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Forecasting the Drift of Things in the Ocean

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Outline

- The task
- Drift models for
  - Oil
  - Ships
  - Search and Rescue (smaller drifting objects)
- Operational services
  - Geophysical forcing data
  - User interfacing
  - Examples
  - Model evaluation (validation)
- Concluding remarks

The task

Accidents happen at sea – people fall overboard, ships lose power, oil is spilled, etc.

These are examples of *things drifting in the sea* with potentially serious consequences – loss of life, maritime safety, environmental damage.

Most nations have services for emergency situations:

- Search-and-rescue (S&R) services are ubiquitous (Coast Guards)
- Oil spill combatment services in some countries
- Drifting ships and other large objects tied to S&R services and Vessel Traffic Services (VTS)

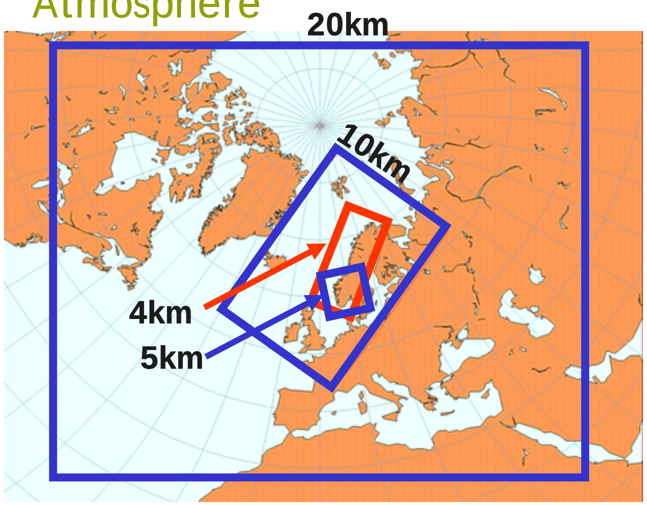
Operational services

- Emergency response services depend on quick and reliable access to drift prognoses
  - response time <30 min
  - 24/7 availability (people & computers)
- Critical component for drift forecasting is access to **real-time prognostic forcing data.**
  - **hence the close link to operational ocean-atmosphere forecasting centers**

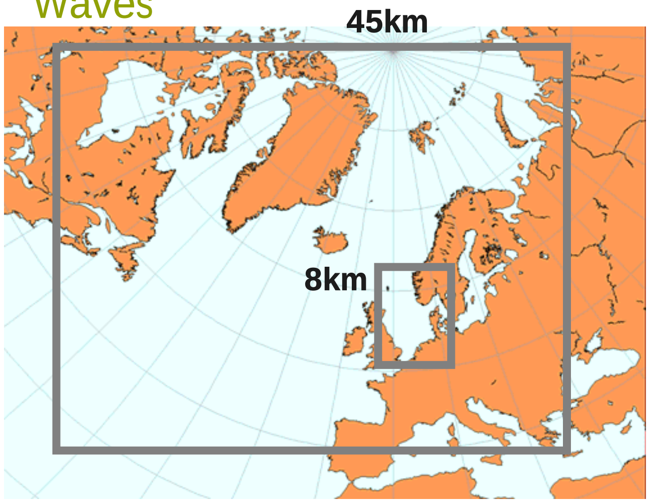
The met.no operational forecast model suite

- Atmospheric models run 4x daily to +48h and +60 h
- Wave models run 4x daily to +60 h
- Ocean models run daily to +60 h
- 7 day archive of selected variables

Atmosphere

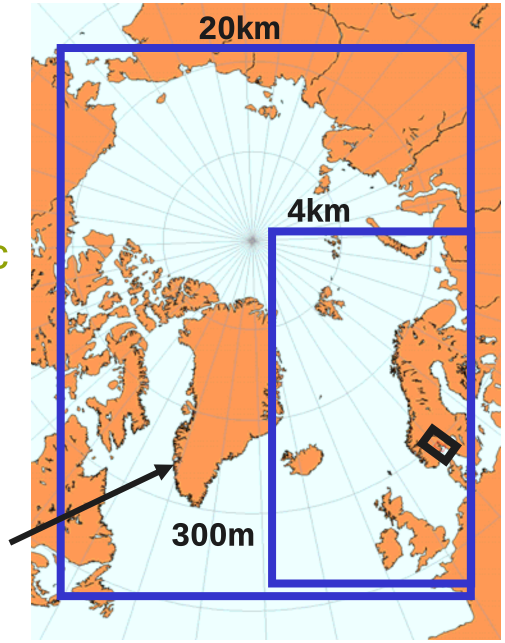


Waves



Ocean

- tides
- atmospheric forcing
- ice
- river runoff



Surface drifting objects

- Forces acting on a drifting object:
  - *Surface current*
  - *Wind*
  - *Waves (excitation and damping)*

- Wind and wave effects are calculated relative to the current:

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

- Wave forces only significant for objects ~50 m or more

Oil drift

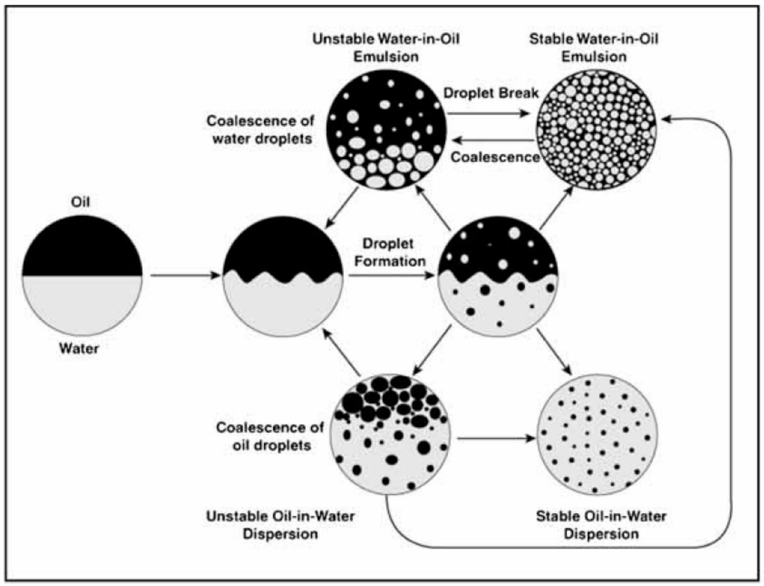
- Oil spill fate models tend to be complicated due to complex chemical interactions with the environment – *weathering*.

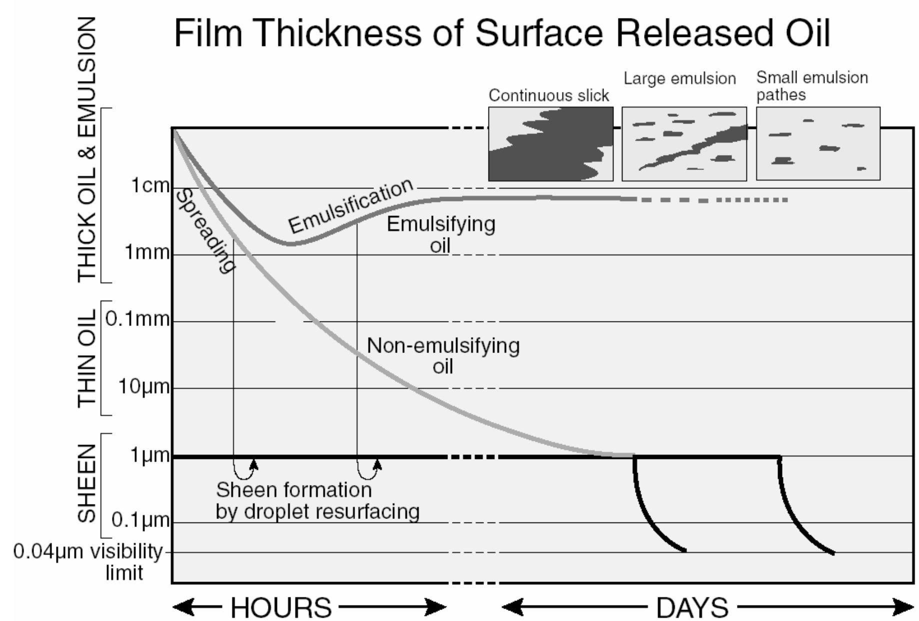
Chocolate mousse à la Prestige – an emulsion

Oil spill processes - weathering

- *Evaporation* removes volatile components
  - For some oil types (crudes) mass loss can be considerable, for other types insignificant
  - Density increases
- *Emulsification* forms water-in-oil mixture
- *Natural dispersion* forms oil-in-water mixture
  - Removes oil from the slick (under threshold concentration)

Emulsification *vs* natural dispersion
Oil spill fate

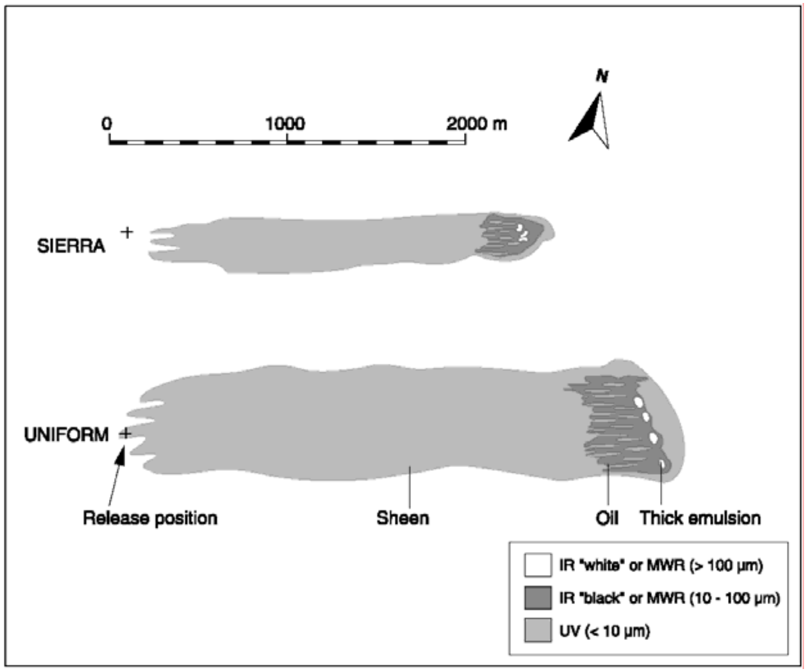




Daling et al. 2003

Oil spill processes
- spreading and advection

- *Spreading* refers to the motion of the oil fluid as it is spilled onto the more dense seawater.
- *Advection* is governed by geophysical forces (currents, wind).
- Spreading is important in the initial phase of the spill, but after some hours *weathering* tends to inhibit the fluid behavior and advective processes take over.



- Effects of weathering on a spreading / advecting spill

Algorithms for oil spill processes

- Oil spill processes are generally modeled by a blend of chemical principles and experimental data.
- Laboratory and field experiments have focused on the individual processes, but there is growing awareness of the complex interplay between all processes.
- Complexity is also due to the wide range of properties in different oil types.

Oil spill modelling

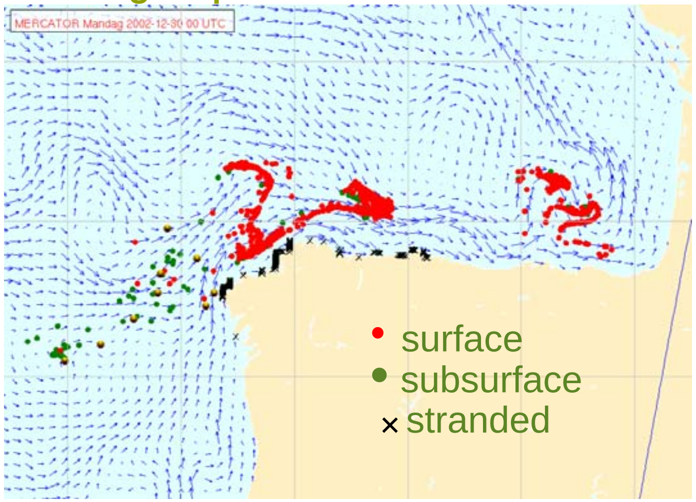
- Common types of model:
  - Simple trajectory models (center of mass)
  - Particle cloud models – *currently most popular (our approach)*
  - Polygon slick models – *under development*

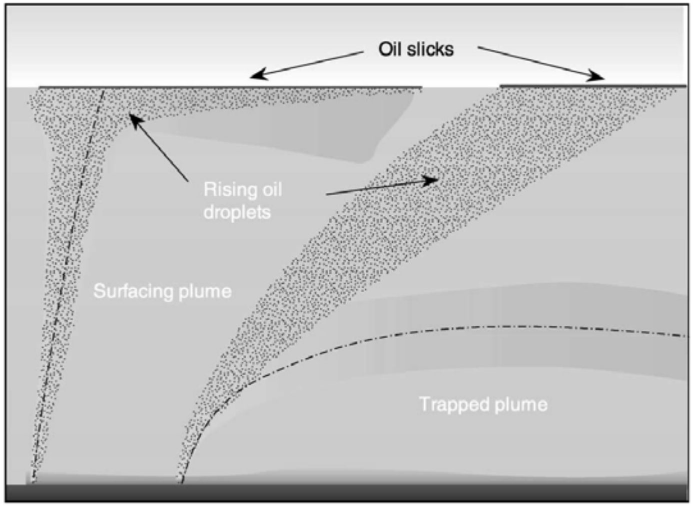
- Example:
  Particle type model at **met.no**, developed with SINTEF Applied Chemistry

Oil spill modelling – OD3D

- Particles seeded continuously according to specified flow rate and duration.
- Fixed mass per particle – mass loss effected by removing particles
- Transport and weathering processes applied on particle-by-particle basis.
- Special seeding module for deep source (bottom blowout)

Prestige spill simulation

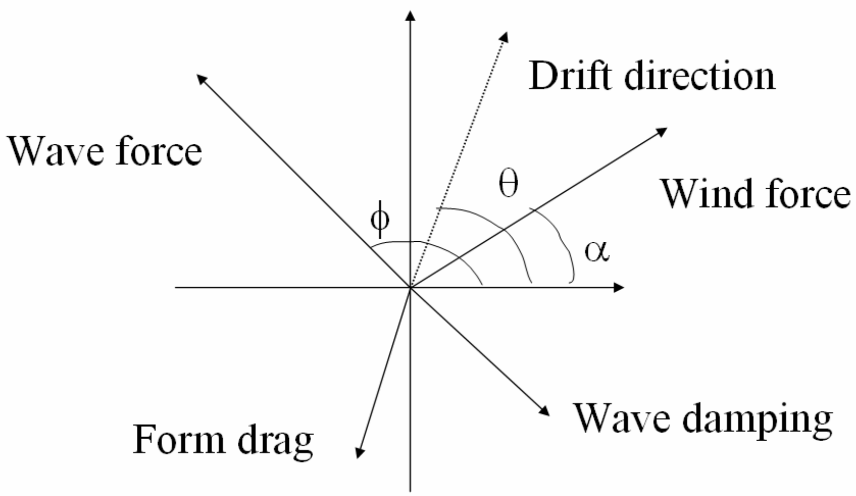




Ship drift

Wave forces significant for objects ~50 m or more, hence wind and wave forces must balance,

$$F_{wind} + F_{wave} + f_{form} + f_{wave} = 0$$



Ship drift

F_{wind} and f_{form} are commonly formulated as

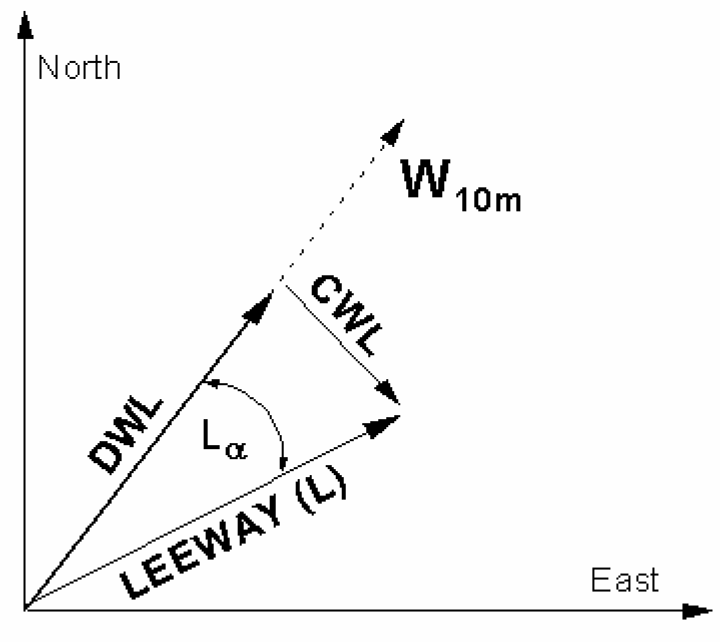
$$F_{wind} = \tfrac{1}{2}\, \rho_a\, (A_h + A_s)\, C_d\, |\mathbf{W}_{10}|\, \mathbf{W}_{10}$$

$$F_{form} = \tfrac{1}{2}\, \rho_w\, A_w\, C_d\, |\mathbf{V}_{rel}|\, \mathbf{V}_{rel}$$

- Box shapes are a fair approximation to a tanker hull, “box-ship” simulations tuned to full scale experimental data yield a lookup table.
- 2D wave spectra from a wave model are used to estimate the wave excitation and damping

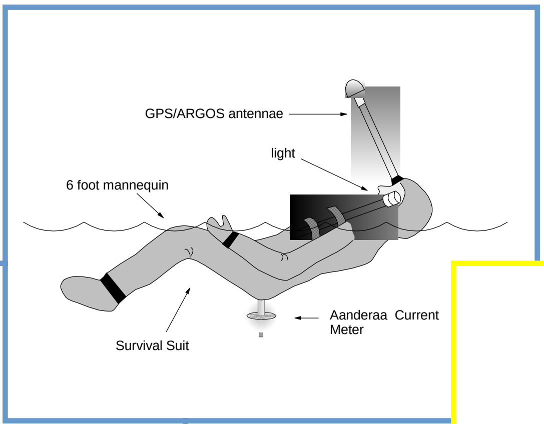
Leeway

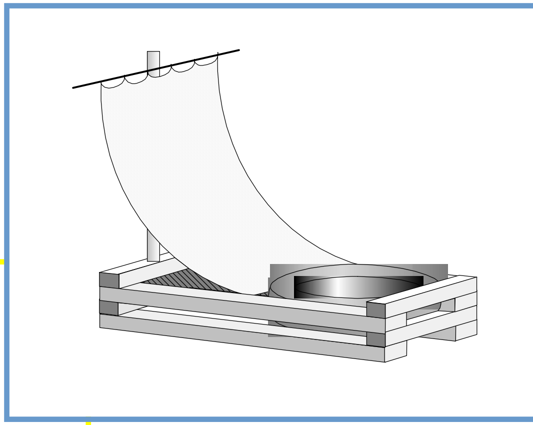
- Objects drift at an angle to the wind (divergence angle), and at a fraction of the wind speed
- The divergence angle depends on the object – shape, draft, freeboard, etc
- Difficult to model, relatively simple to parameterize, hence empirical methods are used

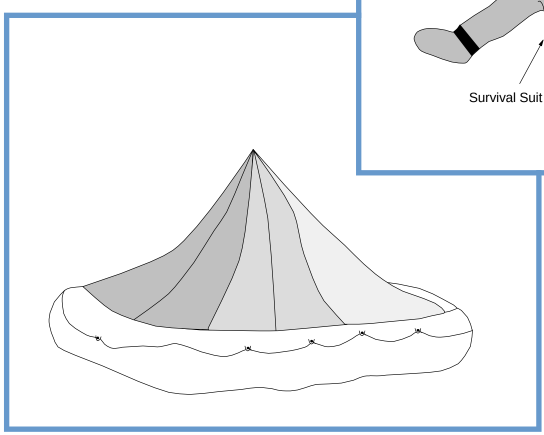


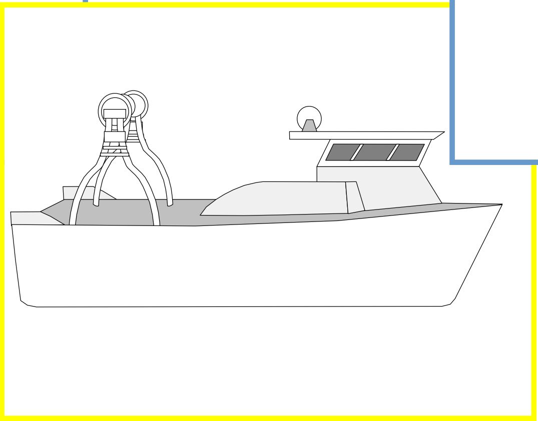
Empirical leeway data

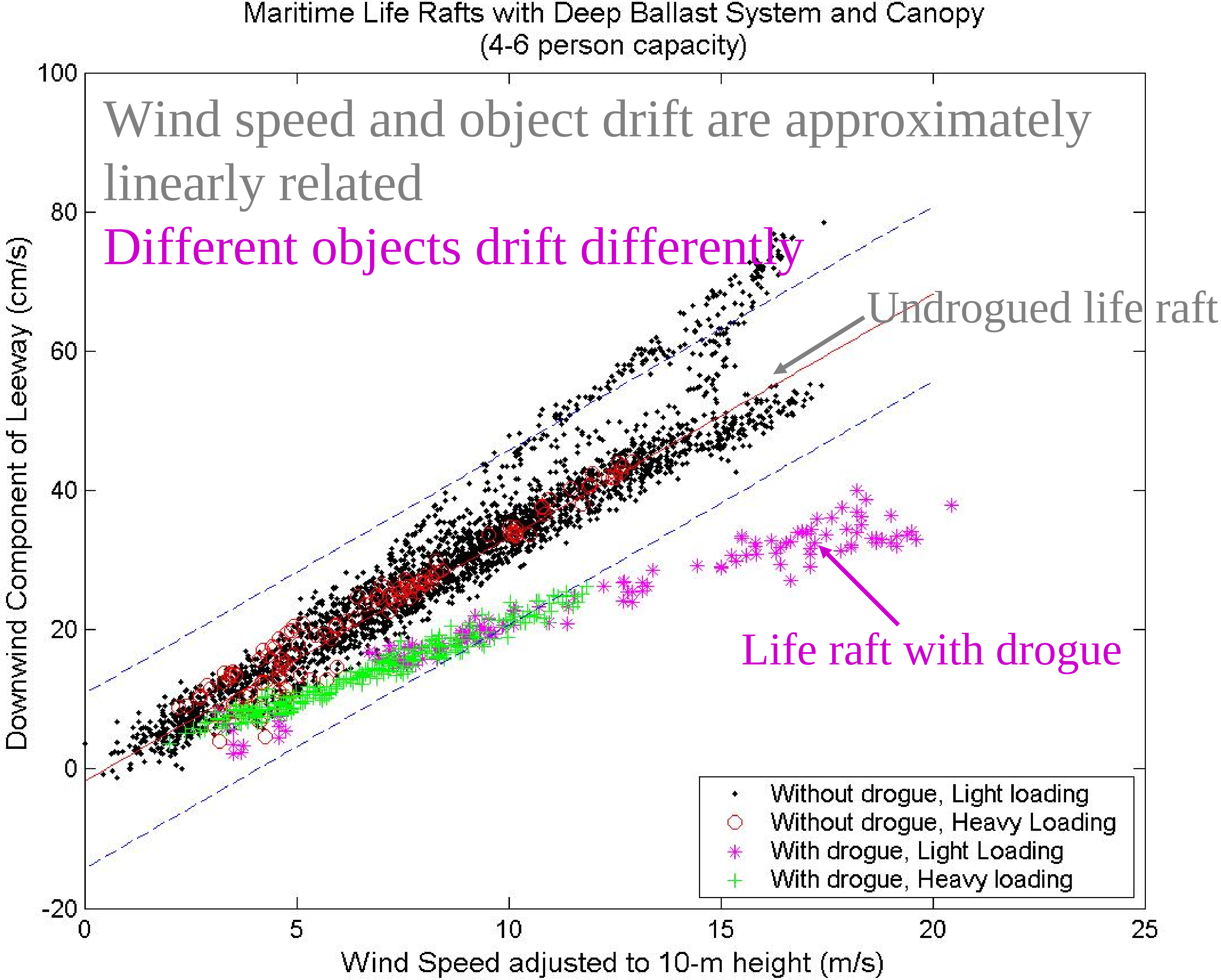
- US Coast Guard has compiled data for 63 classes of S&R objects through extensive field campaigns, generously made available to our operational service







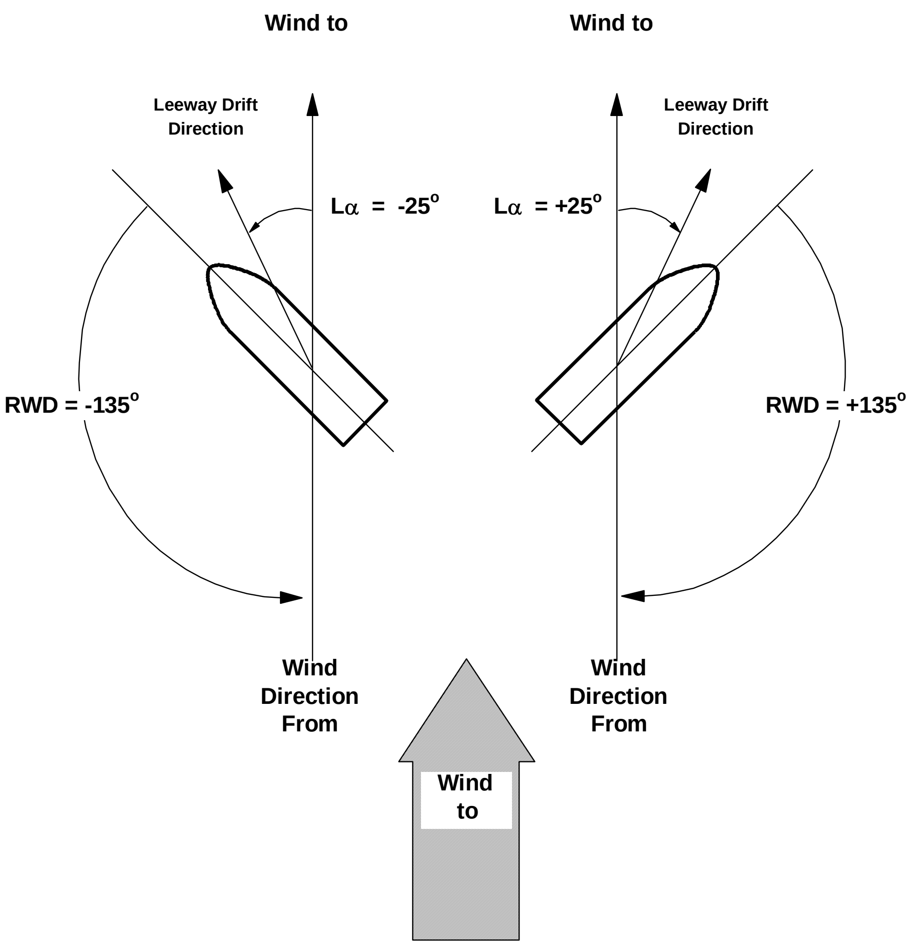




Maritime Life Rafts with Deep Ballast System and Canopy
(4-6 person capacity)
Wind speed and object drift are approximately linearly related
Different objects drift differently
Undrogued life raft
Life raft with drogue
Downwind Component of Leeway (cm/s)
100
80
60
40
20
0
-20
0
5
10
15
20
25
Wind Speed adjusted to 10-m height (m/s)
Without drogue, Light loading
Without drogue, Heavy Loading
With drogue, Light Loading
With drogue, Heavy loading

Leeway bimodality

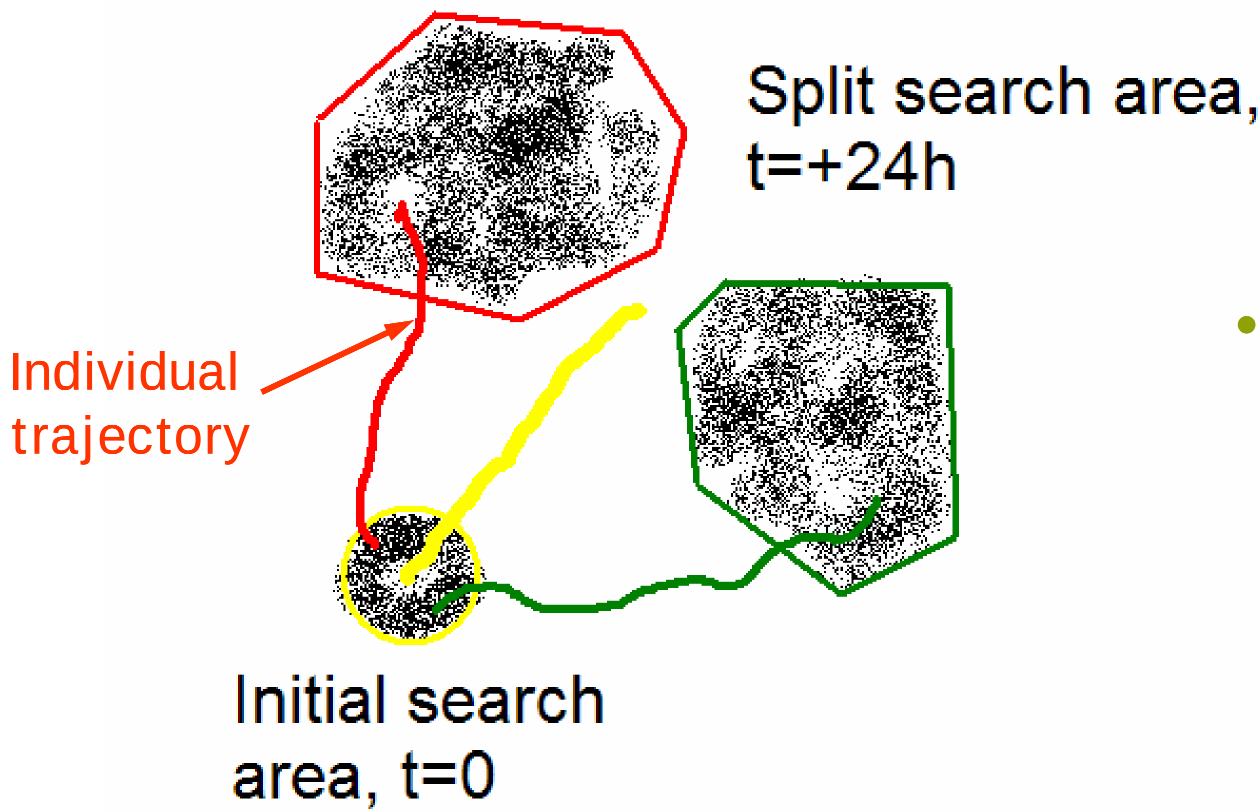
- Experiments produce two stable drift directions, left and right of downwind
- In practice, we cannot know which side will be "selected" by the object.
- Leeway model must account for both possibilities



Leeway model - assumptions

- Monte Carlo ensemble approach:
  - S&R object represented by *O*(500) ***particles***, each with the characteristics of the object
  - Uncertainties in the model, initial conditions and forcing are accounted for by seeding strategy and perturbations to the forcing
  - The changing cloud of particles represents a probability density for the object location
- The leeway of the object is related linearly to the wind speed and direction
- Wave excitaion and damping is ignored as S&R objects are small
- Stokes drift is assumed included in the empirical leeway data from USCG

Monte Carlo modelling



- Initial particle cloud represents uncertainty in Last Known Position (LKP)
- Search area grows with time (error growth) due to uncertainties in
  - Wind field
  - Leeway properties
- Split search area due to bimodal leeway divergence

Operational services – user interface

- The operational drift model machinery must be supplemented with a well-designed **user-interface**:
  - Input of initial conditions and reception of results.
  - Intuitively understood and used – response teams are in a hurry and have many things on their minds.

    $\Rightarrow$ tailored graphical rendition of results essential
  - Robust, rapid communications.

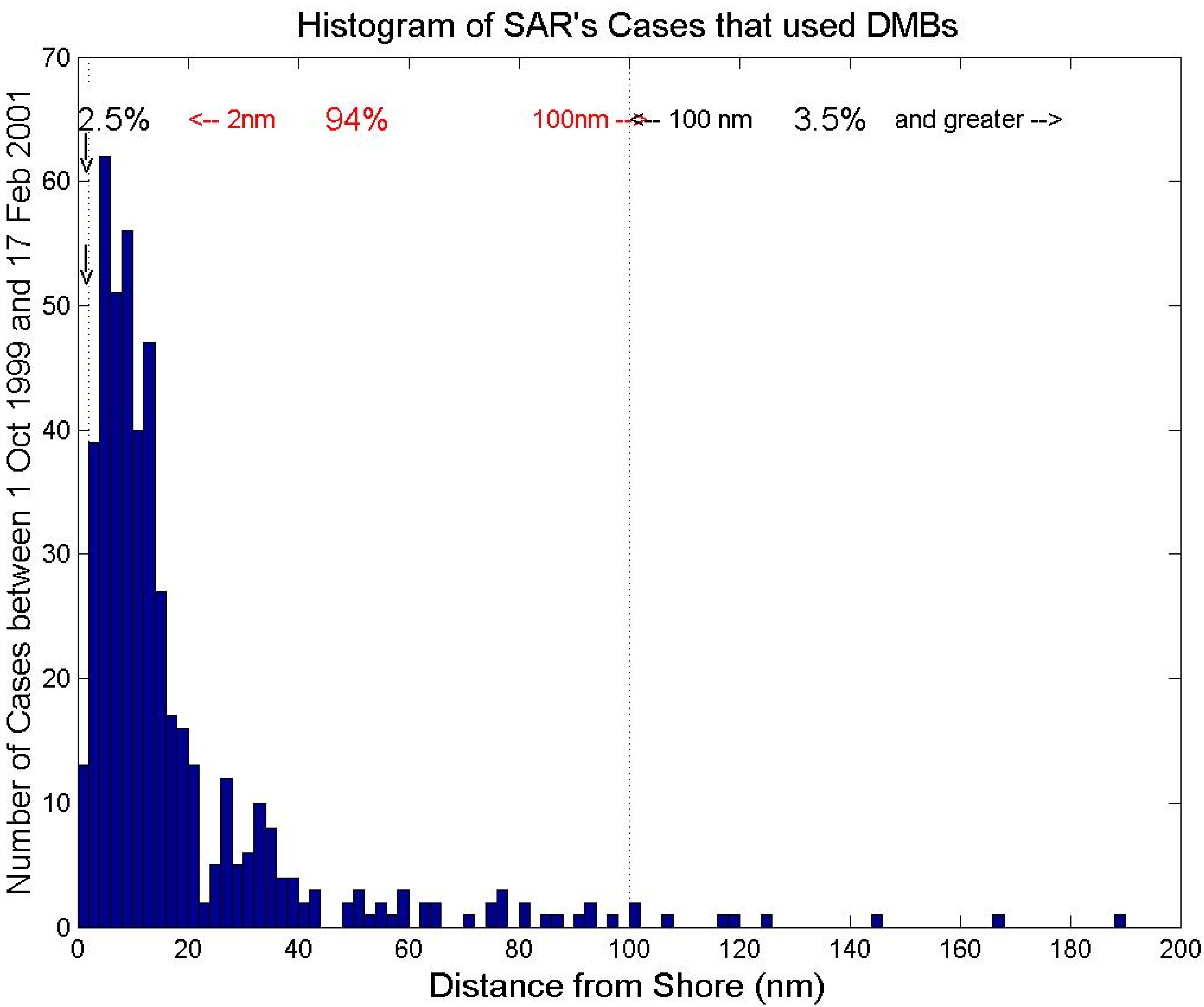
Example: Norwegian S&R service

- User is **JRCC** (Joint Rescue Coordination Center Norway).
- JRCC goal:
  to reduce the time and resources necessary to find the lost object
- Goal of drift forecasting*:*
  to help JRCC reduce the size of the search area as much as possible (but no more).

Search maths

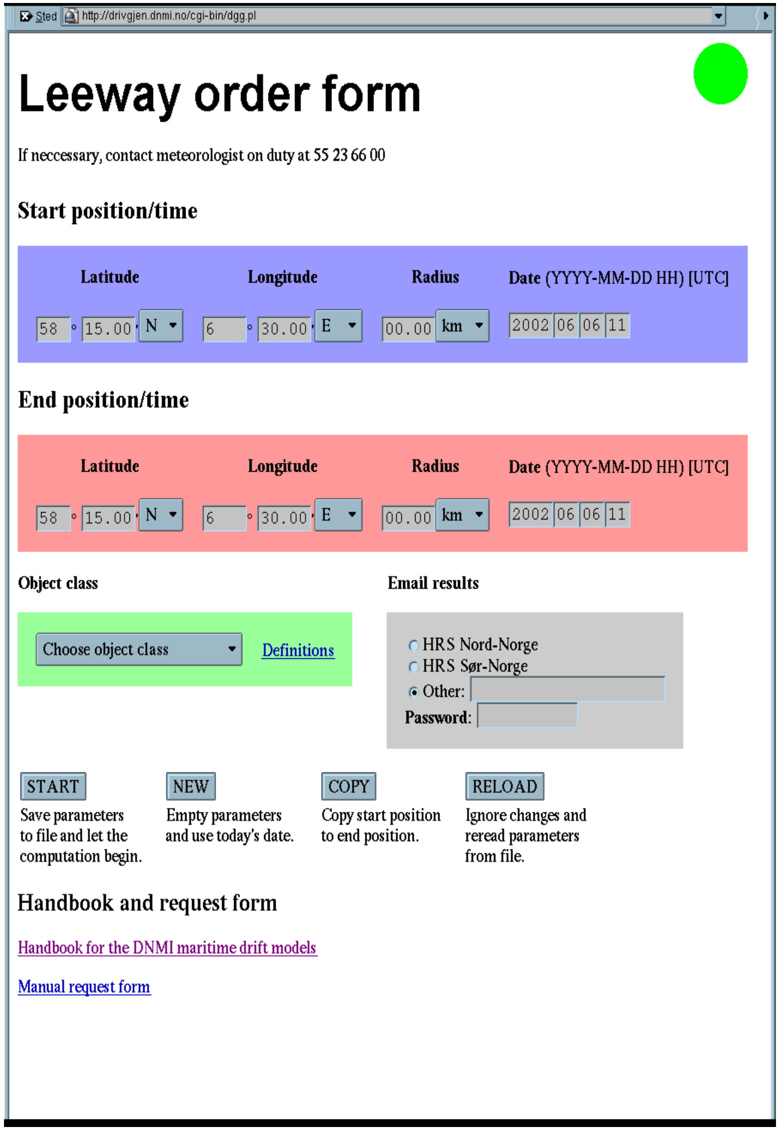
POS = *POD* x *POC*

- *POS*: Probability of success (do we find what we are looking for?)
- *POS*: Probability of success (do we find what we are looking for?)
- *POC*: Probability of containment (are we searching in the right place?), our business


Histogram of SAR's Cases that used DMBs
2.5%
<-- 2nm
94%
100nm -->
<-- 100 nm
3.5%
and greater -->
Number of Cases between 1 Oct 1999 and 17 Feb 2001
Distance from Shore (nm)
0
10
20
30
40
50
60
70
0
20
40
60
80
100
120
140
160
180
200

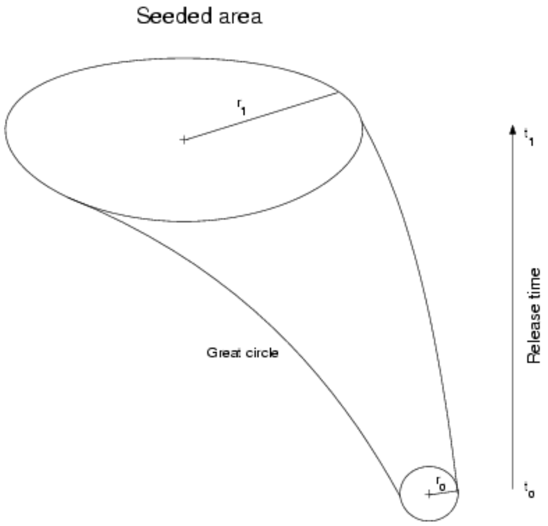
Example: Norwegian S&R service

- Service consists of 2 parts:
  - *Leeway* forecast model run at met.no
  - *SARA* graphical analysis tool run at JRCC
- Procedure:
  1. JRCC requests *Leeway* forecast using web order form
  2. Model is run automatically at met.no, data file returned via email
  3. Results fed into *SARA*



Example: Norwegian S&R service

1. Leeway request by the JRCC:
    - LKP and its uncertainty - entered as 2 time/position data
    - Object class: Uncertainty of the object type is tackled by making several requests for similar objects.

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Person In Water (PIW):

PIW-1: PIW, unknown state (mean values)
 PIW-2: PIW, vertical
 PIW-3: PIW, sitting
 PIW-4: PIW, horisontal, survival suit
 PIW-5: PIW, horisontal, scuba suit
 PIW-6: PIW, horisontal, deceased

Life raft with no ballast system (NB):

LIFE-RAFT-NB1: Life-raft, no ballast system, general (mean values)
 LIFE-RAFT-NB2: Life-raft, no ballast system, no canopy, no drogue
 LIFE-RAFT-NB3: Life-raft, no ballast system, no canopy, with drogu
 LIFE-RAFT-NB4: Life-raft, no ballast system, with canopy, no drogu
 LIFE-RAFT-NB5: Life-raft, no ballast system, with canopy, with drc

Life raft with shallow ballast system (SB):

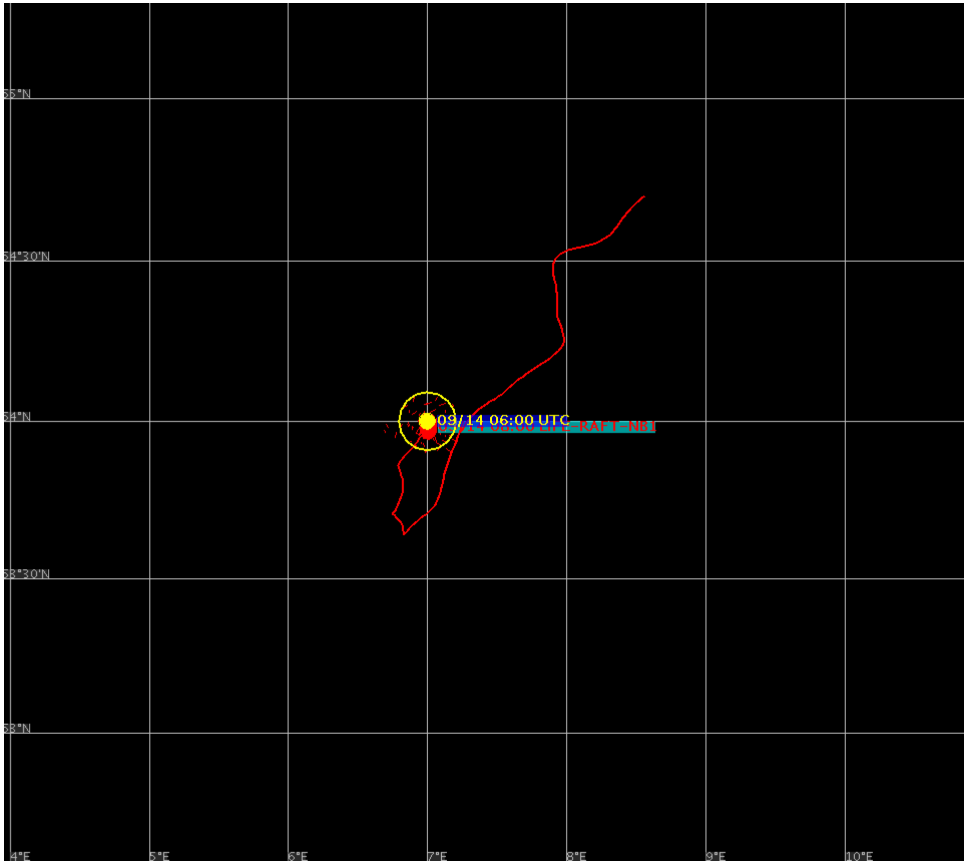
LIFE-RAFT-SB6: Life-raft, shallow ballast system AND canopy, genera
 LIFE-RAFT-SB7: Life-raft, shallow ballast system AND canopy, no dr
 LIFE-RAFT-SB8: Life-raft, shallow ballast system AND canopy, with
 LIFE-RAFT-SB9: Life-raft, shallow ballast system AND canopy, capsi

Life raft with deep ballast system (DB):

LIFE-RAFT-DB10: general, unknown capacity and loading (mean values)
 LIFE-RAFT-DB11: 4-6 person capacity, general (mean values)
```

Example: Norwegian S&R service

2. Return data file
3. Feed into SARA
   - Display on map layers – digital navigation charts
   - Animation
   - Add search areas manually



Simulation start – life raft

Example: Norwegian S&R service

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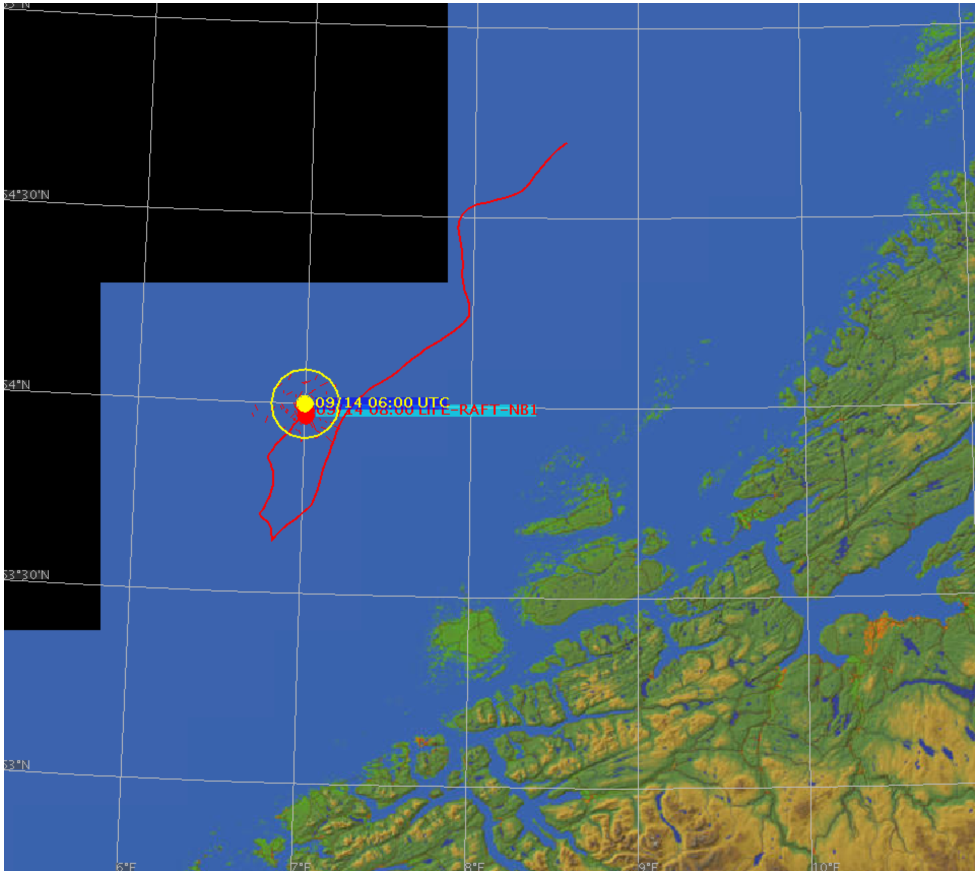

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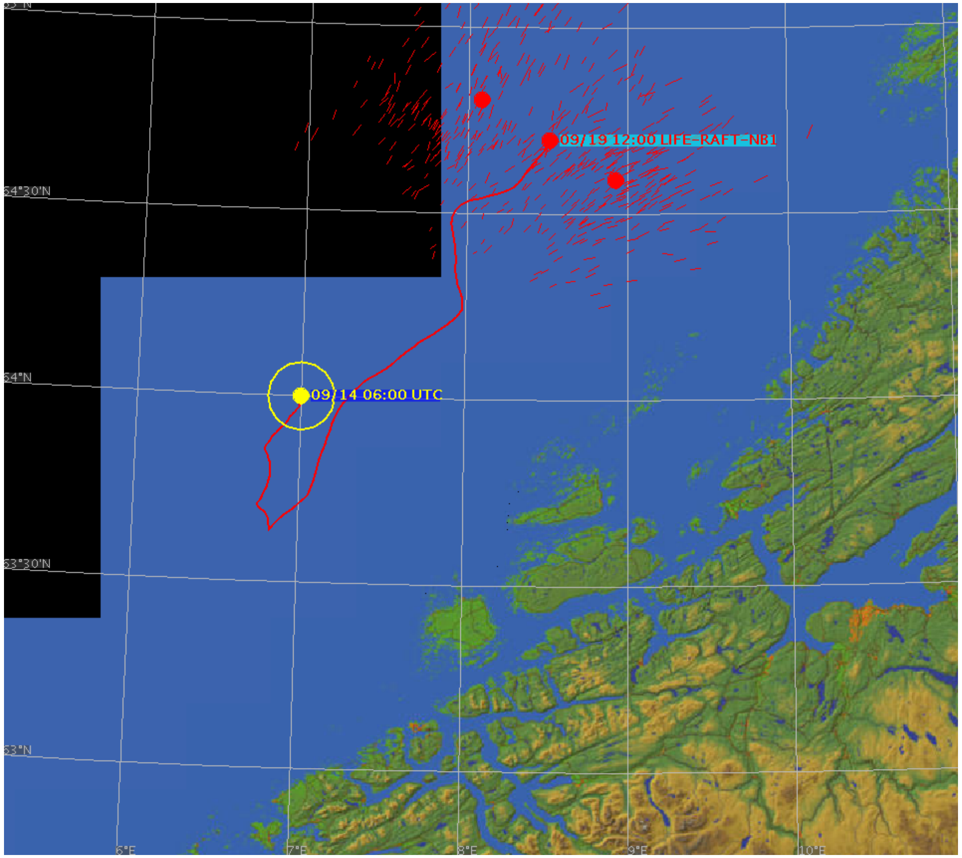

Simulation stop – life raft

Example: Norwegian S&R service

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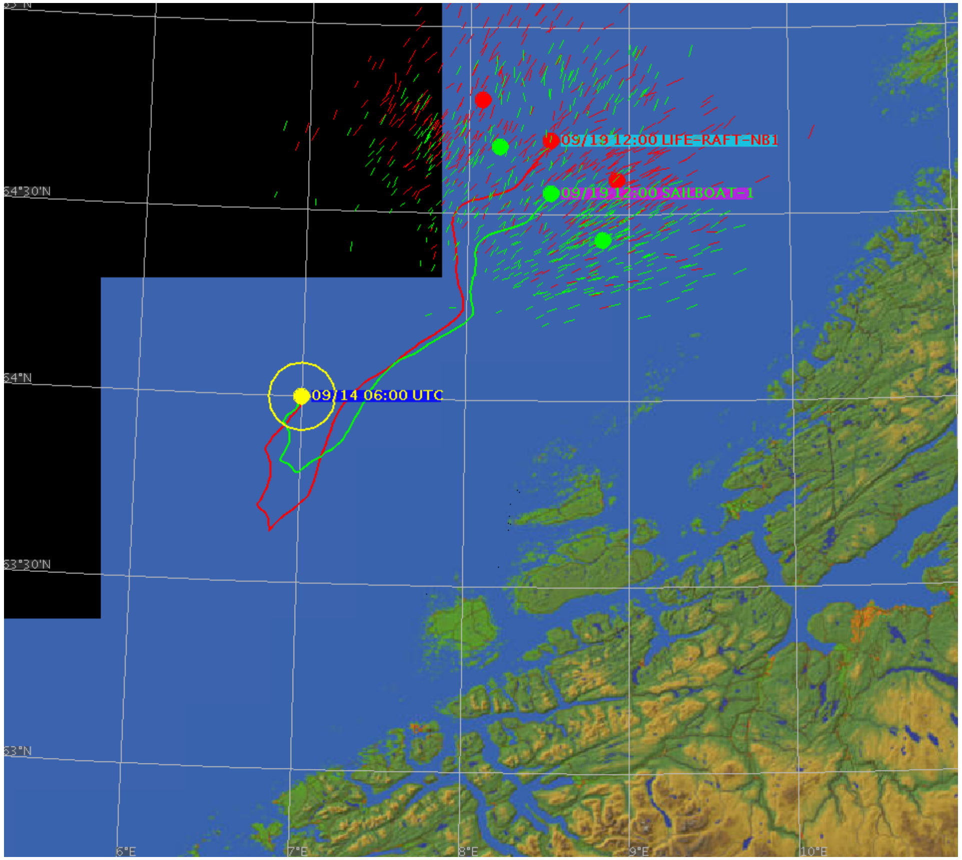
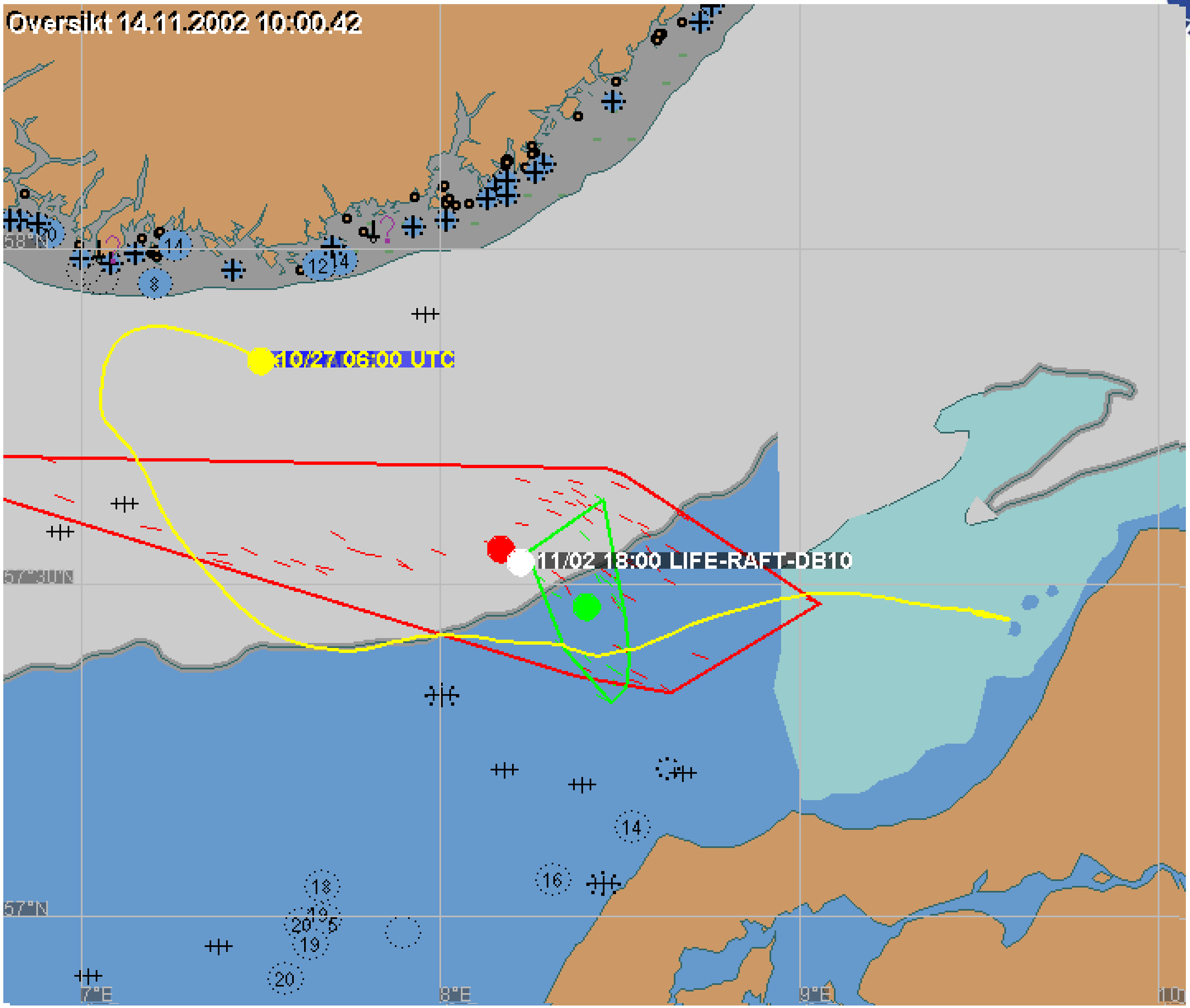
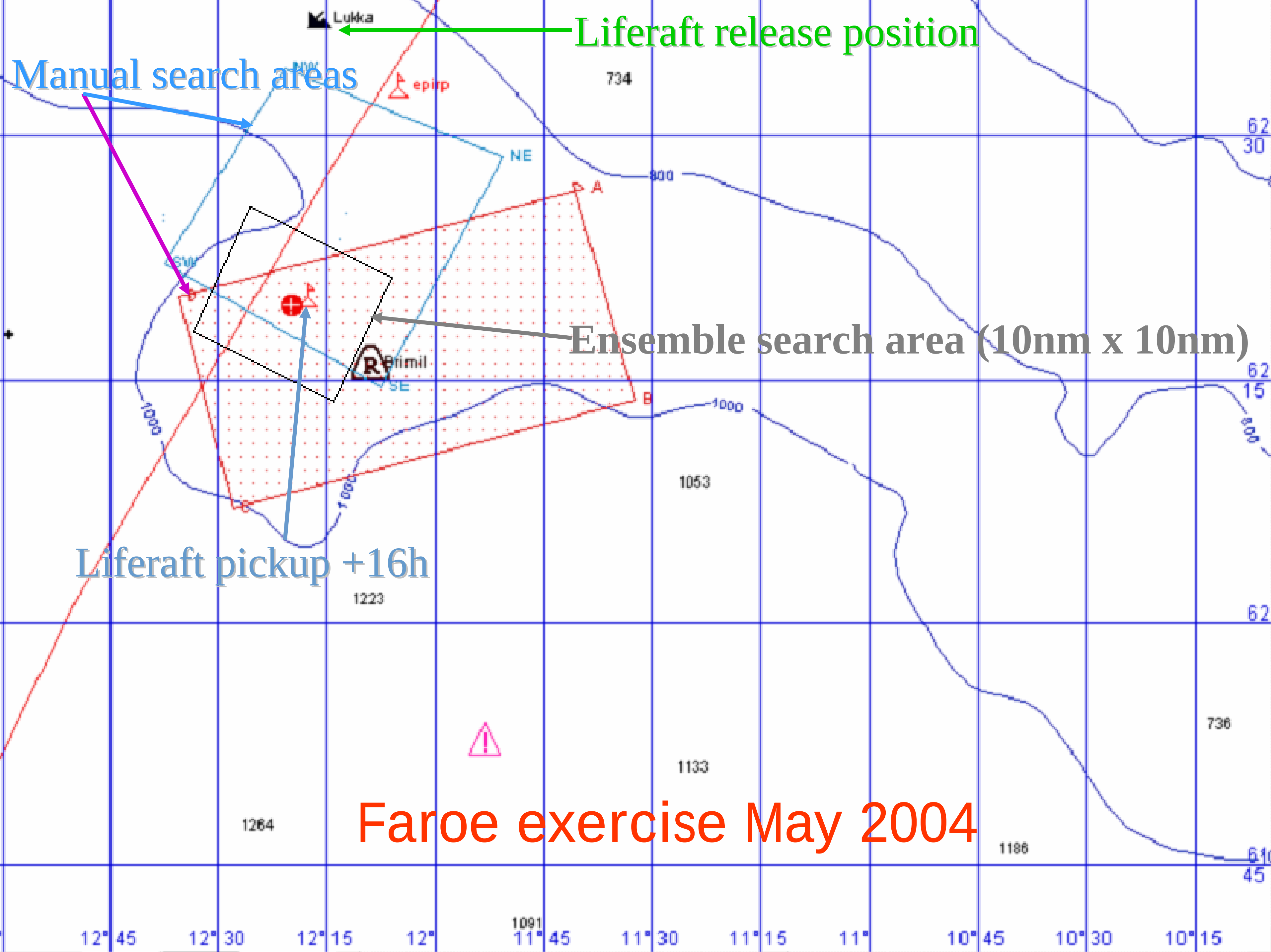
3. Feed into SARA
   - Display on map layers – digital navigation charts
   - Animation
   - Add search areas manually



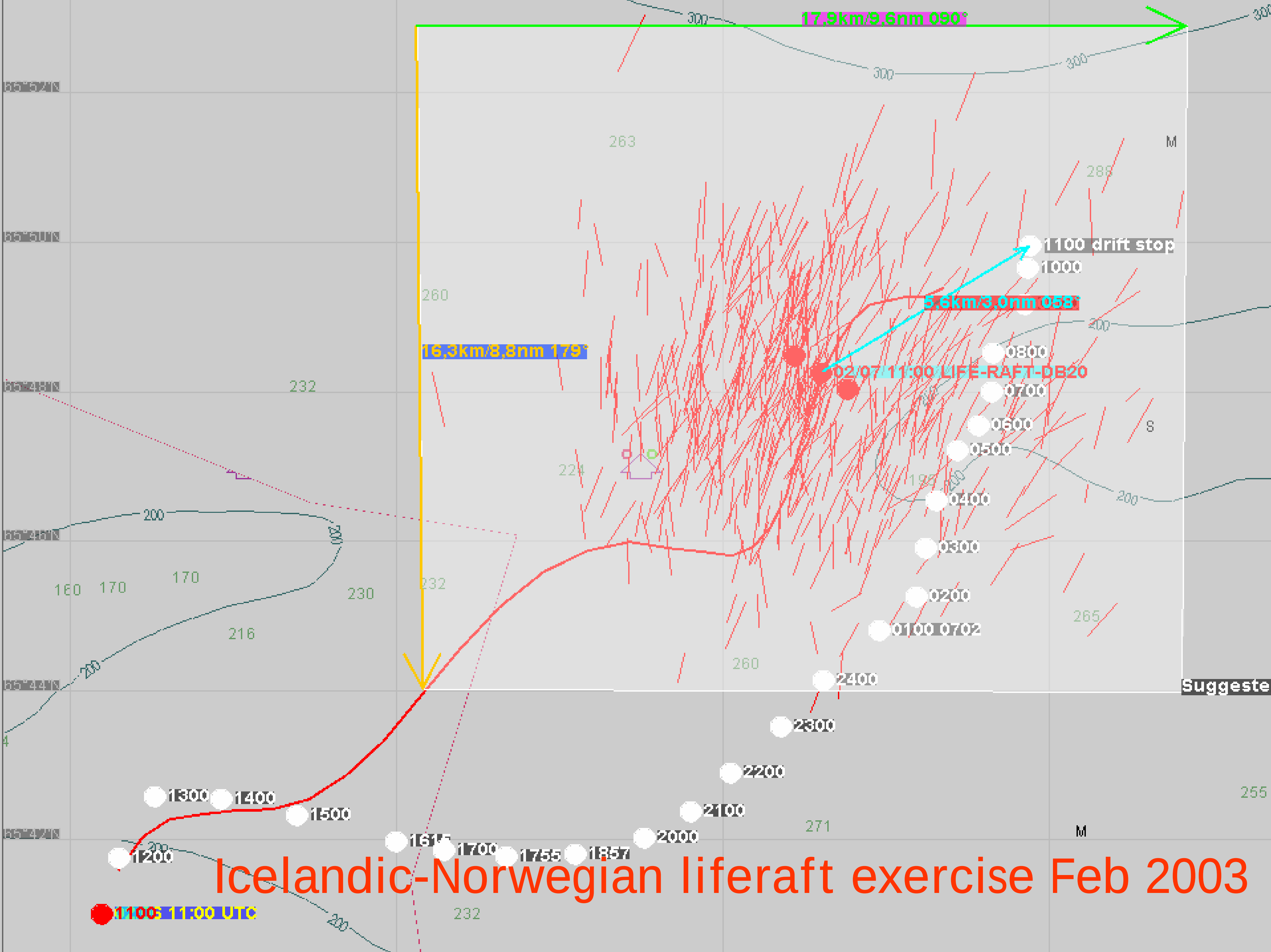
Simulation stop – life raft & sailboat

Example: A liferaft in Skagerrak during six days



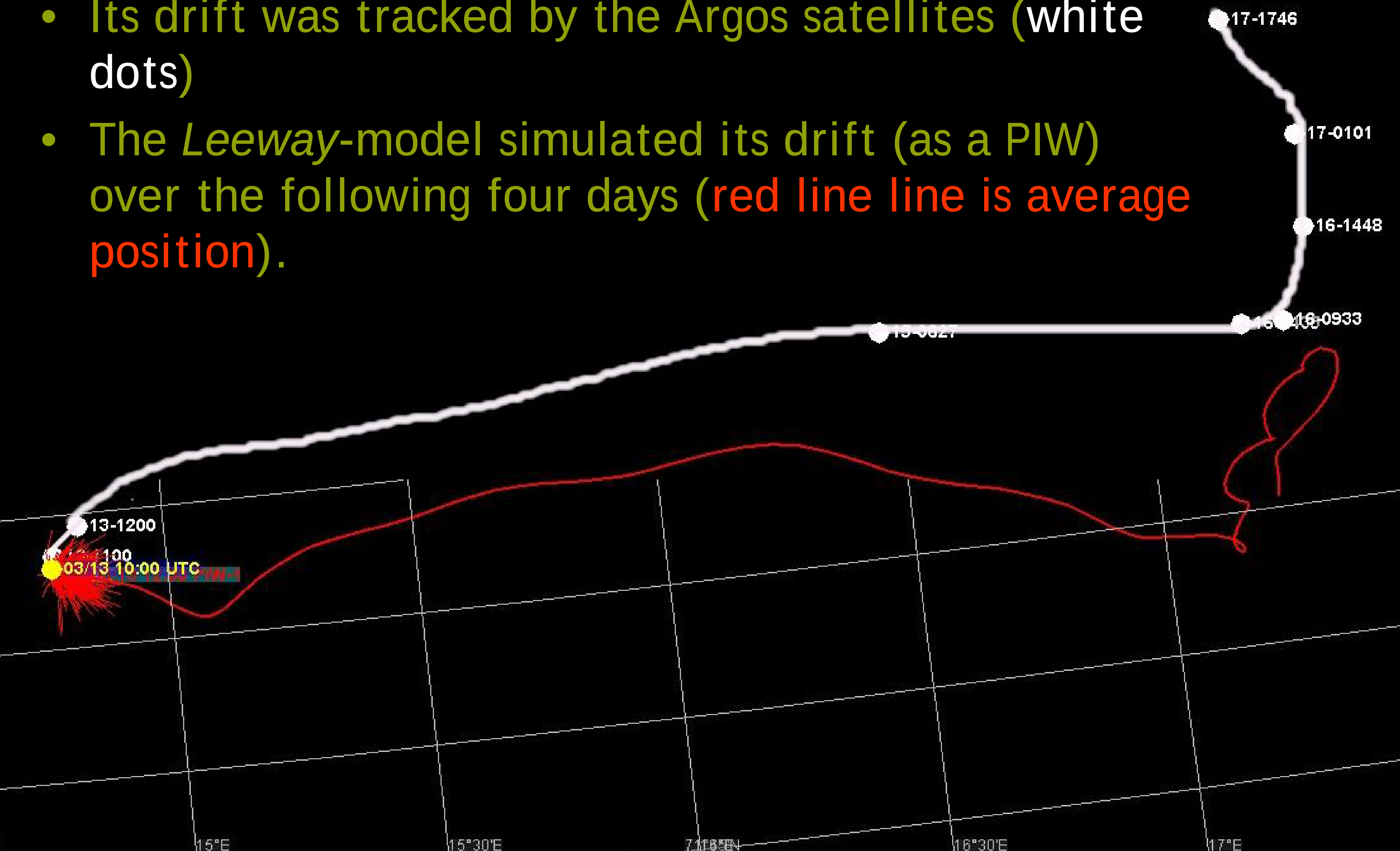


Lukka
Liferaft release position
Manual search areas
NW
epirp
734
NE
800
A
SW
62
30
Ensemble search area (10nm x 10nm)
Primil
SE
62
15
B
1000
1000
800
1053
C
1000
Liferaft pickup +16h
1223
62
736
1133
1264
Faroe exercise May 2004
1186
45
1091
12° 45
12° 30
12° 15
12°
11° 45
11° 30
11° 15
11°
10° 45
10° 30
10° 15



Icelandic-Norwegian liferaft exercise Feb 2003

- Alfred-Wegener-Institut, Germany, lost a benthic lander on 2002-03-14 when it surfaced due to malfunctioning.
- Its drift was tracked by the Argos satellites (white dots)
- The *Leeway*-model simulated its drift (as a PIW) over the following four days (red line line is average position).



Concluding remarks

- Emergency drift services are very demanding applications for an operational ocean forecasting system (cf. GMES) – challenge is cool
- Operational current, wind, and wave prognoses are the backbone of drift forecasting
- Evaulation of the drift models is a constant requirement, although both the S&R and oil spill services have shown skill in assisting emergency operations and exercises
- "Taxonomy" field/lab work:
  - The drift of objects and ships is based on empirical data and the "taxonomy" of S&R objects and ship classes must be continuously updated and expanded
  - Oil fate models are also dependent on empirical (laboratory) data for different oil types, long-term weathering effects are not well understood (cf. Prestige tar balls).
- Our three classes of drifting things (people, ship, and oil) are often related ("*crew abandons ruptured tanker…*").
- Particle-based drift models are also applicable to other "things" (e.g. plankton).
- User interface: Good forecast services need good interfacing to the users. Speed and reliability of delivery are essential.

End