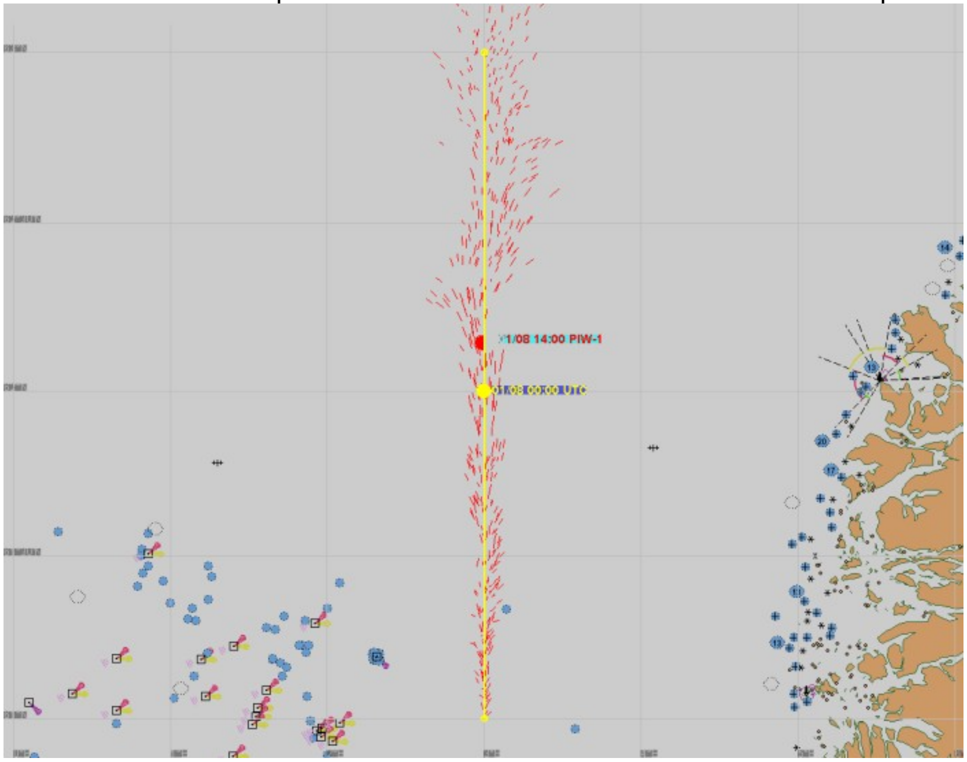
- Start position (latitude and longitude)
- Start time [UTC]
- Start radius of uncertainty [km]
- Stop position (latitude and longitude)
- Stop time
- Stop radius of uncertainty

Three examples illuminate the process of defining the initial search area.

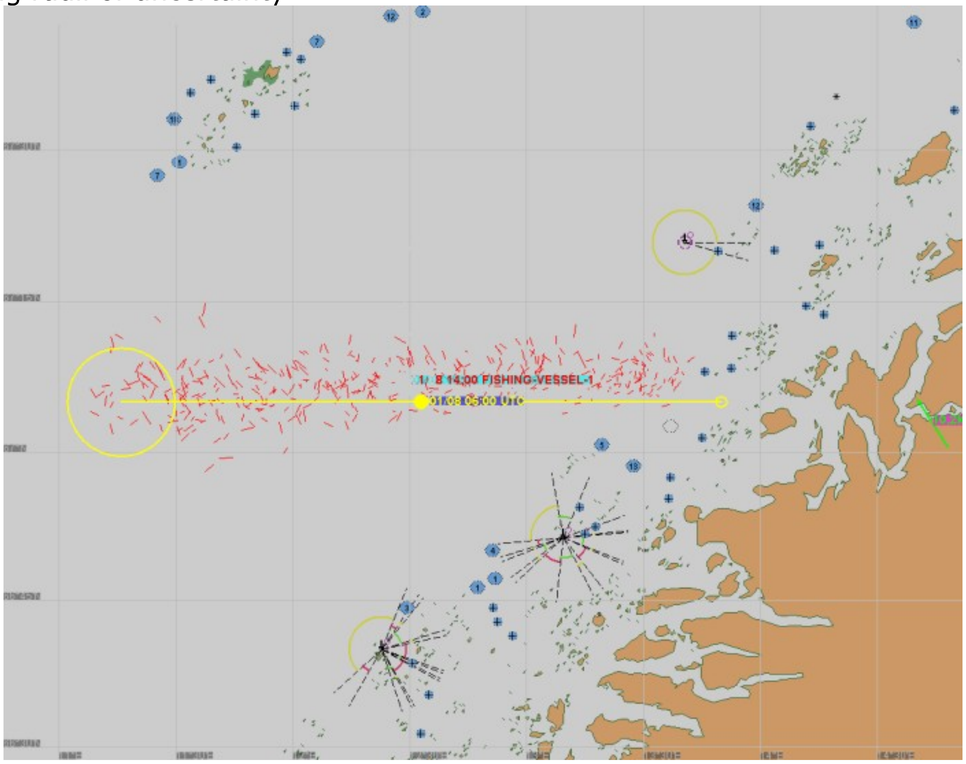
Last known position: This is the most common way to define an incident or accident at sea. A datum point consists of latitude, longitude and time. The SAR object is assumed to start drifting from there on. This is achieved in our formulation by setting both the start and stop positions and the start and stop times equal, thus releasing all particles instantaneously and in the same circular area. The start and stop radii are equal and define the dimensions of this circular area. The figure below illustrates the such a distribution soon after the particles were released.



Great circle line: A ship is steaming along when a man falls overboard. He was last seen around midnight and was reported missing 12 hours later. Let the ship's position at midnight represent the start position and start time, and the ship's position as 12:00 the following day the stop position and stop time. Let the radius of uncertainty be equal and small (say 0.5 nm) for start and stop as we are very certain of the ship track (due to GPS). The figure below shows the distribution of particles at time 12:00 when all particles have been released. Note that the particles in the northernmost part have drifted for 12 hours when this snapshot was taken.



Cone shaped initial area: A fishing boat is headed for the fishing banks. The boat leaves harbour at 06:00 and is supposed to arrive at the banks at 12:00, six hours later. The boat is supposed to report back when it arrives but fails to do so. Let the harbour at 06:00 represent the start position and start time. Let the start radius be small as we know exactly where the boat left harbour. Let the fishing banks at 12:00 represent the stop position and stop time as this is most likely the last place where the accident may have occurred. Let the radius of uncertainty be large enough to cover the entire bank as we don't know exactly where the captain was headed. The two yellow circles in the figure below indicate the start and stop positions and the corresponding radii of uncertainty.



Forcing fields

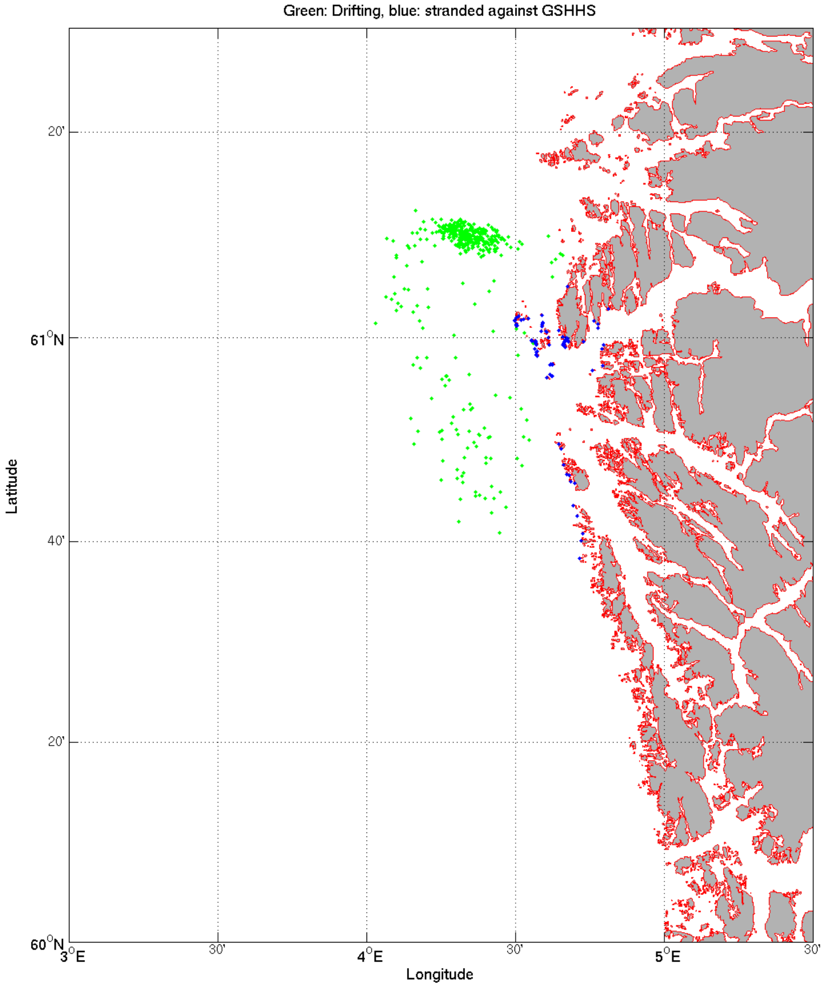
The Leeway ensemble of search objects (also referred to as particles) is forced by wind (10m level) and near-surface currents. The operating range of Leeway is constrained by the geographic extent of the ocean model. Particles are assumed to strand when they hit the shoreline of the ocean model grid (this option may be switched off, in which case the particles will continue to drift under the influence of wind alone onshore). The Leeway ensemble is forced by 10m wind vectors, a standard meteorological parameter. A Gaussian perturbation with user-specified standard deviation is added to each of the wind components to account for subgrid scale effects and errors in the modelled wind field. The wind perturbations are assumed uncorrelated in time. The particles are advected with the surface current from a numerical ocean model. For small objects (defined to be smaller than 50m length), the wave force is considered negligible and is left out. Furthermore, the Stokes drift is already included in the empirical leeway coefficients presented by Allen (2005) and is thus left out (see also Breivik and Allen, 2008). The object is assumed to move with the local surface current in the absence of wind and is also assumed to adjust its motion immediately when the current changes.

Projections

All wind and current fields must be in GRIB1 format. The grid can be regular latitude-longitude, rotated spherical or on a polar stereographic projection. Vectors must be decomposed along the local grid (*i.e.*, not in east and north components when dealing with rotated spherical or polar stereographic grids).

Stranding and coastline contours

Particles strand and stick when they hit the shoreline. Stranding is determined either by comparing with the current grid or by reading a file containing a coastline contour based on the Global Self-consistent Hierarchical High-resolution Shoreline database (GSHHS). The latter method is highly recommended (and the default) as it allows much more precise stranding of particles.



Appendix 1: Technical documentation and installation guide

Compilation

The model has been tested under various Linux enviroments (Redhat, Fedora, KDE). The software relies solely on standard open source packages that come bundled with all Linux installations. Requirements are Linux with gmake, gcc. Note that the model should also compile under Unix, including Darwin (the Macintosh version of Free BSD Unix). To test GRIB files, wgrib, a GRIB reader, is useful. It is available at www.cpc.ncep.noaa.gov/products/wesley/wgrib.html.

To install and compile the software:

```
% gunzip leeway_gshhs.tar.gz
% tar xvf leeway_gshhs.tar
% cd Leeway
% make all
```

Running seeder and model

The process of defining a simulation and starting the seeder and the model can be seen more clearly with the following tableau *(programs* in italics):

`<lwseed.in>` > *lwseed* > `<leeway.in>` > *leeway* > `<leeway.out>`

The following sample session in Linux executes the steps outlined above:

```
% cd Leeway/bin
# Choose an arbitrary identity tag for the simulation - e.g. TEST001 (referred to
below as <idtag>)
# Edit lwseed.in if necessary - include the <idtag> on line 13
# Make sure that the GRIB files are available in Leeway/bin/
% lwseed lwseed.in leeway.in

% leeway leeway.in leeway.out
```

Seeder input file

The initial locations of the ensemble members and their individual starting times are contained in the input file (`<leeway.in>`). This ASCII file may be edited or generated by the user, or it can be generated by the seeder (`lwseed`) that comes bundled with the Leeway model. The seeder takes a simpler ASCII file as input, `<lwseed.in>`, which generates an ensemble in time and space with the following degrees of freedom:

1. Start lon (lon0)
2. Start lat (lat0)
3. End lon (lon1)
4. End lat (lat1)
5. Start radius (r0)
6. End radius (r1)
7. Start date (t0)
8. End date (t1)
9. Object class id

The particles are spread out in a cone-shaped region starting at position (lon0,lat0) with radius *r0* and ending in position (lon1,lat1) with radius *r1*. The exact positions of the particles are determined by a selecting from a circular normal distribution with a given standard deviation from a center position along a great circle arc connecting the start and end positions. The radius of uncertainty equals two standard deviations (2*s*) in the circular normal distribution, *i.e.*, 86% of the particles will on average fall within the radius. Because we want the particle cloud to assume a cone shape, we let the radius vary linearly from *r*0 to *r1* (see the description above).

The seeder input file looks like this:

```
Leeway seeder - do not remove this line
2.5     # Leeway version - do not remove this line
004     # startLon  [deg]               (int)
30.00   # startLon  [decimal minutes] (float)
60      # startLat  [deg]               (int)
30.00   # startLat  [decimal minutes] (float)
004     # endLon    [deg]               (int)
30.00   # endLon    [decimal minutes] (float)
60      # endLat    [deg]               (int)
30.00   # endLat    [decimal minutes] (float)
0.0     # startRad  [km]                (float)
0.0     # endRad    [km]                (float)
GSHHS   # Optional object description - do not remove this line
01      # objectClassId                 (int)
2008    # startDate [year]              (int)
04      # startDate [month]             (int)
01      # startDate [day]               (int)
06 15   # startDate [hh mm]             (int)
2008    # endDate   [year]              (int)
04      # endDate   [month]             (int)
01      # endDate   [day]               (int)
07 20   # endDate   [hh mm]             (int)
0 0.0 0.0 # Constant current, east and north components [m/s] (true=1, false=0)
0 0.0 0.0 # Constant wind, east and north components [m/s] (true=1, false=0)
0         # Particles do not strand (true=1, false=0)
3600      # Output timestep, must be multiple of model timestep [seconds]
```

Comments may be added after "#". Note that line 1 is not in use but must always be present.

Leeway input file

The model input file <leeway.in> generated by lwseed (see above section) could just as well be generated by a more sophisticated seeder. It is also possible to edit the input file, *e.g.* to enter user-specified leeway coefficients, specify other forcing fields, or to employ a more sophisticated time-space distribution of the ensemble members (see Appendix 2).

The model input file looks like this:

```
# Drift simulation initiated [UTC], output interval [s] & identifier:
simDate simTime outputInterval  ID
2008-07-02      12:43:13           3600 GSHHS
# Model version, no strand option (false=0), coastline:
modelVersion    noStrand        coastFile
```

```
 2.50   0       coastline.bs
# Object class id & name:
objectClassId   objectClassName
   1                             PIW-1
# Seeding start time, position & radius:
startDate       startTime       startLon        startLat        startRad
2008-04-01      06:15:00           4.5000        60.5000            0.000
# Seeding end time, position & radius:
endDate endTime endLon  endLat  endRad
2008-04-01      07:20:00           4.5000        60.5000            0.000
# Total no of seeded particles:
seedTotal
 500
# Right leeway coeffs; slope [%], offset [cm/s], std dev [cm/s]:
aRight  bRight  sdRight
    0.54    0.00    9.40
# Left leeway coeffs; slope [%], offset [cm/s], std dev [cm/s]:
aLeft   bLeft   sdLeft
   -0.54    0.00    9.40
# Downwind leeway coeffs; slope [%], offset [cm/s], std dev [cm/s]:
aDownwind       bDownwind       sdDownwind
    0.96    0.00   12.00
# Hourly probability of jibing [%]:
pJibe
 4.00
# Wind stats; east & north std dev [m/s]; east & north integral time scale [h]:
sdEastwind      sdNorthwind     tsEastwind      tsNorthwind
    2.60    2.60    0.00    0.00
# Current stats; east & north std dev [m/s]; east & north integral time scale [h]:
sdEastcurrent   sdNorthcurrent  tsEastcurrent   tsNorthcurrent
    0.00    0.00    0.00    0.00
# Wind file [Lat-lon GRIB]:
windFile
wind.grb
# Current file [Lat-lon GRIB]:
currentFile
current.grb
# Particle data:
id      lon     lat     orientation     rdw     rcw     birth
    1       4.5000        60.5000         1           2.210           0.556             0
    2       4.5000        60.5000         0           1.205           0.010             7
    3       4.5000        60.5000         1          -0.646           0.342            15
    4       4.5000        60.5000         0          -1.100          -0.027            23
    5       4.5000        60.5000         1          -0.499          -0.713            31
    6       4.5000        60.5000         0           0.329           0.432            39
...
```

Leeway output file

The model output file is a self-explanatory ASCII file. The header contains variables separated by tabs (\t). Each model output time starts with a sub-header with information about the number of particles seeded now and the total number seeded so far. The individual particles follow. Note that "state" indicates whether a particle is still drifting (state=11) or stranded (state=41).

The output file looks like this:

```
# Drift simulation initiated [UTC]:
simDate simTime
2008-07-02      12:43:13        GSHHS
# Model version:
modelVersion
  2.50
# Object class id & name:
objectClassId   objectClassName
   1     PIW-1
# Seeding start time, position & radius:
startDate       startTime       startLon        startLat        startRad
2008-04-01      06:15:00           4.5000        60.5000            0.000
# Seeding end time, position & radius:
endDate endTime endLon  endLat  endRad
2008-04-01      07:20:00           4.5000        60.5000            0.000
# Duration of seeding [min] & [timesteps]:
seedDuration    seedSteps
      65      1
# Length of timestep [min]:
timeStep
   60
# Length of model simulation [min] & [timesteps]:
simLength       simSteps
   3180     54
# Total no of seeded particles:
seedTotal
  500
# Particles seeded per timestep:
seedRate
  500
# Date [UTC]:
nowDate nowTime
2008-04-01      06:15:00
# Time passed [min] & [timesteps], now seeded, seeded so far:
timePassed      nStep   nowSeeded       nSeeded
       0      1    116     116
# Mean position:
meanLon meanLat
    4.5000        60.5000
# Particle data:
id      lon     lat     state   age     orientation
    1       4.5000        60.5000         11          0   1
    2       4.5000        60.5000         11          0   0
    3       4.5000        60.5000         11          0   1
    4       4.5000        60.5000         11          0   0
    5       4.5000        60.5000         11          0   1
    6       4.5000        60.5000         11          0   0
...
```

Forcing fields in GRIB format

The wind and current forcing fields must appear in separate files. The temporal and spatial resolution is arbitrary as the model interpolates fields in time and space. The model halts upon reaching end of file of either the wind or the current fields. It is expected that the GRIB files are arranged chronologically, with alternating east and north components (east first). The files must not contain additonal fields. The spatial resolution for lat-lon grids is computed from the bounding box of the grid rather than from the dlon and dlat defined in the GRIB file because these are measured in millidegrees and are thus insufficiently precise for grids finer than approximately 4km.

Below is given a typical listing of the contents of the current and wind GRIB files, respectively, using wgrib:

```
% wgrib -v current.grb
1:0:D=2003112920:UOGRD:0 m below sea level:kpds=49,160,0:anl:winds are N/S:"u of current [m/s]
2:1331400:D=2003112920:VOGRD:0 m below sea level:kpds=50,160,0:anl:winds are N/S:"v of current [m/s]
3:2662800:D=2003112922:UOGRD:0 m below sea level:kpds=49,160,0:anl:winds are N/S:"u of current [m/s]
4:3994200:D=2003112922:VOGRD:0 m below sea level:kpds=50,160,0:anl:winds are N/S:"v of current [m/s]
5:5325600:D=2003113000:UOGRD:0 m below sea level:kpds=49,160,0:anl:winds are N/S:"u of current [m/s]
6:6657000:D=2003113000:VOGRD:0 m below sea level:kpds=50,160,0:anl:winds are N/S:"v of current [m/s]

        ...

% wgrib -v wind.grb
1:0:D=2003113018:UGRD:10 m above gnd:kpds=33,105,10:anl:winds are N/S:"u wind [m/s]
2:120720:D=2003113018:VGRD:10 m above gnd:kpds=34,105,10:anl:winds are N/S:"v wind [m/s]
3:241440:D=2003113018:UGRD:10 m above gnd:kpds=33,105,10:3hr fcst:winds are N/S:"u wind [m/s]
4:362160:D=2003113018:VGRD:10 m above gnd:kpds=34,105,10:3hr fcst:winds are N/S:"v wind [m/s]
5:482880:D=2003120100:UGRD:10 m above gnd:kpds=33,105,10:anl:winds are N/S:"u wind [m/s]
6:603600:D=2003120100:VGRD:10 m above gnd:kpds=34,105,10:anl:winds are N/S:"v wind [m/s]

        ...
```

Matlab presentation

The following Matlab sample session reads the output file into a struct and displays the ensemble members and the mean trajectory:

```
% cd Leeway/bin
% matlab &
>> lw=read_leeway('leeway.out');      % Read Leeway output file into struct lw.
>> left=lw.orientation(5,:)==1;               % Find all left-drifting particles
at timestep 5
>> pcolor(xx,yy,bs1852);                      % Plot bottom topography for
reference
>> shading flat; caxis([0 400]); colorbar     % Fix plot
>> set(gca,'dataaspectratio',[1 0.5 1]);      % Fix aspect ratio
>> xlabel 'Longitude [deg]'
>> ylabel 'Latitude [deg]'
>> hold on
>> plot(lw.lon(5,left),lw.lat(5,left),'r.')   % Plot all left-drifting particles
at timestep 5 in red
>> plot(lw.lon(5,~left),lw.lat(5,~left),'g.') % Plot all right-drifting particles
at timestep 5 in green
>> plot(lw.meanlon(:),lw.meanlat(:),'k')      % Plot mean trajectory
>> k=convhull(lw.lon(5,:),lw.lat(5,:));       % Find the convex hull polygon that
encloses all particles
>> plot(lw.lon(5,k),lw.lat(5,k),'r');         % Plot convex hull
```

Files

- lwseed/Src/lwseed.c - A seeder that generates an ensemble of start positions for Leeway
- leeway/Src/leeway.c - The Leeway model
- bin/read_leeway.m - The Matlab reader
- bin/OBJECTPROP.DAT - the leeway coefficient table for all object categories, the file is self-explanatory
- bin/lwseed.in - a sample seeder input file
- bin/leeway.in - the Leeway model input file - editable
- bin/current.grb - GRIB current file
- bin/wind.grb - GRIB wind file

Appendix 2: Object taxonomy with leeway coefficients

1.
   ```
   PIW-1                      1
   Person-in-water (PIW), unknown state (mean values)
          0.96     0.00     12.00      0.54      0.00      9.40     -0.54      0.00      9.40
   ```

2.
   ```
   PIW-2                      2
   >PIW, vertical
            0.48     0.00      8.30      0.15      0.00      6.70     -0.15      0.00      6.70
   ```

3.
   ```
   PIW-3                      3
   >PIW, sitting
            1.60    -3.98      2.42      0.13      0.33      2.11     -0.13     -0.33      2.11
   ```

4.
   ```
   PIW-4                      4
   >PIW, horisontal, survival suit
            1.71     1.12      3.93      1.36     -3.30      1.71     -0.13     -2.65      1.62
   ```

5.
   ```
   PIW-5                      5
   >PIW, horisontal, scuba suit
            0.63     0.00      5.30      0.31      0.00      4.50     -0.31      0.00      4.50
   ```

6.
   ```
   PIW-6                      6
   >PIW, horisontal, deceased
            1.30     0.00      8.30      0.74      0.00      6.70     -0.74      0.00      6.70
   ```

7.
   ```
   LIFE-RAFT-NB1              7
   ```

```
    Life-raft, no ballast (NB) system, general (mean values)

            3.70     0.00     12.00     1.98       0.00      9.40     -1.98      0.00      9.40


8.  LIFE-RAFT-NB2              8

    >Life-raft, no ballast system, no canopy, no drogue

            5.34     9.91      9.82     2.26       1.04      9.08     -2.26     -1.04      9.08


9.  LIFE-RAFT-NB3              9

    >Life-raft, no ballast system, no canopy, with drogue

            3.15    -4.47      4.00     1.51       0.00      5.00     -1.51      0.00      5.00


10.  LIFE-RAFT-NB4             10

    >Life-raft, no ballast system, with canopy, no drogue

            3.39     0.00      2.40     1.49       0.00      2.40     -1.49      0.00      2.40


11.  LIFE-RAFT-NB5             11

    >Life-raft, no ballast system, with canopy, with drogue

            2.65     0.00     12.00     1.42       0.00      9.40     -1.42      0.00      9.40


12.  LIFE-RAFT-SB6             12

    Life-raft, shallow ballast (SB) system AND canopy, general (mean values)

            2.68     0.00     12.00     1.10       0.00      9.40     -1.10      0.00      9.40


13.  LIFE-RAFT-SB7             13

    >Life-raft, shallow ballast system AND canopy, no drogue

            2.96     0.00      1.50     1.21       0.00      1.70     -1.21      0.00      1.70


14.  LIFE-RAFT-SB8             14

    >Life-raft, shallow ballast system AND canopy, with drogue

            2.31     0.00      4.00     0.95       0.00      3.50     -0.95      0.00      3.50


15.  LIFE-RAFT-SB9             15

    >Life-raft, shallow ballast system AND canopy, capsized

            1.68     0.00      2.40     0.24       0.00      2.40     -0.24      0.00      2.40


16.  LIFE-RAFT-DB10            16

    Life raft, deep ballast (DB) system, general, unknown capacity and loading (mean values)

            3.52    -2.50      6.10     0.62      -3.00      3.50     -0.45     -0.20      3.60


17.  LIFE-RAFT-DB11            17

    >4-6 person capacity, deep ballast system, general (mean values)

            3.50    -1.80      6.40     0.78      -3.60      3.60     -0.47     -0.10      3.90


18.  LIFE-RAFT-DB12            18

    >>4-6 person capacity, deep ballast system, no drogue

            3.75    -2.30      4.40     0.78      -3.60      3.60     -0.47     -0.10      3.90


19.  LIFE-RAFT-DB13            19
```

```
>>>4-6 person capacity, deep ballast system, no drogue, light loading

        3.75    -2.32      4.51      1.00     -5.31      3.91     -0.47     -0.14      3.91
```

20. LIFE-RAFT-DB14 20

```
>>>4-6 person capacity, deep ballast system, no drogue, heavy loading

        3.59    -1.92      2.56      0.48     -0.16      2.17     -0.48      0.16      2.17
```

21. LIFE-RAFT-DB15 21

```
>>4-6 person capacity, deep ballast system, with drogue

        1.91     0.90      1.60      0.78     -3.60      3.60     -0.47     -0.10      3.90
```

22. LIFE-RAFT-DB16 22

```
>>>4-6 person capacity, deep ballast system, with drogue, light loading

        1.95    -0.53      3.59      0.21      1.29      2.15     -0.21     -1.29      2.15
```

23. LIFE-RAFT-DB17 23

```
>>>4-6 person capacity, deep ballast system, with drogue, heavy loading

        2.19    -0.96      1.01      1.39     -7.90      1.46     -1.39      7.90      1.46
```

24. LIFE-RAFT-DB18 24

```
>15-25 person capacity, deep ballast system, general (mean values)

        3.68    -4.96      5.37      0.34     -1.85      2.50     -0.49      1.58      2.63
```

25. LIFE-RAFT-DB19 25

```
>>15-25 person capacity, deep ballast system, no drogue, light loading

        3.93    -3.30      3.01      0.38     -3.33      2.16     -0.59      1.59      2.28
```

26. LIFE-RAFT-DB20 26

```
>>15-25 person capacity, deep ballast system, with drogue, heavy loading

        3.15    -4.49      3.35      0.39     -1.80      2.50     -0.38      2.98      1.64
```

27. LIFE-RAFT-DB21 27

```
deep ballast system, general (mean values), capsized

        0.88     0.00      2.50      0.18      0.00      2.40     -0.18      0.00      2.40
```

28. LIFE-RAFT-DB22 28

```
deep ballast system, general (mean values), swamped

        0.99     0.00      2.40      0.14      0.00      2.30     -0.14      0.00      2.30
```

29. LIFE-CAPSULE 29

```
Life capsule

        3.52     0.00      1.90      1.44      0.00      2.00     -1.44      0.00      2.00
```

30. USCG-RESCUE 30

```
USCG Sea Rescue Kit

        2.48     0.00      3.80      0.32      0.00      3.40     -0.32      0.00      3.40
```

31. AVIATION-1 31

```
    Life-raft, 4-6 person capacity, no ballast, with canopy, no drogue

            3.39     0.00      2.40      1.49      0.00      2.40     -1.49      0.00      2.40


32. AVIATION-2                32

    Evacuation slide with life-raft, 46 person capacity

            2.71     0.00      3.80      0.72      0.00      3.40     -0.72      0.00      3.40


33. SEA-KAYAK                 33

    Sea Kayak with person on aft deck

            1.16    11.12      4.12      0.41      0.00      4.39     -0.41      0.00      4.39


34. SURFBOARD                 34

    Surf board with person

            1.93     0.00      8.30      0.51      0.00      6.70     -0.51      0.00      6.70


35. WINDSURFER                35

    Windsurfer with mast and sail in water

            2.25     5.03      2.50      0.69     -1.30      2.96     -0.69      1.30      2.96


36. SAILBOAT-1                36

    Mono-hull, full keel, deep draft

            2.00     0.00      8.30      2.23      0.00      6.70     -2.23      0.00      6.70


37. SAILBOAT-2                37

    Mono-hull, fin keel, shoal draft

            2.67     0.00      8.30      2.98      0.00      6.70     -2.98      0.00      6.70


38. SKIFF-1                   38

    Skiff, flat bottom

            3.15     0.00      2.20      1.29      0.00      2.20     -1.29      0.00      2.20


39. SKIFF-2                   39

    Skiff, V-hull

            2.87     3.98      3.33      0.32     -2.93      2.53     -0.62      1.03      3.05


40. SKIFF-3                   40

    Skiff, V-hull, swamped

            1.65     0.00      3.10      0.39      0.00      2.90     -0.39      0.00      2.90


41. SPORT-BOAT                41

    Sport boat, no canvas (*1), modified V-hull

            6.54     0.00      3.00      2.19      0.00      2.80     -2.19      0.00      2.80


42. SPORT-FISHER              42

    Sport fisher, center console (*2), open cockpit

            5.55     0.00      3.30      2.27      0.00      3.00     -2.27      0.00      3.00


43. FISHING-VESSEL-1          43
```

Fishing vessel, general (mean values)

2.47 0.00 12.00 2.76 0.00 9.40 -2.76 0.00 9.40

44. FISHING-VESSEL-2 44

Fishing vessel, Hawaiian Sampan (*3)

2.67 0.00 8.30 2.98 0.00 6.70 -2.98 0.00 6.70

45. FISHING-VESSEL-3 45

>Fishing vessel, Japanese side-stern trawler

2.80 0.00 8.30 3.13 0.00 6.70 -3.13 0.00 6.70

46. FISHING-VESSEL-4 46

>Fishing vessel, Japanese Longliner (*3)

2.47 0.00 8.30 2.76 0.00 6.70 -2.76 0.00 6.70

47. FISHING-VESSEL-5 47

>Fishing vessel, Korean fishing vessel (*4)

1.80 0.00 3.79 2.01 0.00 3.30 -2.01 0.00 3.30

48. FISHING-VESSEL-6 48

>Fishing vessel, Gill-netter with rear reel (*3)

3.72 -0.87 3.33 1.41 2.00 3.36 -1.41 -2.00 3.36

49. COASTAL-FREIGHTER 49

Coastal freighter. (*5)

1.87 0.00 8.30 2.09 0.00 6.70 -2.09 0.00 6.70

50. FV-DEBRIS 50

Fishing vessel debris

1.97 0.00 8.30 0.36 0.00 6.70 -0.36 0.00 6.70

51. BAIT-BOX-1 51

Bait/wharf box, holds a cubic metre of ice, mean values (*6)

0.72 15.18 5.59 1.86 -5.26 4.20 -1.86 5.26 4.20

52. BAIT-BOX-2 52

Bait/wharf box, holds a cubic metre of ice, lightly loaded

2.53 9.01 3.05 1.09 -2.76 4.14 -1.09 2.76 4.14

53. BAIT-BOX-3 53

>Bait/wharf box, holds a cubic metre of ice, full loaded

1.15 7.94 3.17 1.48 -0.32 2.99 -1.48 0.32 2.99

54. REFUGEE-RAFT-1 54

Immigration vessel, Cuban refugee-raft, no sail (*7)

1.56 8.30 1.53 0.078 2.70 1.52 -0.078 -2.70 1.52

55. REFUGEE-RAFT-2 55

```
     Immigration vessel, Cuban refugee-raft, with sail (*7)

              6.43    -3.47      3.63      2.22      0.00      7.12     -2.22      0.00      7.12


56.  SEWAGE                     56

     Sewage floatables, tampon applicator

              1.79     0.00      3.10      0.16      0.00      2.90     -0.16      0.00      2.90


57.  MED-WASTE-1                57

     Medical waste (mean values)

              2.75     0.00     12.00      0.50      0.00      9.40     -0.50      0.00      9.40


58.  MED-WASTE-2                58

     >Medical waste, vials

              3.64     0.00     12.00      0.67      0.00      9.40     -0.67      0.00      9.40


59.  MED-WASTE-3                59

     >>Medical waste, vials, large

              4.34     0.00      3.10      0.74      0.00      2.90     -0.74      0.00      2.90


60.  MED-WASTE-4                60

     >>Medical waste, vials, small

              2.95     0.00      5.40      0.54      0.00      4.50     -0.54      0.00      4.50


61.  MED-WASTE-5                61

     >Medical waste, syringes

              1.79     0.00     12.00      0.16      0.00      9.40     -0.16      0.00      9.40


62.  MED-WASTE-6                62

     >>Medical waste, syringes, large

              1.79     0.00      3.10      0.16      0.00      2.90     -0.16      0.00      2.90


63.  MED-WASTE-7                63

     >>Medical waste, syringes, small

              1.79     0.00      2.40      0.16      0.00      2.30     -0.16      0.00      2.30

___________________________________________________________________________
The nine columns describing the drift properties of an object are as follows:

           Column 1         2          3          4          5          6          7          8          9

           downwind downwind  downwind      right      right      right       left       left       left

               slope   offset   std dev      slope     offset   std dev      slope     offset   std dev

                  [%]   [cm/s]     [cm/s]        [%]     [cm/s]     [cm/s]        [%]     [cm/s]     [cm/s]
___________________________________________________________________________
```

The object classes are marked with indentation (>, >> and >>>) to indicate classes and sub-classes. No indentation indicates a major class with general (mean) values. Use major classes (mean values) unless specific information about the SAR object is available.

Footnotes:
*1 Cuddy Cabin, p B5.5-1 (Allen and Plourde, 1999)

*2 p B5.6-1
*3 p B5.8-1
*4 p 2-16
*5 p B5.9-1
*6 p 2-17
*7 p 2-16

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- Allen, A A, 2005: *Leeway divergence*, Technical Report CG-D-05-05, US Coast Guard Research and Development Center, 1082 Shennecossett Road, Groton, CT, USA
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- Press, W H, S A Teukolsky, W T Vetterling, and B P Flannery, 1992: *Numerical Recipes in FORTRAN, 2nd edition*, Cambridge University Press, 970 pp
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