Numerical modelling of organic waste dispersion from a marine fish farm

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12. May 2010, JONSMOD2010

Joint work with:
Øyvind Thiem and Jarle Berntsen

Research supported by the Research Council of Norway as a part of the ECORAIS project

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Outline

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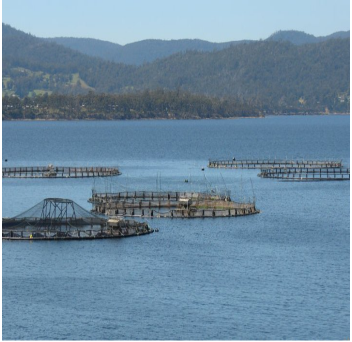
Fish farms

Typical coastal fish farming: growing of fish in floating net cages.



Background and motivation

- Fish farming supplies more than 50 percent of the fish consumed globally which contributes to reducing pressures on natural fisheries resources.
- A typical salmon farm of 200,000 fish discharges faecal waste roughly equivalent to a city of 65,000 people.
  (Pure Salmon Campaign)
- The impact of organic waste of the fish farming on the marine ecosystem and the local environment has become a major concern for the fish industry.
- This has resulted in destruction of the wild salmon and decreasing of the potential production of the farm itself.
- Good aquaculture modelling provides tools that help in understanding, assessing, predicting, and managing this waste, therefore sustainable and environmentally friendly aquaculture could be achieved.

Sea lice problem

Escaped farmed fish infested by sea lice.

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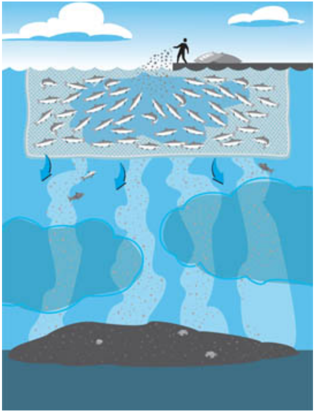
Sea lice problem

- Juvenile wild salmon migrate into the open ocean pick up parasites if they swim by fish farm.
- This causes a high death rate reaches up to 95 percent. (CBC News, Martin Krkosek)

(Alexandra Morton)

Organic waste problem

- Enrichment of both the water column and the sea floor with organic matter (fish faeces and food pellets)
- This waste represents a source of toxic gases emissions.



(Pure Salmon Campaign)

Particle tracking model

- Three processes influence the particles movement in 3D:

  1-Advection by water currents .

  2-Turbulent diffusion modeled with random walk.

  3- Vertical movement towards the bottom (sinking) due to particles weights.

Particle position $\vec{x}(t) = (x(t), y(t), z(t))$ at time $(t + \Delta t)$ is

$$\vec{x}(t + \Delta t) = \vec{x}(t) + (\vec{U}(t) + (0, 0, -w_s)) * \Delta t + r * \vec{U}_{std}(t) * \Delta t,$$

where $\vec{U}(t)$ is the velocity field, $\vec{U}_{std}(t)$ denotes the standard deviation of $\vec{U}$, w_s is the sinking velocity, and r is a stochastic variable with a Qaussian distribution.

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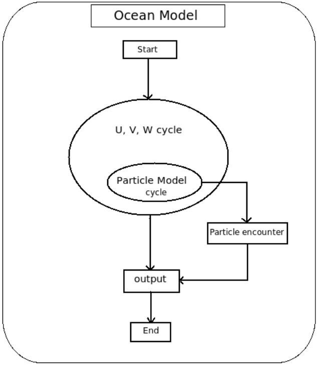
Coupling to the Bergen ocean model (BOM)

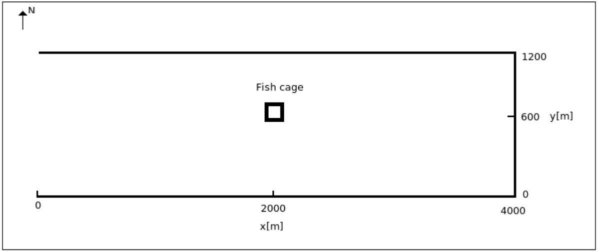
At each time step:

- Estimate the currents velocities by the ocean model.
- Then move all particles by the particle model.
- Count for particles that reach the bottom as non active.



Model setup

- An idealized fjord of homogeneous water with open western boundary.
- Tidal currents considered as driving forces.
- Flat bottom with $H = 100m$ as a constant depth.
- Horizontal resolution: $dx = dy = 100$m
  and 21 equally spaced sigma layers in the vertical.



Particle model setting

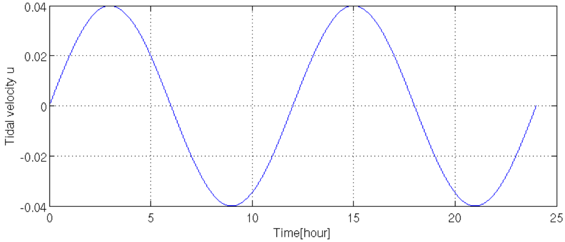
- Cage horizontal dimensions: (length×width)[m]= 100×100.
- Continuous releasing of particles at depth of 5m for 24hours, the number of particles set to be 10^5.
- The initial horizontal position of a particle is chosen randomly with uniform distribution.
- The sinking velocity w_s is determined randomly with normal distribution with mean and standard deviation.

Tidal horizontal velocity u

Harmonic representation of the tidal velocity in x direction

$$u = u_0 * cos(f * t - \phi)$$

where $f = \frac{360}{T}$ is tidal frequency ; T is the tidal period, u_0 donates the velocity amplitude and ϕ is the tide phase.



Analytical model (2D)

Particle position $(x(t), z(t))$ at time $(t + \Delta t)$ is

$$x(t + \Delta t) = x(t) + u(t) * \Delta t,$$

$$z(t + \Delta t) = z(t) - w_s * \Delta t,$$

where $u(t)$ is the tidal velocity in x direction.

Particle final position

Particle sinking time t_s

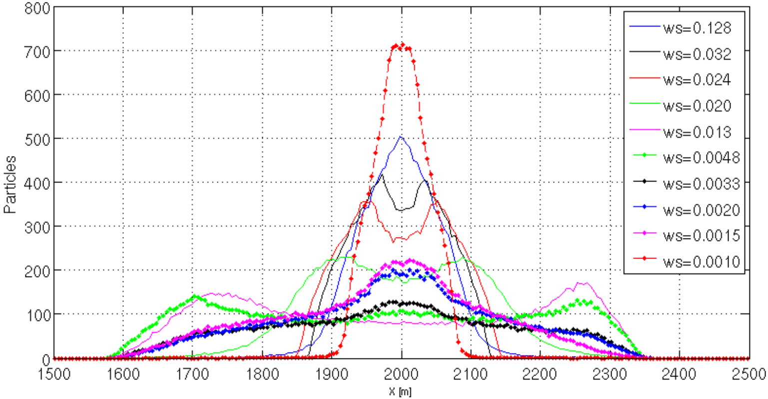
$$t_s = \frac{H}{w_s}.$$

The final position of a particle p in x direction is

$$x_p(t_s) = a + r * (b - a) + \int_{t_0}^{t_0+t_s} u_0 * cos(f * t - \phi)dt,$$

where t_0 represents the time at which the particle p was released, and $(b - a)$ is the cage length in x direction.

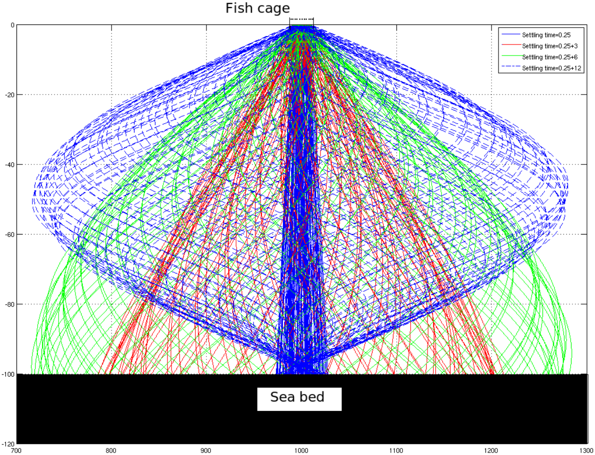
Sensitivity to $w_s[ms^{-1}]$ (BOM)



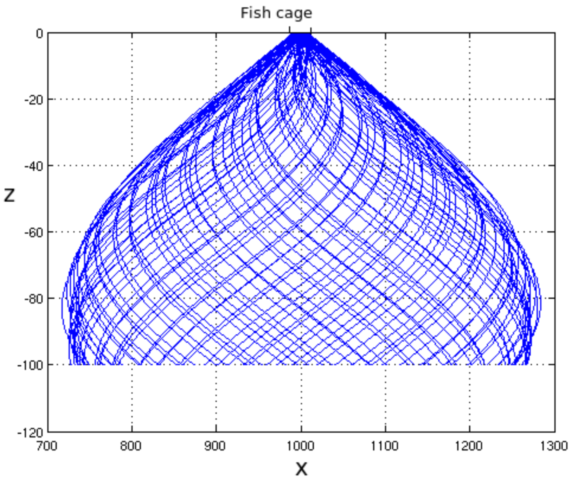
Particles accumulation over the sea bottom (width integrated)

Sinking time $\frac{H}{w_s}$ vs tidal period (T)

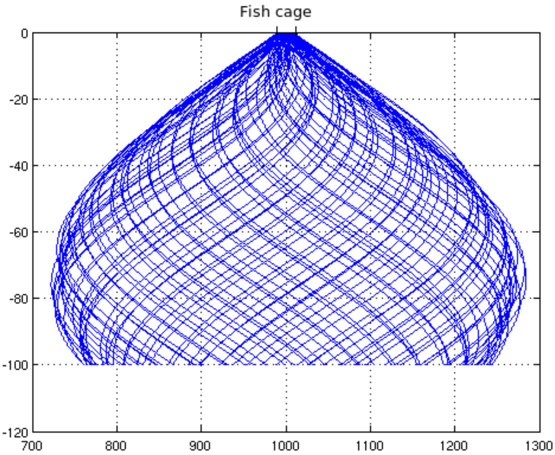
H/w_s (hours)	0.25	$0.25 + T/4$	$0.25 + T/2$	$0.25 + T$



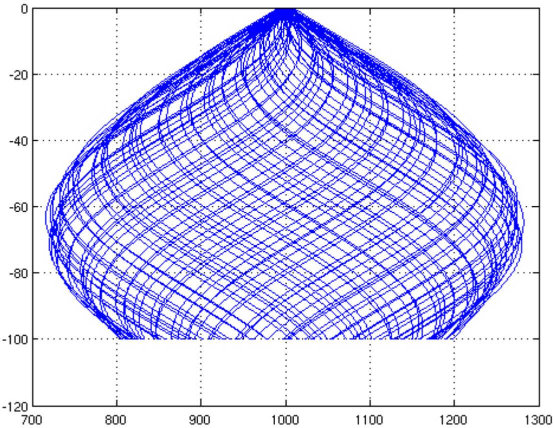
Sinking time: $\frac{H}{w_s} = \frac{100}{w_s} = 07$ hours.



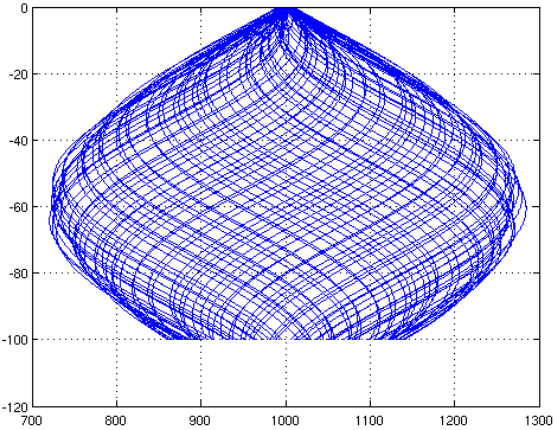
Sinking time: $\frac{H}{w_s} = \frac{100}{w_s} = 08$ hours.



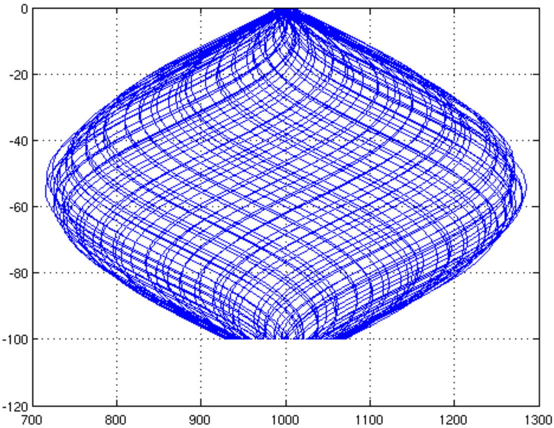
Sinking time: $\frac{H}{w_s} = \frac{100}{w_s} = 09$ hours.



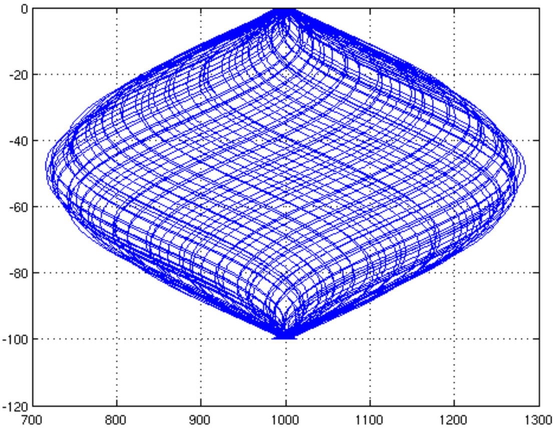
Sinking time: $\frac{H}{w_s} = \frac{100}{w_s} = 10$ hours.



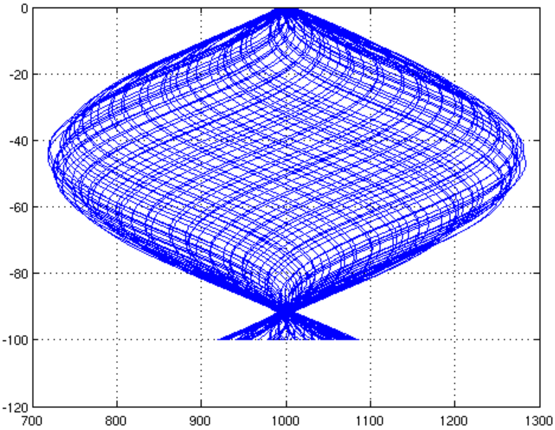
Sinking time: $\frac{H}{w_s} = \frac{100}{w_s} = 11$ hours.



Sinking time: $\frac{H}{w_s} = \frac{100}{w_s} = 12$ hours.



Sinking time: $\frac{H}{w_s} = \frac{100}{w_s} = 13$ hours.



Maximum accumulation

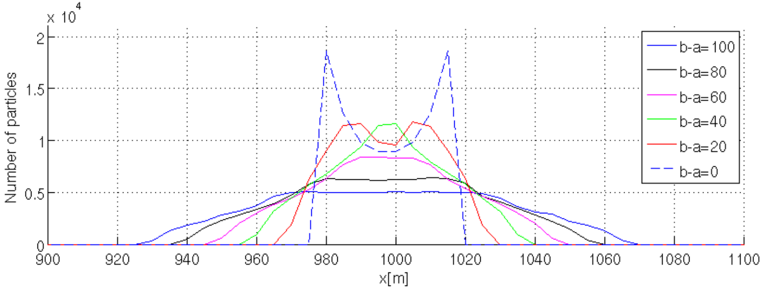
The location of the maximum concentration point depends on the cage size $(b - a)$ and the maximum horizontal distance that a particle can travel $d_{max}(H, w_s, u_0)$:

- If $d_{max}(H, w_s, u_0) < \frac{b-a}{2} \Rightarrow$ one maximum concentration point just beneath the fish cage center,
- If $d_{max}(H, w_s, u_0) > \frac{b-a}{2} \Rightarrow$ two maximum concentration points outside the fish cage area.

Sensitivity to the cage size $b-a$

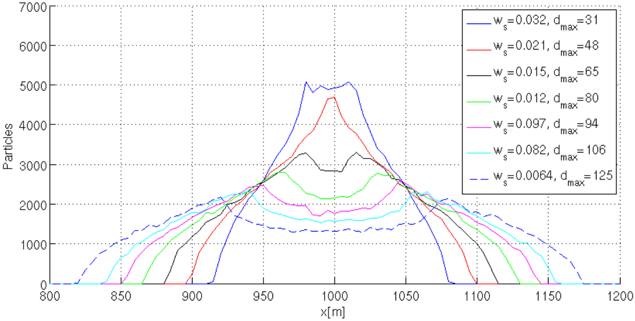
Cage length: $b-a$, $u_0 = 0.02,\ w_s = 0.12\ ms^{-1}$

and $d_{max} \approx 18m$



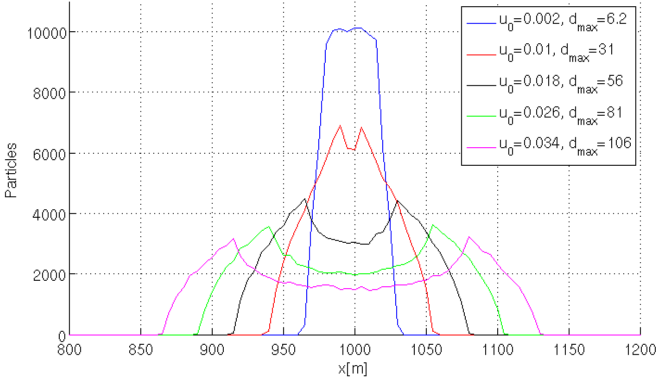
Sensitivity to the sinking velocity W_s

Cage length: $b - a = 100$ centered at $x = 1000$, and $u_0 = 0.01$



Sensitivity to the tide intensity u_0

Cage length: $b - a = 50$ centered at $x = 1000$, and $ws = 0.032$



Summary

- 3D particle tracking model is coupled to BOM and tested in an idealized fjord with tidal forcing.
- The results of particles accumulation were consistent with the analytical model.
- The last position where a particle settles depends on the tidal current intensity, fjord depth and settling velocity.
- If the sinking time is close to the tidal period, everything will end up under the fish cage. This happens also for the very fast sinking particles.
- Increasing cage size increases the likelihood for that everything is ending up beneath the fish farm, and larger farms means larger biomasses which makes it even more polluted under the fish farm.

Thank you for your attention