Lagrangian dispersion models

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Lagrangian or particle tracking models

A release of radionuclides is simulated by a number of discrete particles. Each particle is equivalent to a number of units.

The paths followed by each particle is computed individually. Diffusion and decay are calculated by a Monte Carlo method.

At the end of the simulation, the density of particles per water volume unit is calculated to obtain concentrations of contaminants.

These models have been widely used to simulate dispersion of passive tracers, radionuclides and oil spills.

Lagrangian or particle tracking models: some advantages

- Well suited to problems in which high concentration gradients are involved since numerical diffusion is not introduced
- Can give very fast answers, specially if hydrodynamic is solved off-line
- Lagrangian models, thus, are very useful predictive tools for the assessment of contamination after accidental or deliberate releases of radionuclides

Advection, diffusion and decay

Advection

$$\frac{\vec{r}(t+\Delta t)-\vec{r}(t)}{\Delta t}=\vec{q}(t)$$

Diffusion

$$D_h = \sqrt{12K_h\Delta t}\cdot\mathrm{RAN}$$

$$\mathrm{Direction} = 2\pi\cdot\mathrm{RAN}$$

$$D_v = \sqrt{2K_v\Delta t}\cdot\mathrm{RAN}$$

Given towards the surface or sea bottom

Radioactive decay

$$\frac{\partial C}{\partial t} = -\lambda C$$

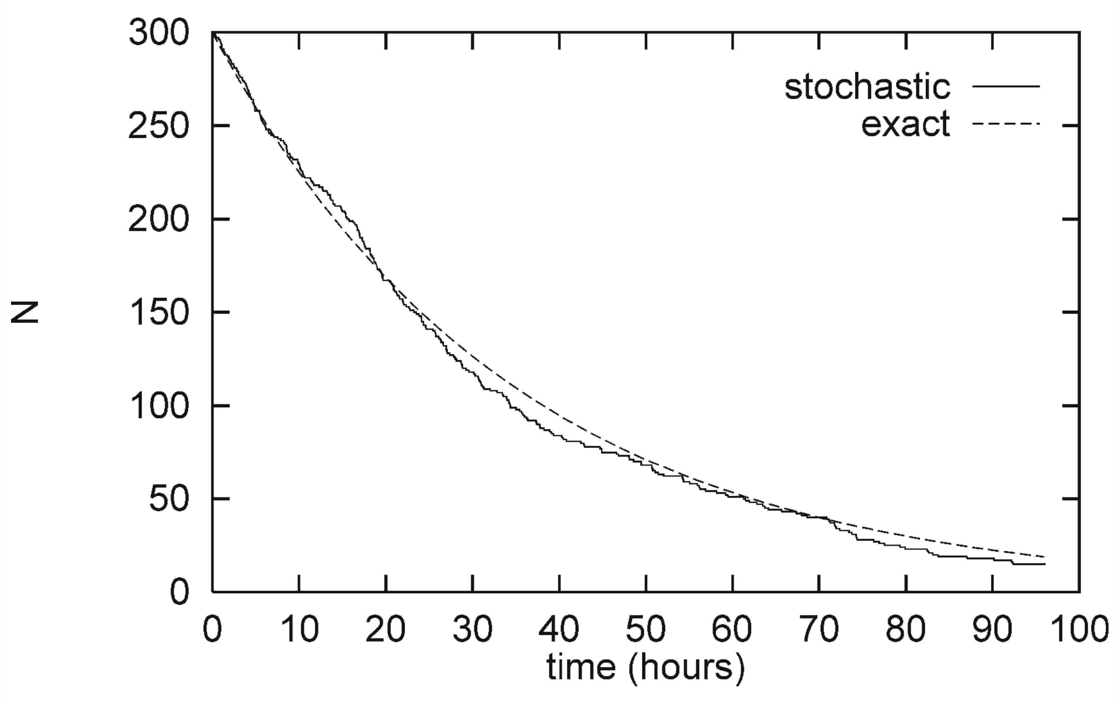
The probability that a particle decays each time step is considered to be:

$$p = 1 - e^{-\lambda \Delta t}$$

A random number is generated for each particle each time step. The particle decays (is removed from the computation) if:

$$\mathrm{RAN} \leq p$$

Radioactive decay



Comparison of the Monte Carlo and exact solutions for a radionuclide with half-life equal to 1 day and using 300 particles

Current profiles

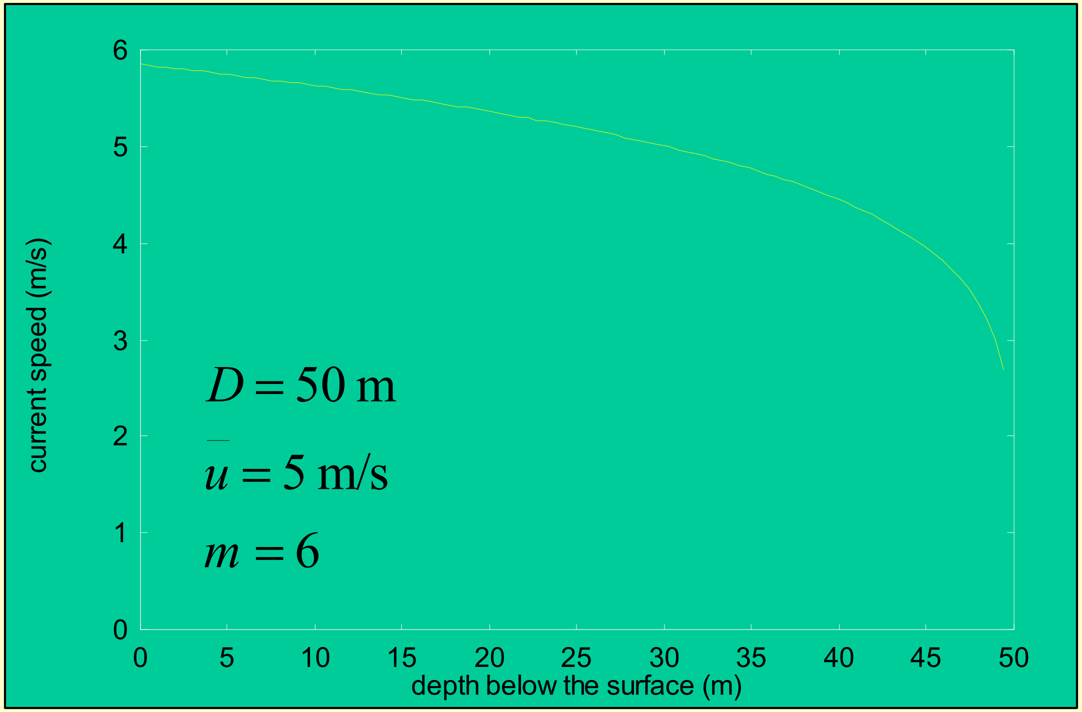
The PT model is 3D. If the hydrodynamic model is depth averaged, a current profile can be generated from the depth averaged current.

The flow increases from the bottom to the surface in the following form:

$$u_z = u_s \left(\frac{D - z}{D} \right)^{1/m}$$

$$u_s = \frac{m+1}{m} \bar{u}$$

$$5 \leq m \leq 7$$



Wind effect

The effect of wind decreases logarithmically to zero at a depth typically taken to be of the order of 20 m.

$$u_z = u_0 - \frac{u^*}{k}\ln\left(\frac{z}{z_0}\right)$$

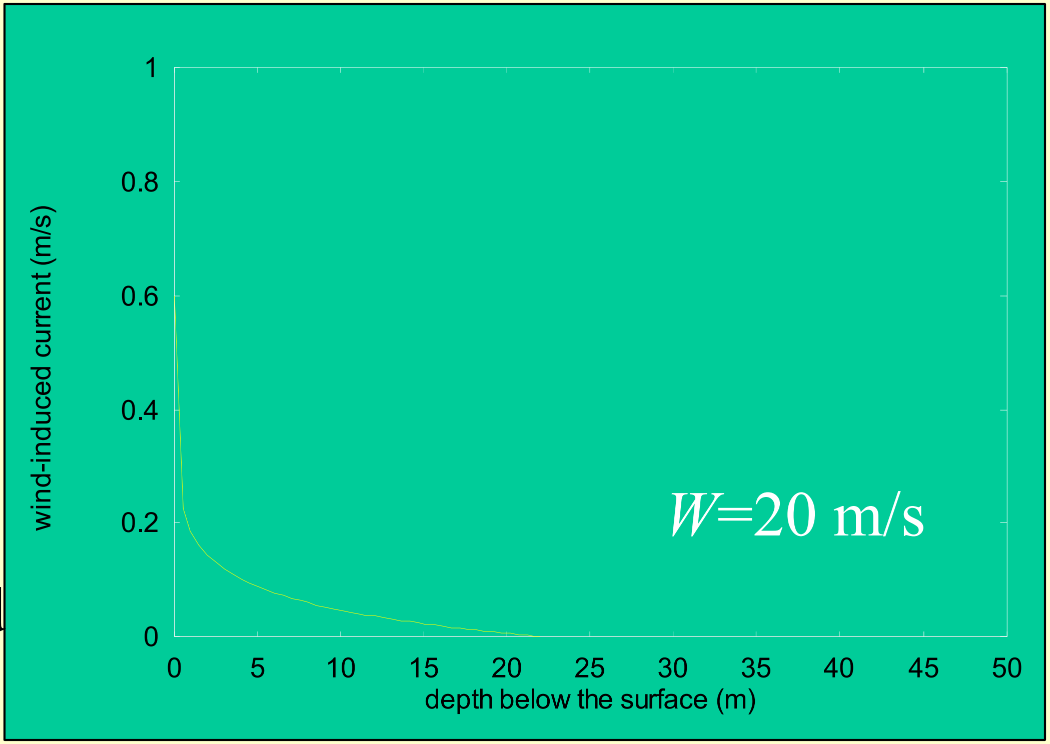
$$u_0 \approx 3\% \cdot W$$

$$u^* = 0.0012W$$

$$k = 0.4$$

$$0.5 \le z_0 \le 1.5\,\mathrm{mm}$$

W: wind speed measured 10 m above the surface.



Boundary conditions

- Closed boundary: particle movements are not allowed or, alternatively, are reflected. This is also valid for the surface and seabed.

- Open boundary: particles that cross them are removed from computations.

In practice, a label is given to each particle. If a particle must be removed from computations (because has left the domain or has decayed) the label is changed. The label of each particle is checked before calculating its movement each time step.

Calculating concentrations of contaminants

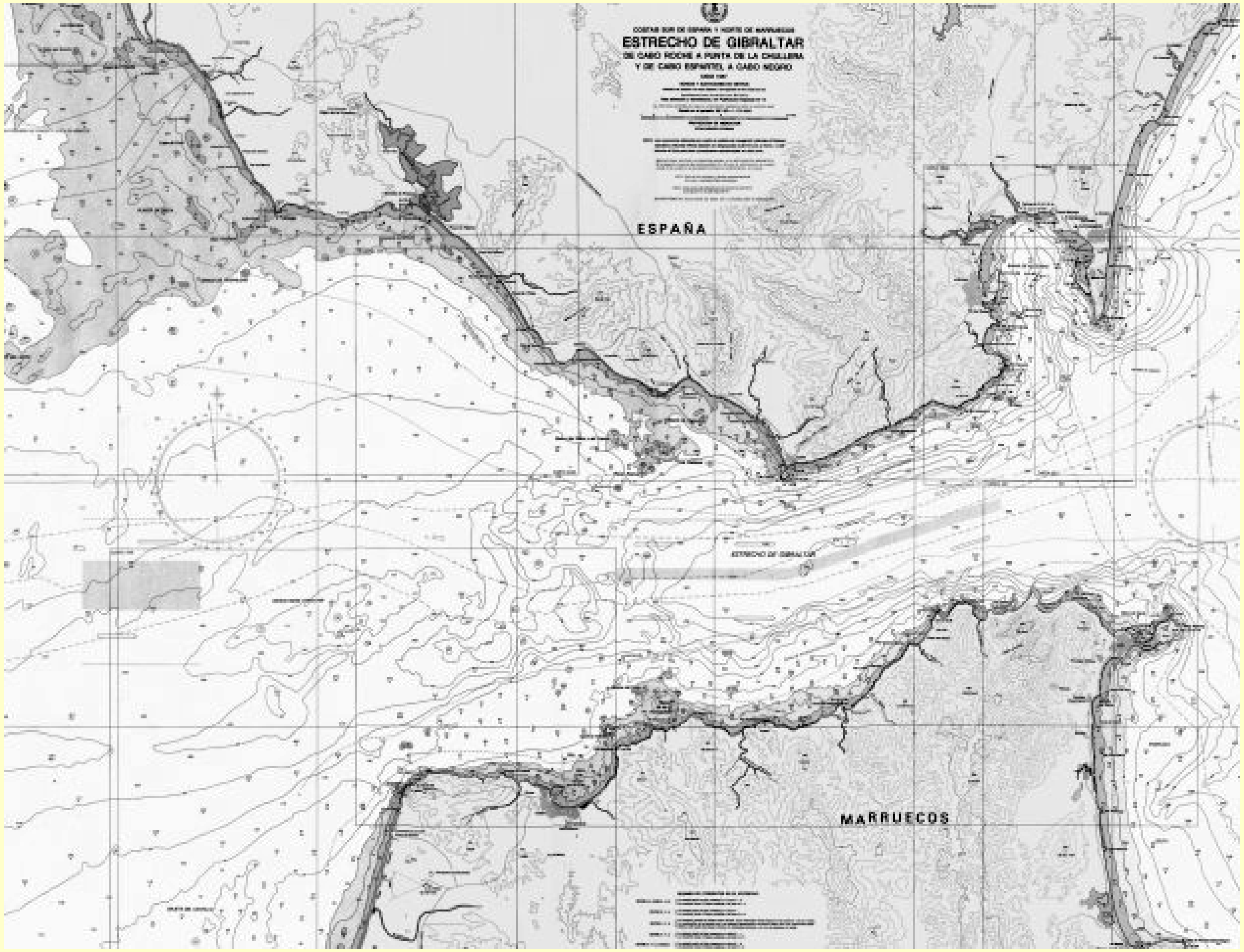
Concetrations are obtained from the density of particles *N* (number of particles per water volume unit):

$$C = N \times R$$

$$R = \frac{I}{NP}$$

Where *I* is the total input and *NP* the number of particles used in the simulations.

GISPART model



GISPART model

Hydrodynamic is solved off-line and tidal analysis is used to calculate tidal constants for the M_2 and S_2 constituents. Residuals are also calculated and stored.

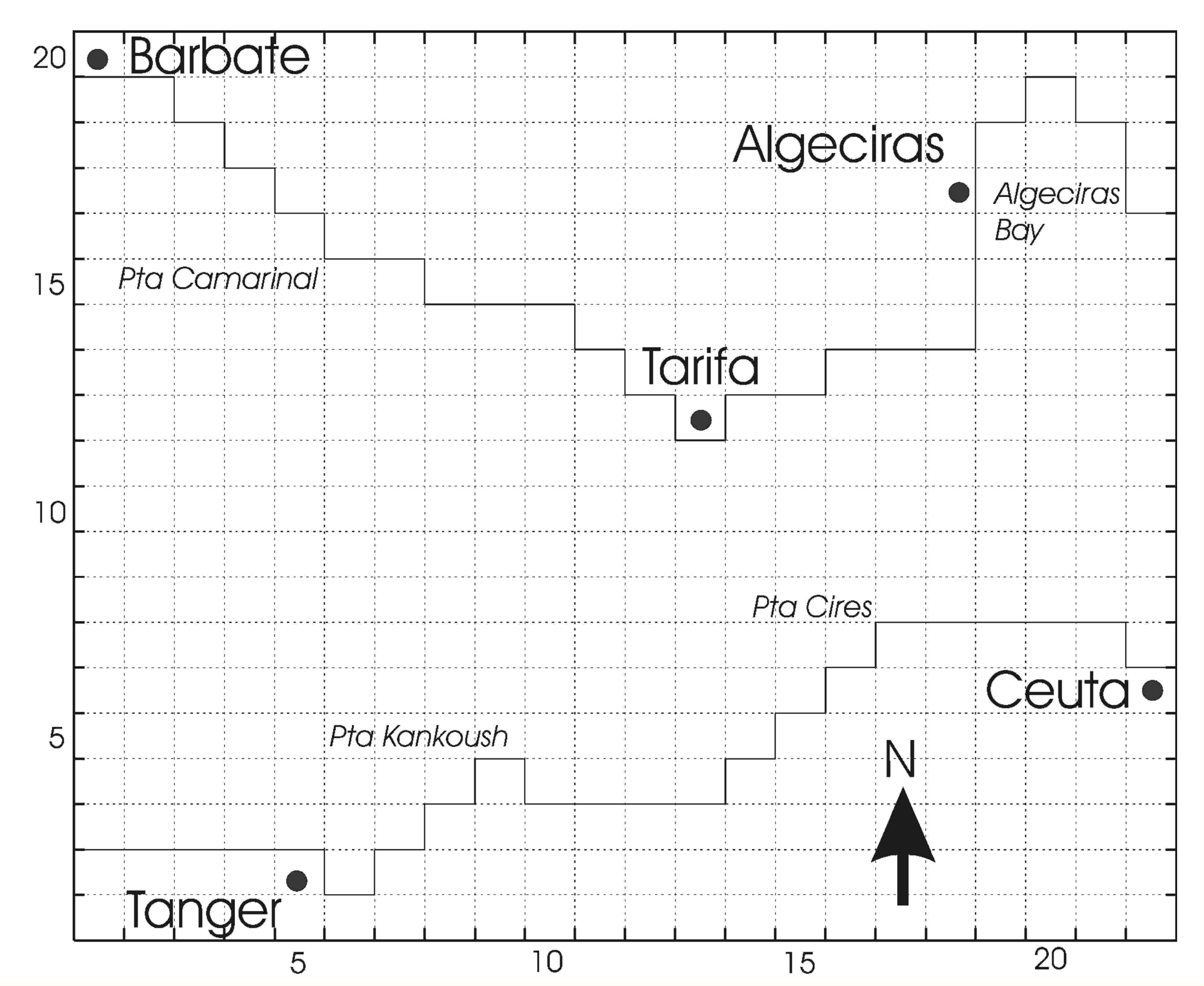
Results from the hydrodynamic model have been extensively compared with measurements (elevations, phases, currents) in the Strait.

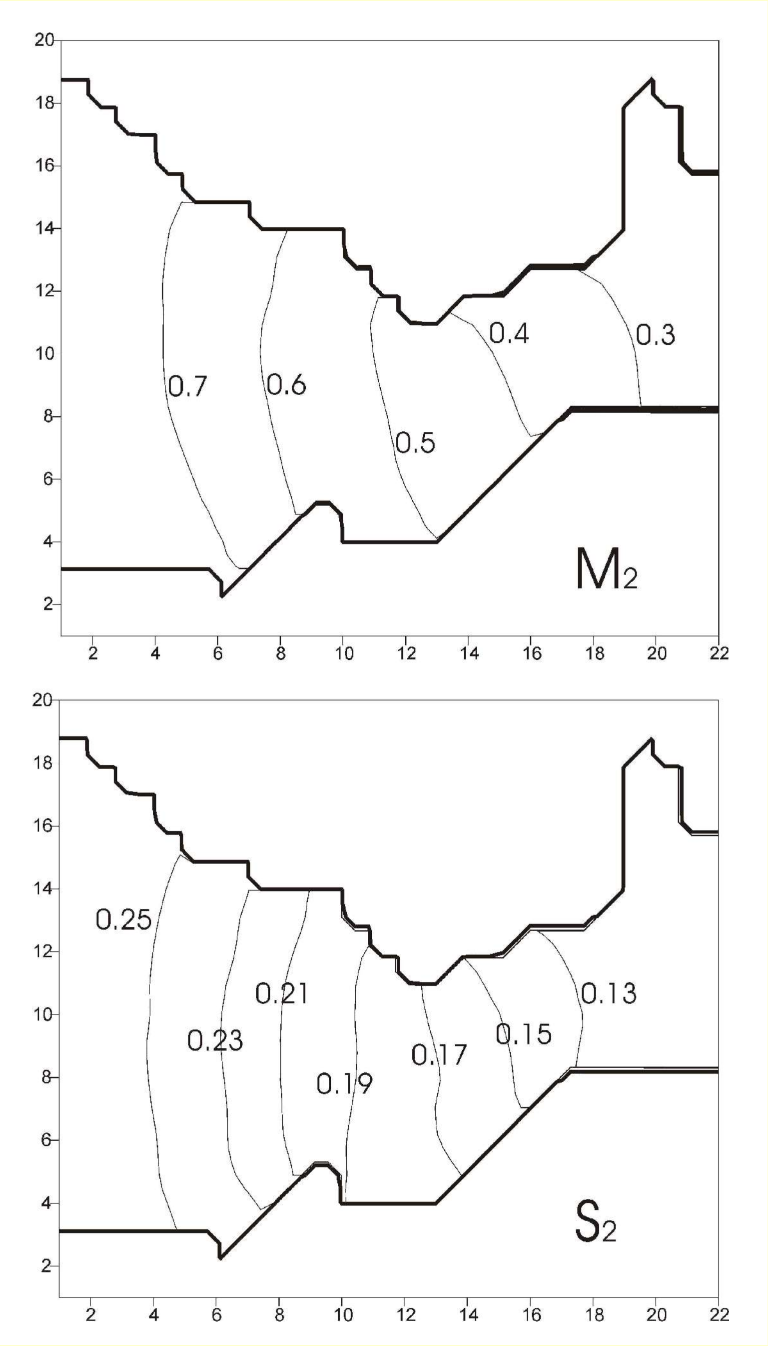
Dispersion model resolution:

$$\Delta x = \Delta y = 2500 \text{ m}$$

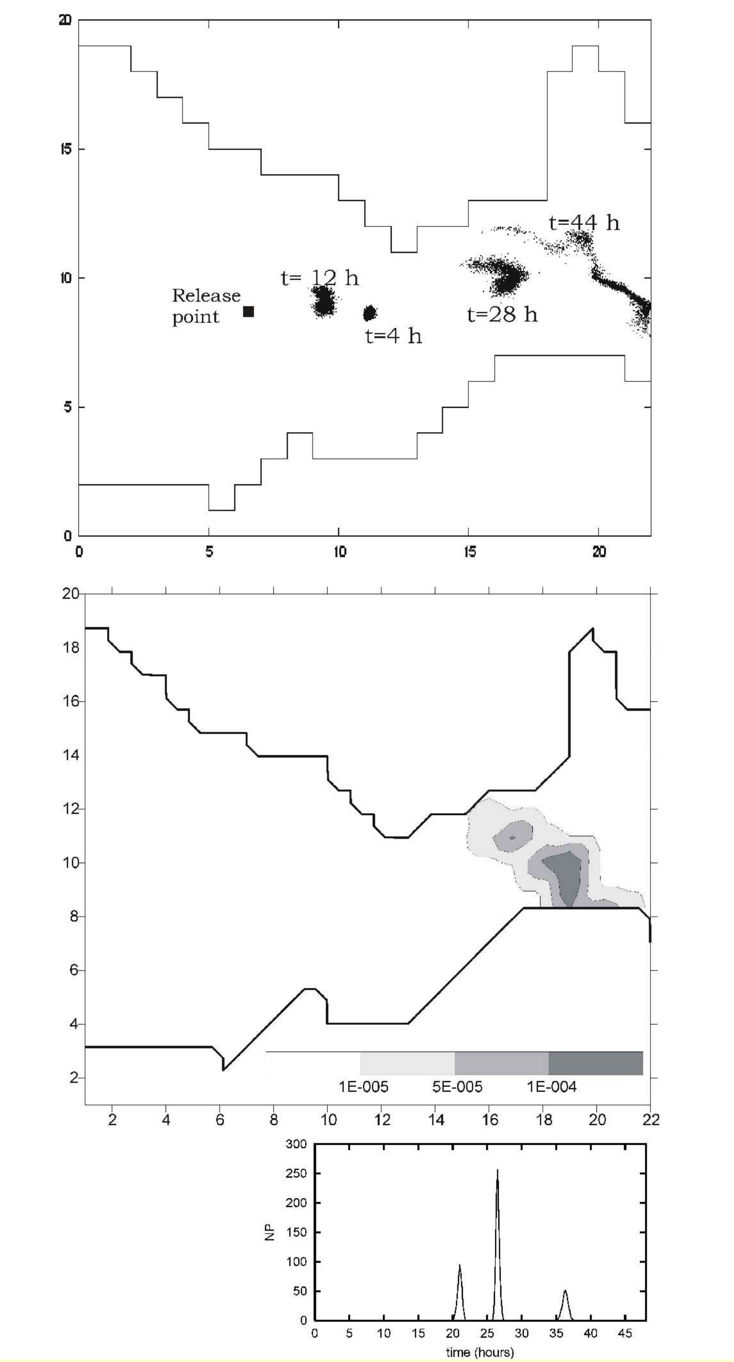
$$\Delta t = 600 \text{ s}$$

GISPART model





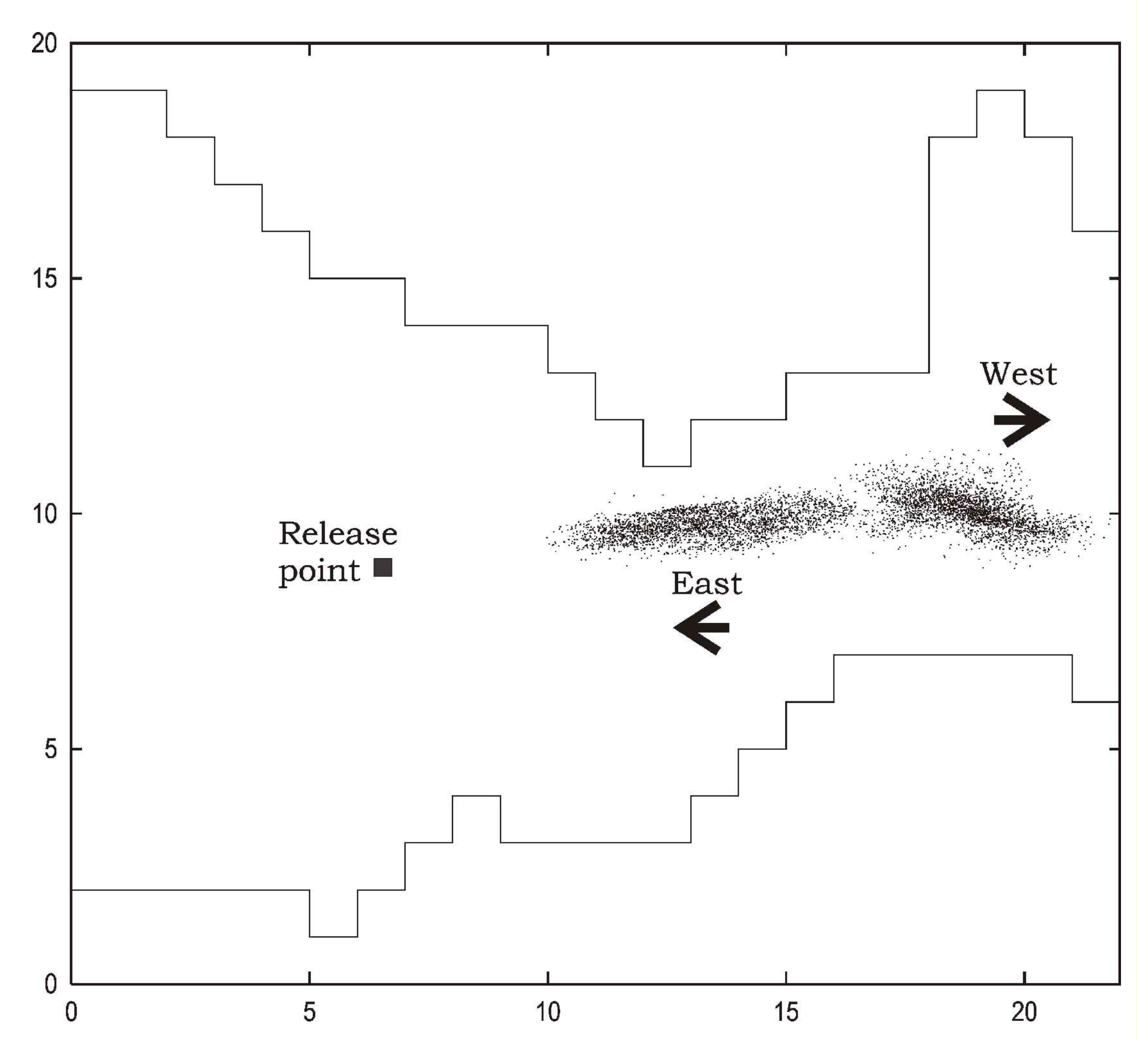
Computed tidal charts for both constituents. Amplitudes are given in m.



Example of the dispersion of an instantaneous release.

The map of computed concentrations is also shown, as well as the time evolution of the number of particles into grid cell (15,9).

Wind effect



Continuous release