Exploring geophysical problems using Gerris

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- DNS of lock-exchange
- Near-field plume mechanics
- Internal solitary waves on sloping topography
- Tidal energy and optimisation of turbine arrays

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Using the lock-exchange problem to understand multi-scale, stratified coastal flows

- Stratified coastal ocean at scales of 1 to 10km ongoing challenge due to range of space and time scales.
- Lock-exchange is a benchmark problem for understanding how well numerical codes represent ocean processes including shear-driven mixing, internal waves, transients flows and gravitationally unstable phases.

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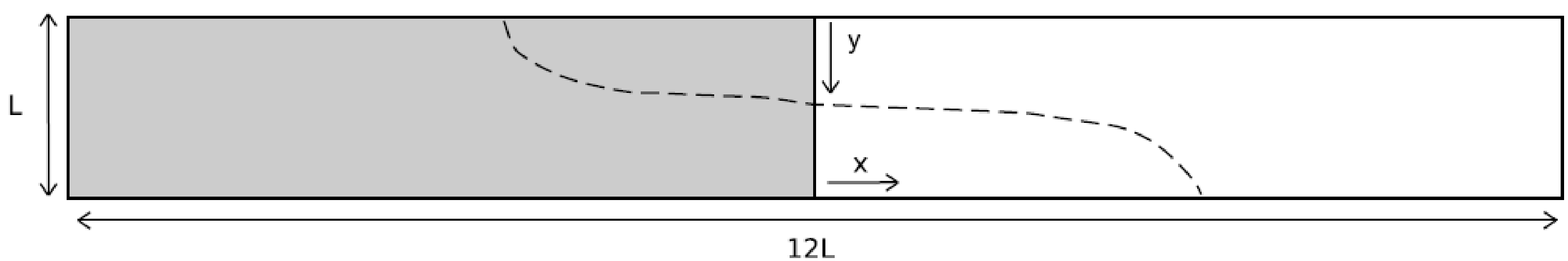
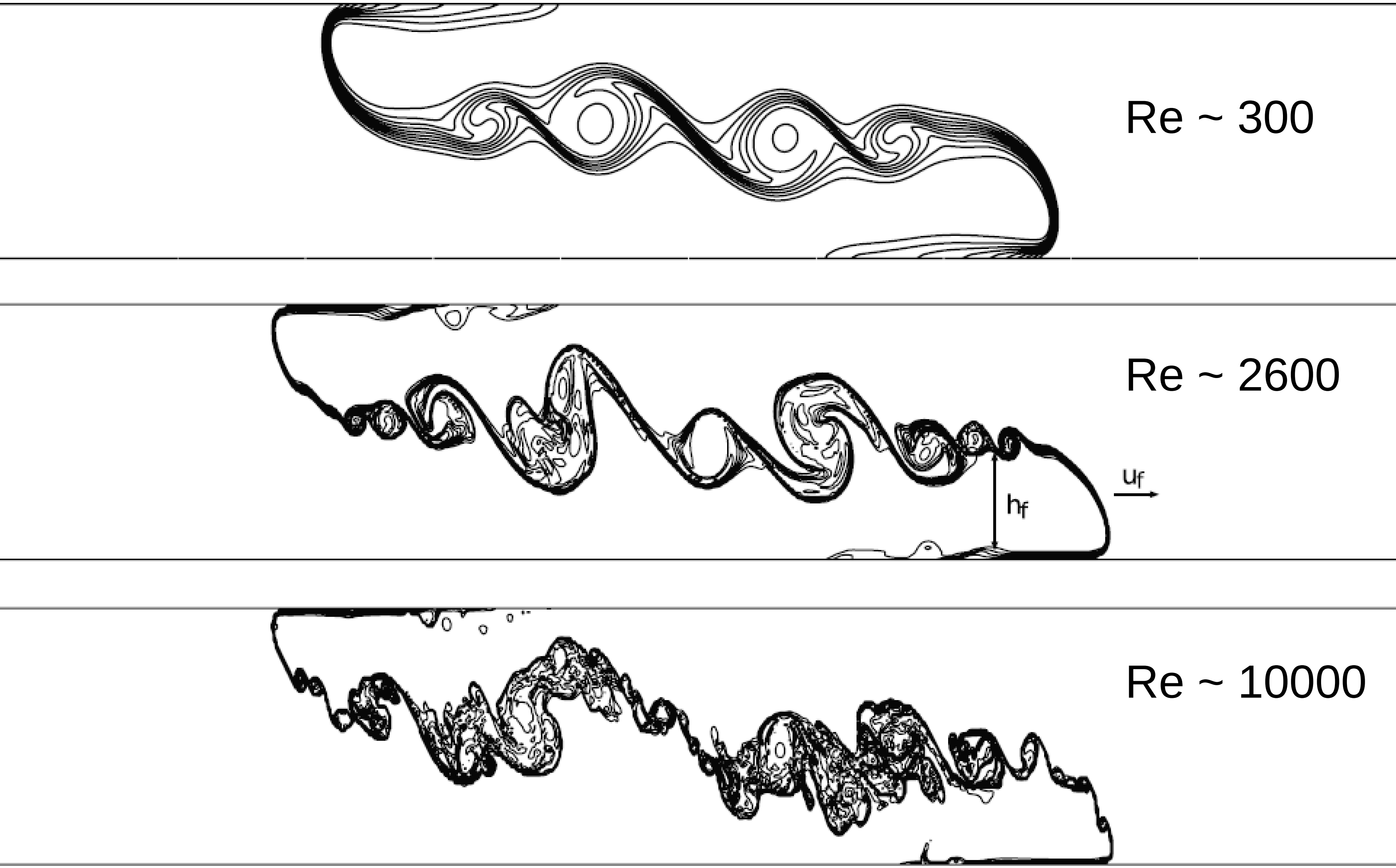
Lock-exchange problem

- Initially no flow, just density difference
- Sufficiently long channel for gravity current setup
- 2D, slip and no slip boundary conditions
- 12 boxes, with L = 0.2 x 2.4 m as per Maxworthy et al (2002) experiments

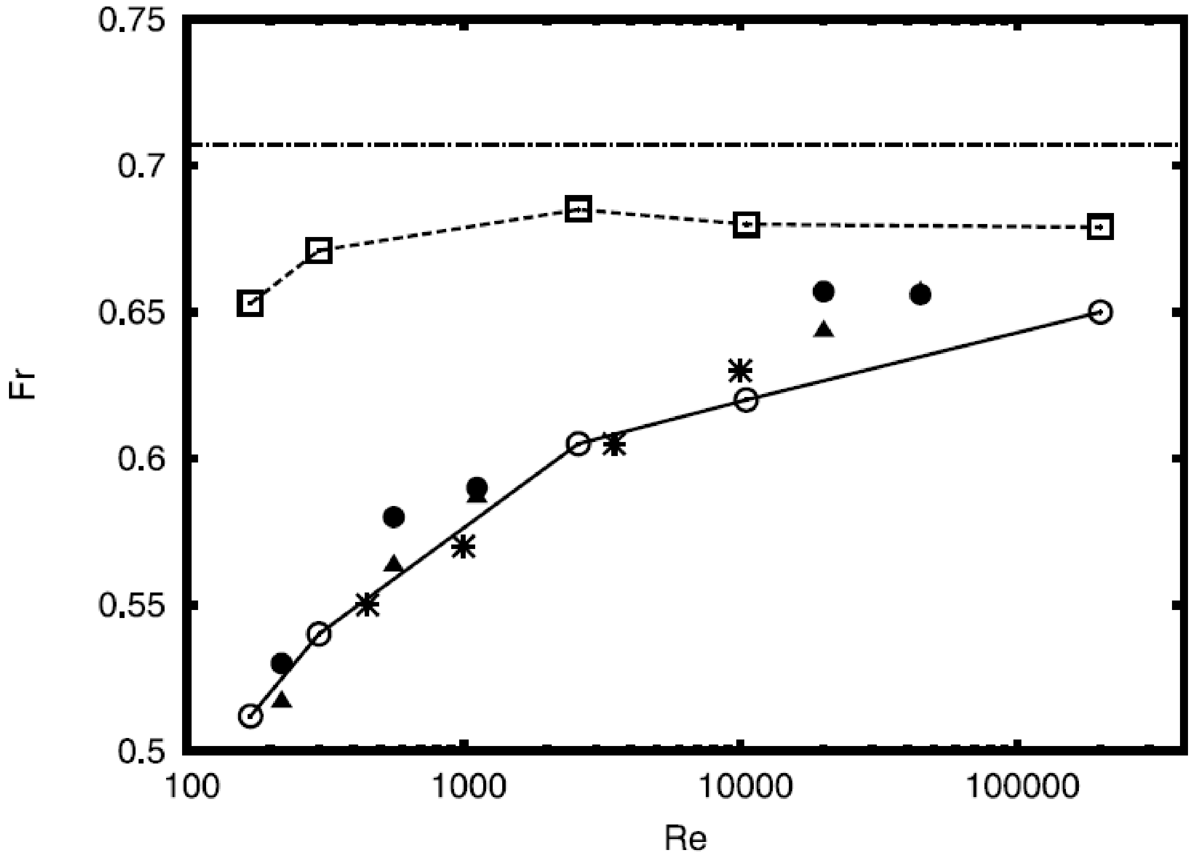


Movies…



Re ~ 300
Re ~ 2600
u_f
h_f
Re ~ 10000

Convergence to lab benchmarks



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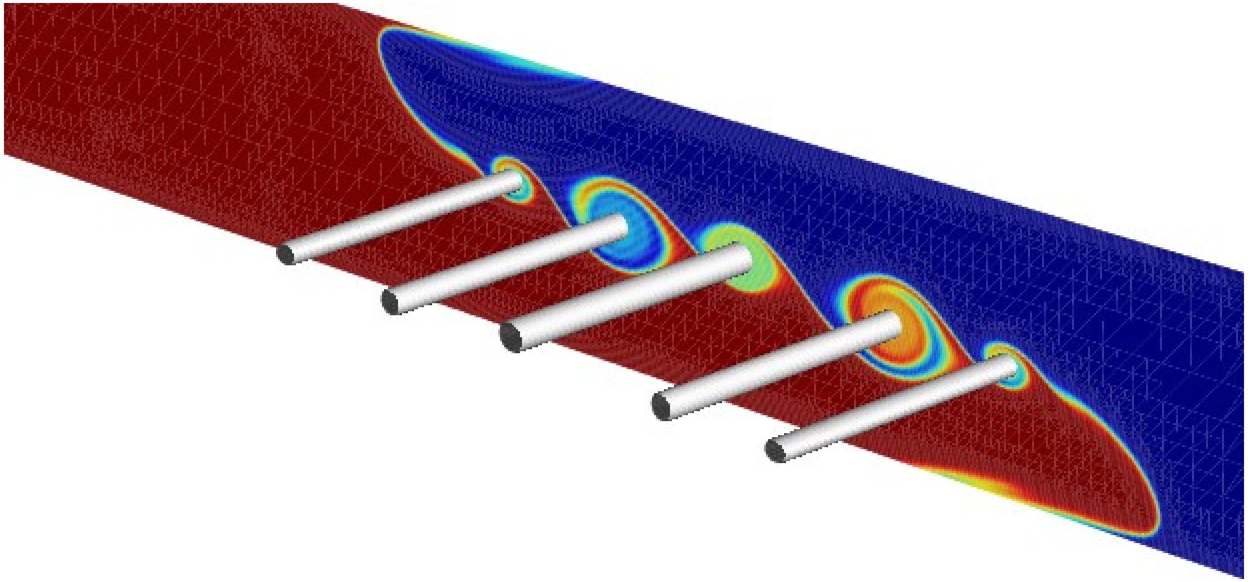
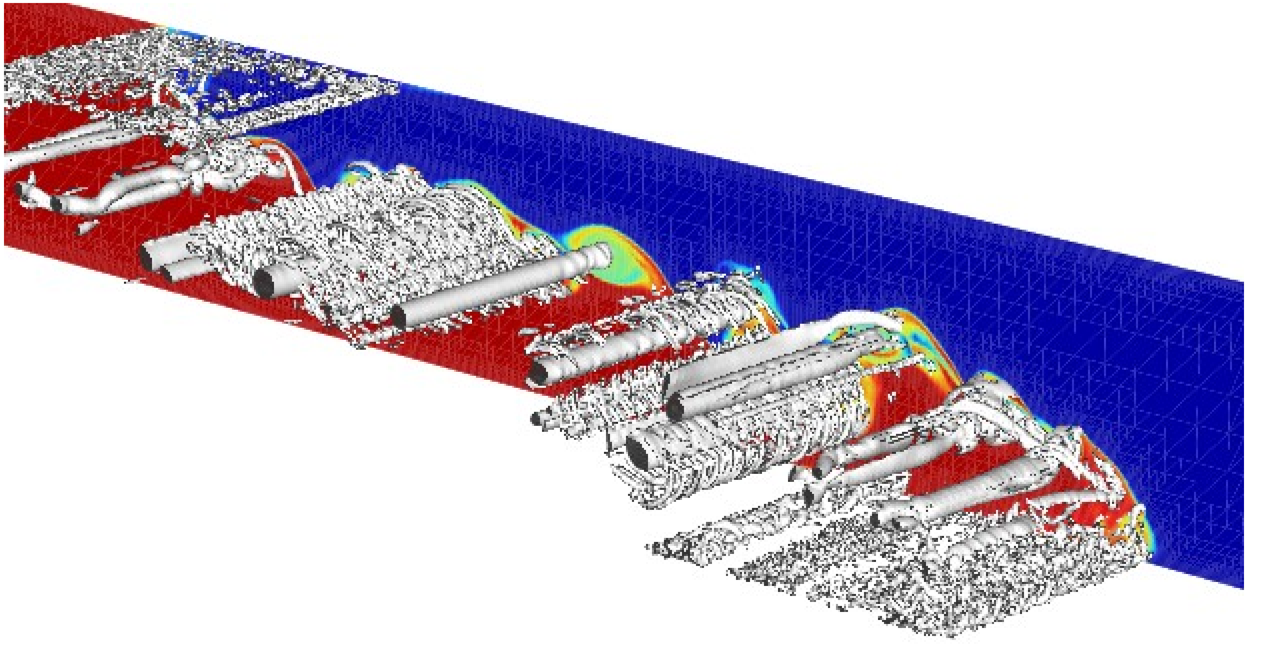
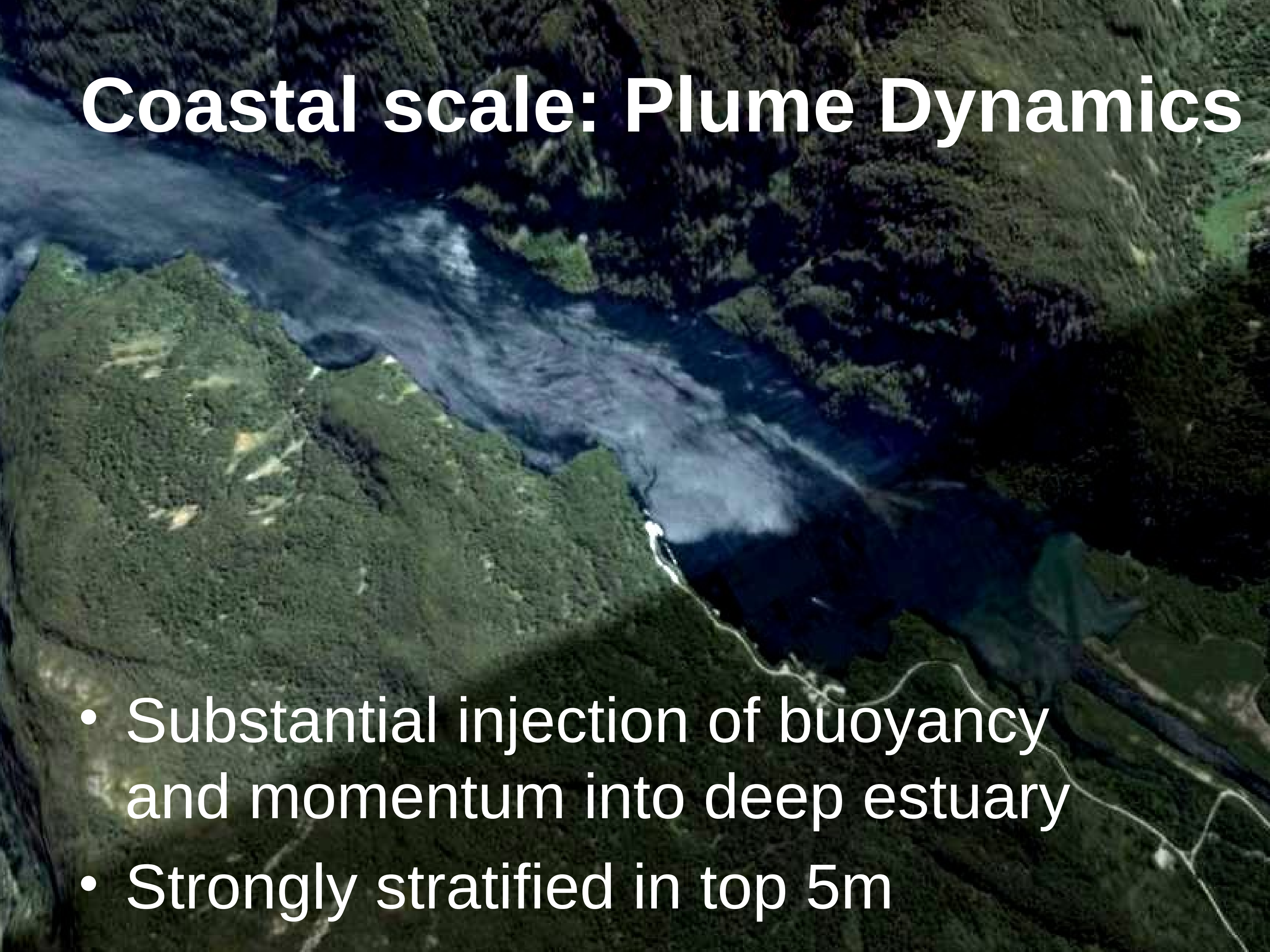
Re ~ 1000



Re ~ 10000



Near future plans: Quantify available potential energy and what differences exist between 2D and 3D lock-exchange. This will be useful for progressing to L > 100 m and be used to determine vertical stirring length scales in the coastal ocean.



Coastal scale: Plume Dynamics

- Substantial injection of buoyancy and momentum into deep estuary
- Strongly stratified in top 5m

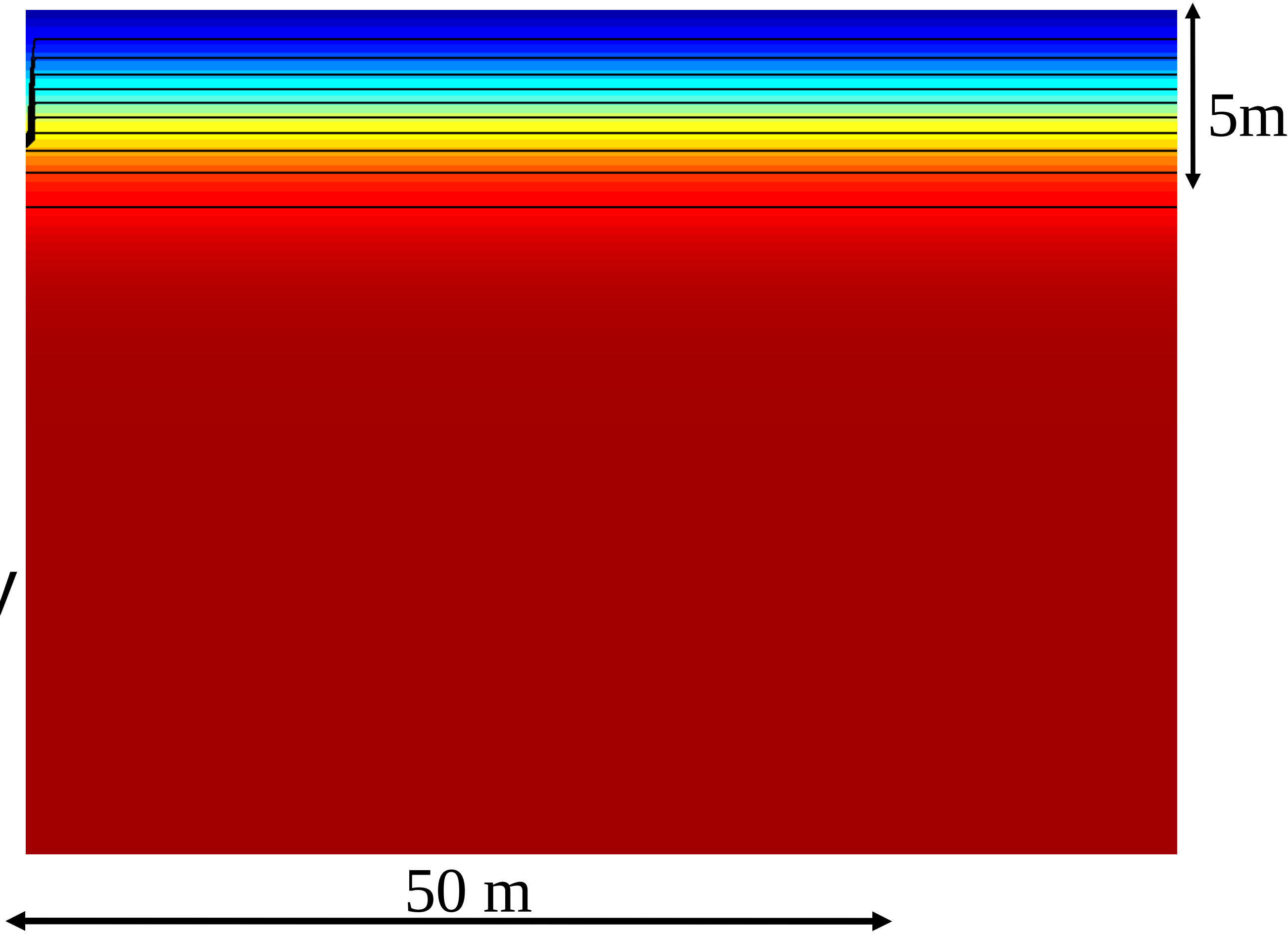
Initial plume dynamics

L = 400 x 50m

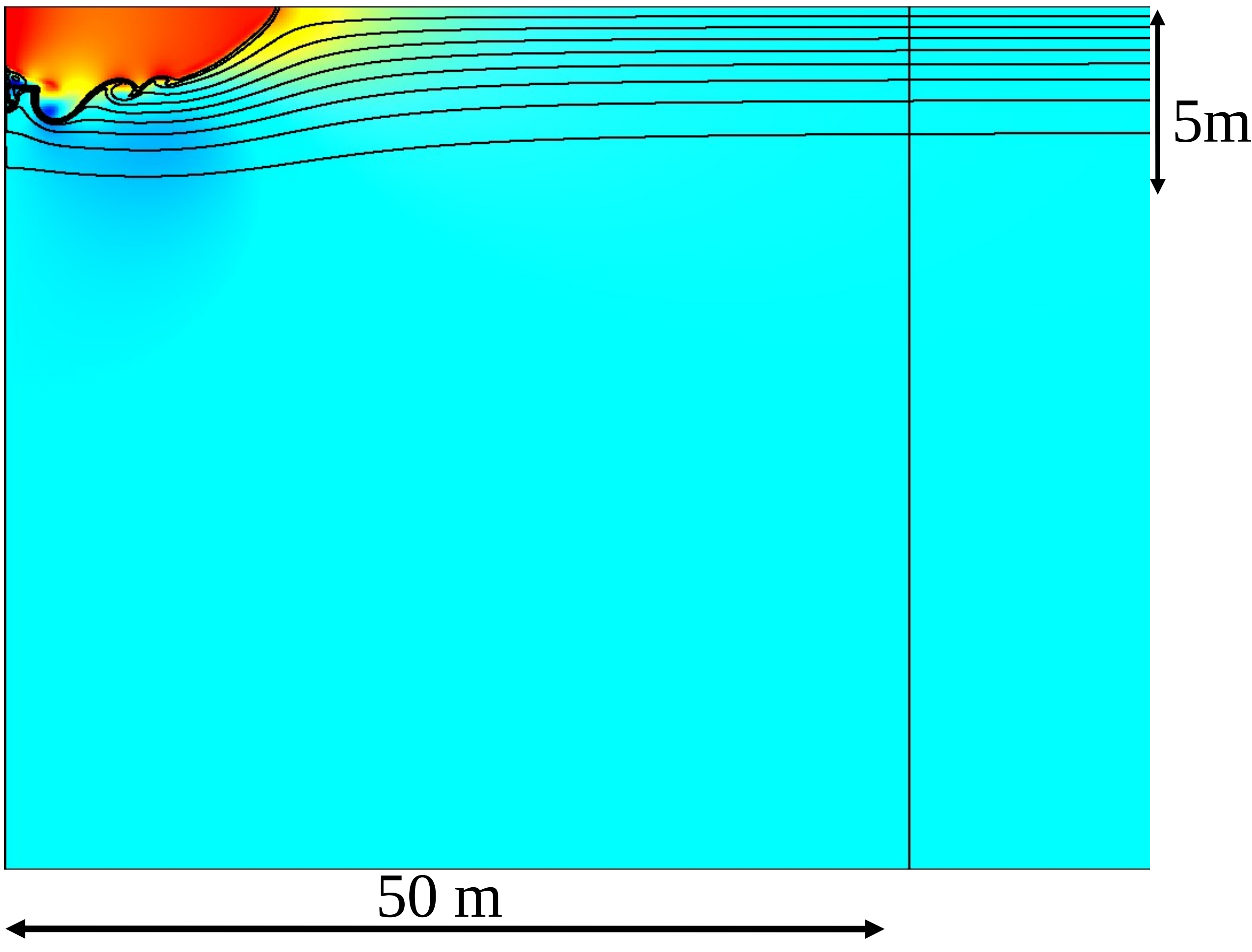
Quadtree level from 5 to 9

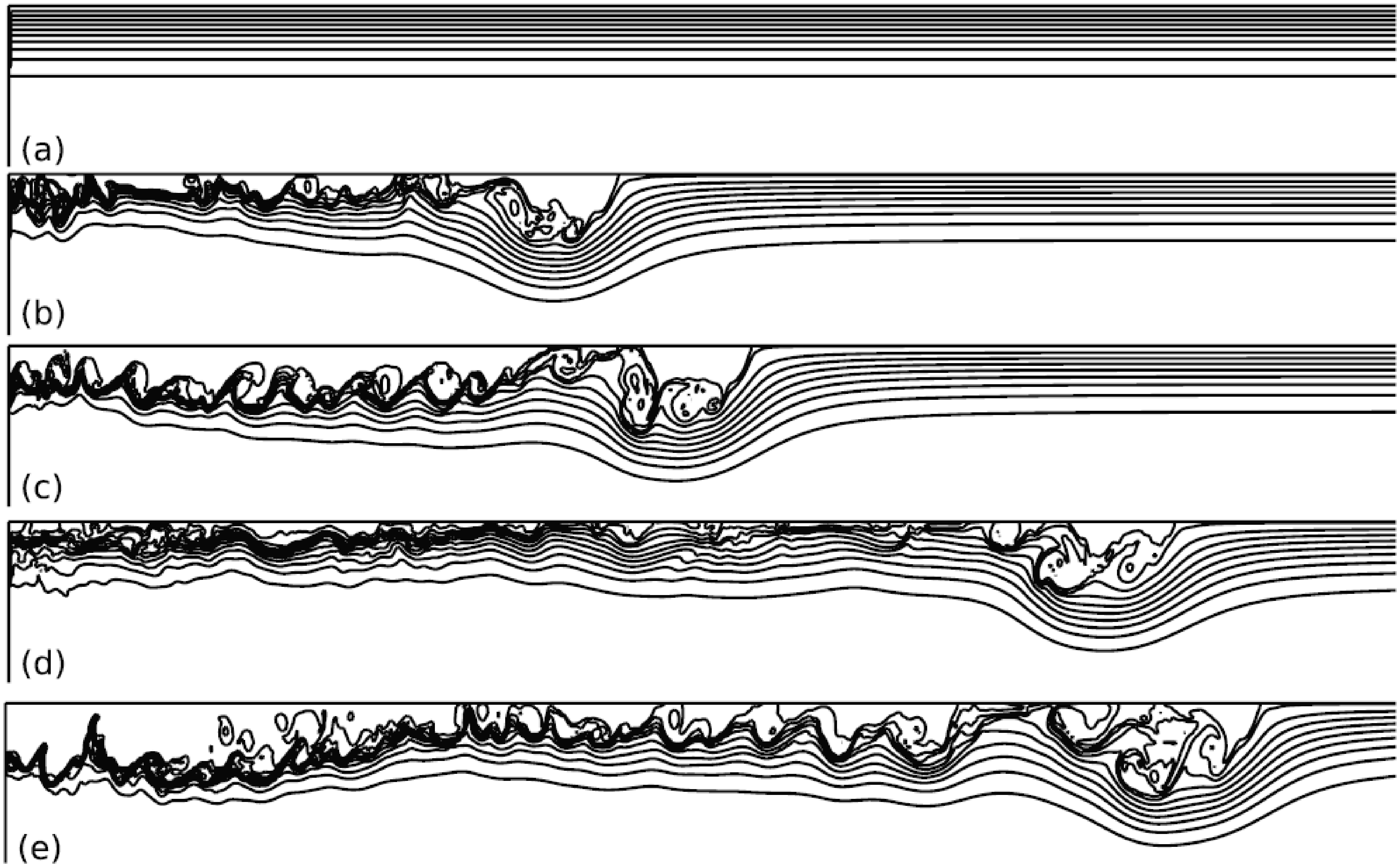
Min cell size ~ $50/2^9$ or 0.09 m

Left BC:
Gaussian velocity with low T and S to replicate less dense tailrace discharge



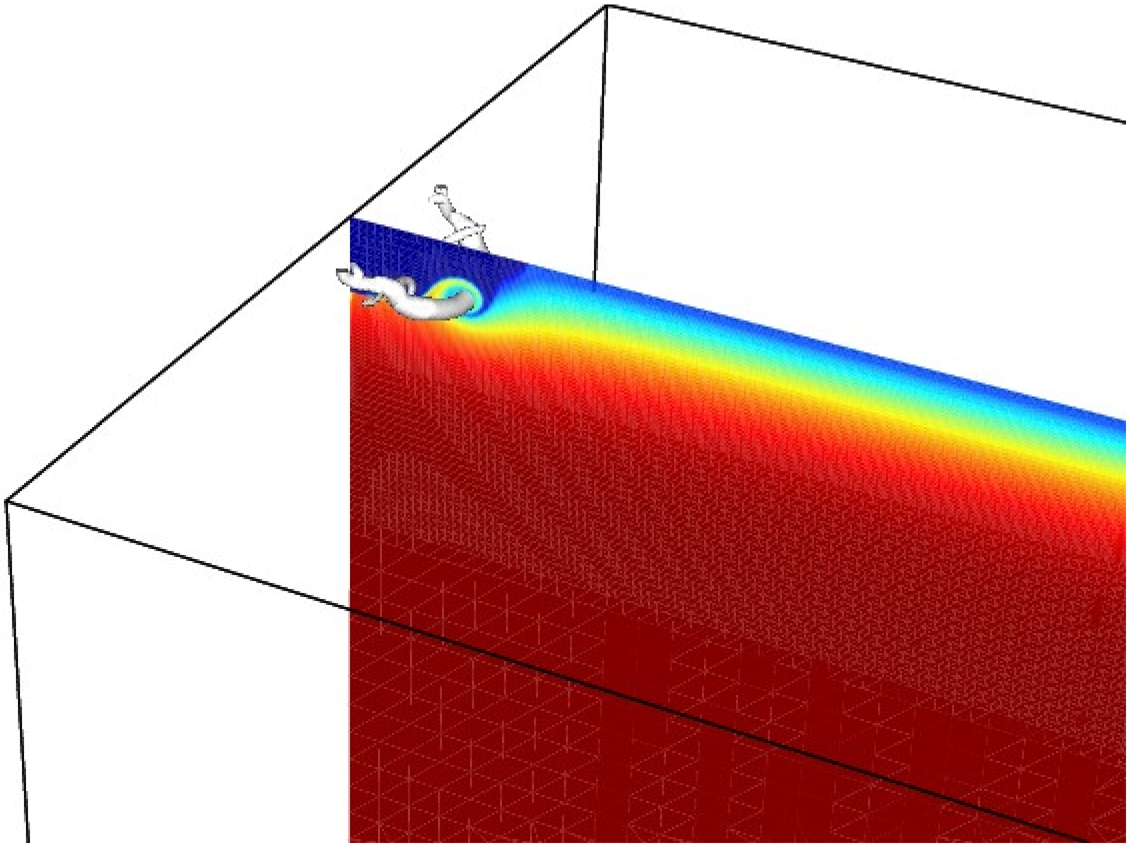
Initial plume dynamics



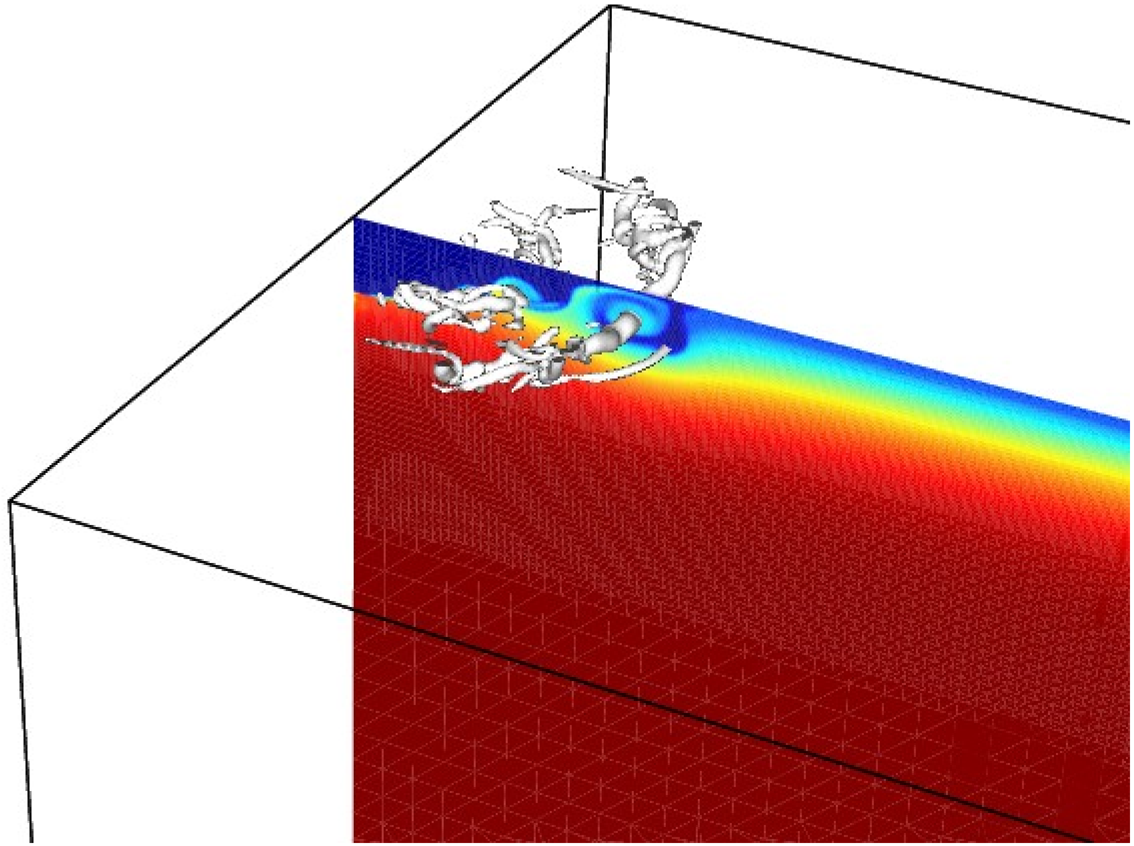


Steady momentum: b and d
Variable momentum: c and e

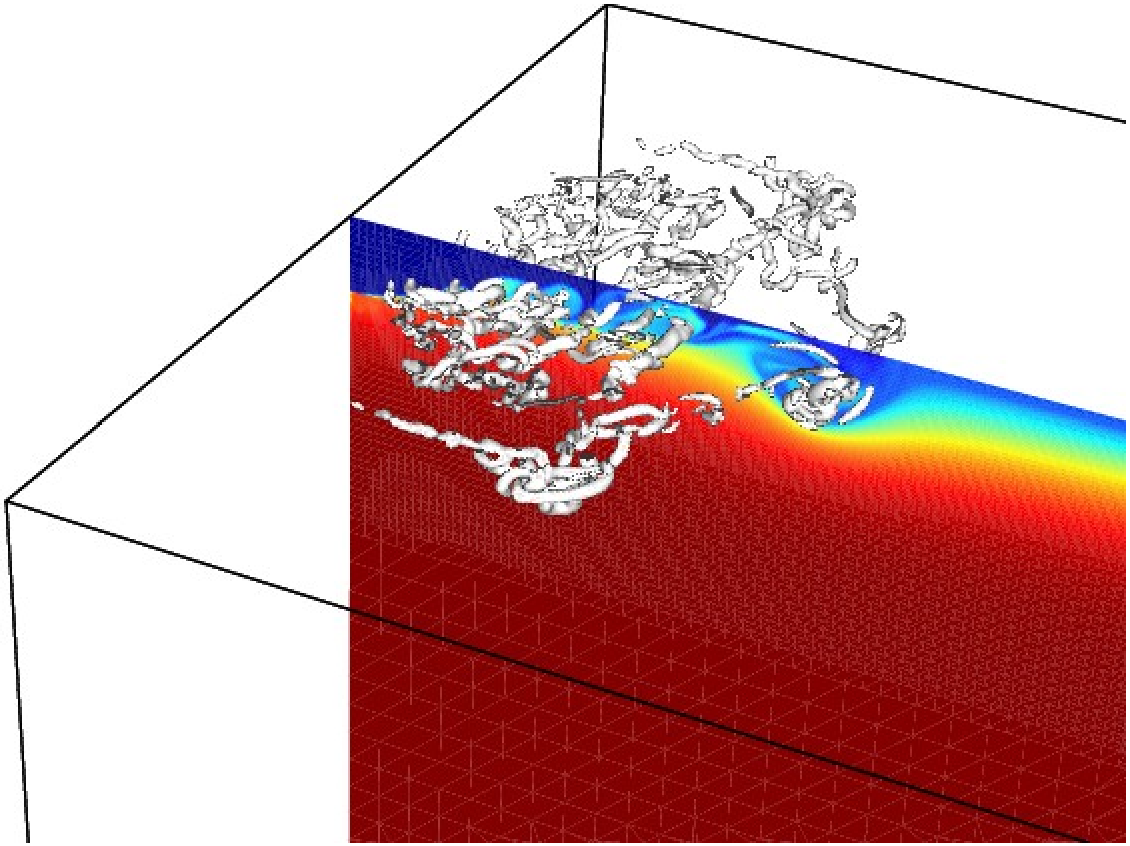
3D plume



3D plume



3D plume



Summary: Buoyant plumes

- Gravity currents forced with momentum have 30% greater velocities
- Substantial compression of the pycnocline as the gravity current passes, with multiple peaks for the variable momentum
- Order of magnitude more mixing when momentum is variable
- ~ 40-50% reduction in CPU using adaptive grid
- 3D runs hot off the press, need to think about mixing quantities in the near-field, rotation.

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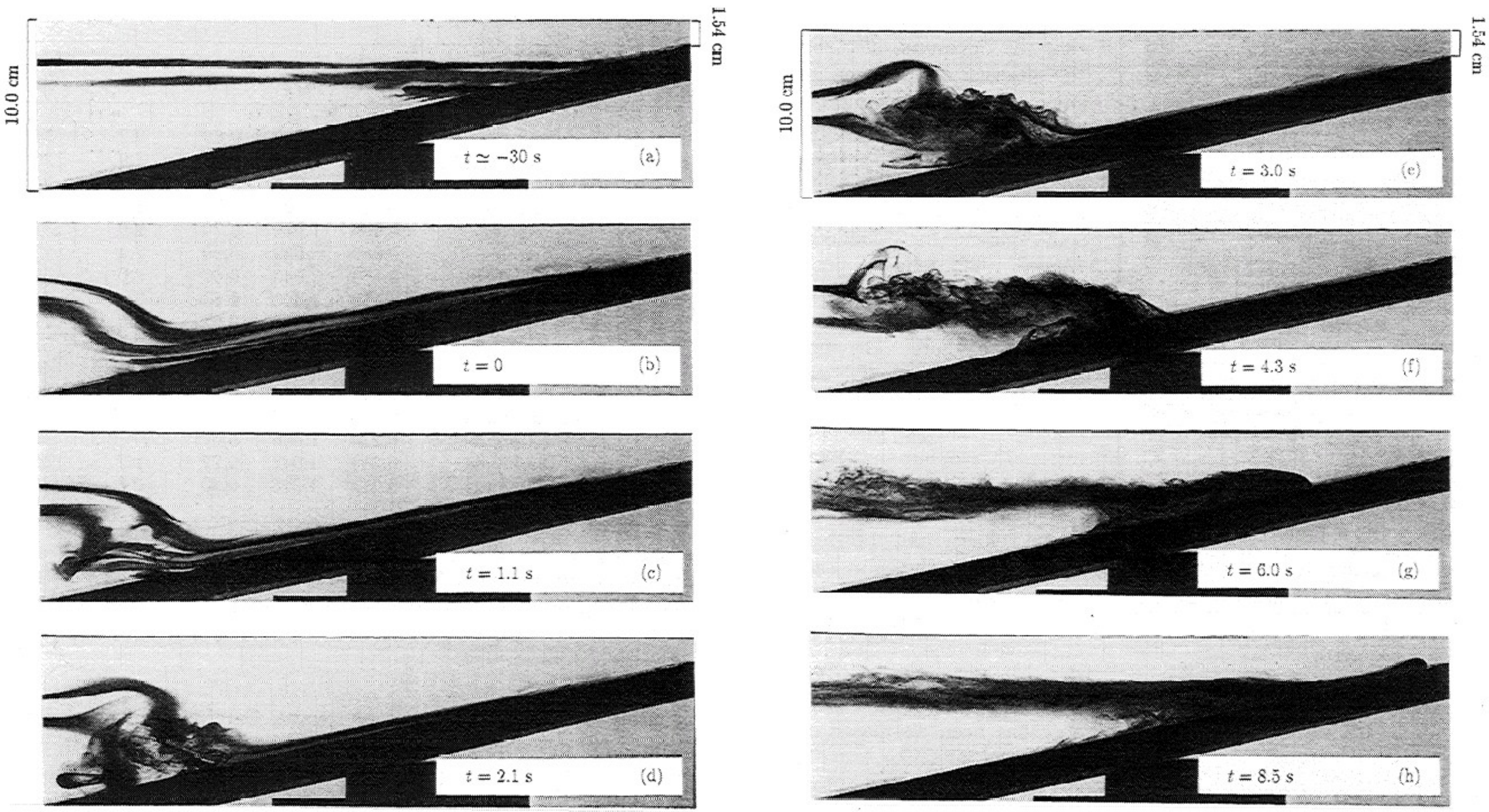
Example : Observations of Breaking of Internal Solitary Waves at Laboratory Scales



From Michallet and Ivey (1999)

Internal solitary wave (ISW) breaking

- Incompressible
- Non-linear
- Boussinesq
- Non-hydrostatic
- Only tracer is density (i.e. no equation of state in this version)
- Rigid Lid
- Viscosity = Diffusivity = 1.e-6 m2/s

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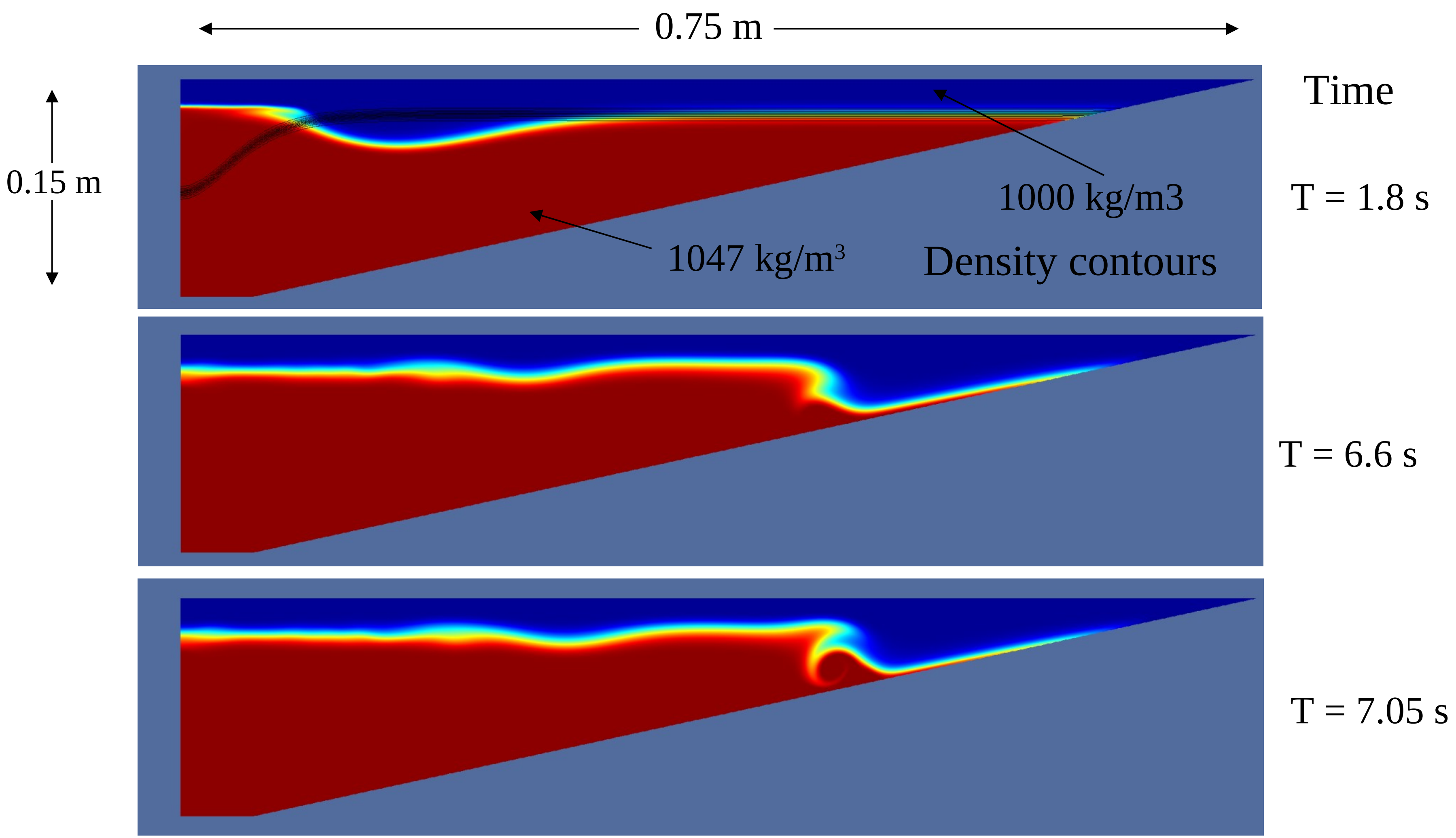
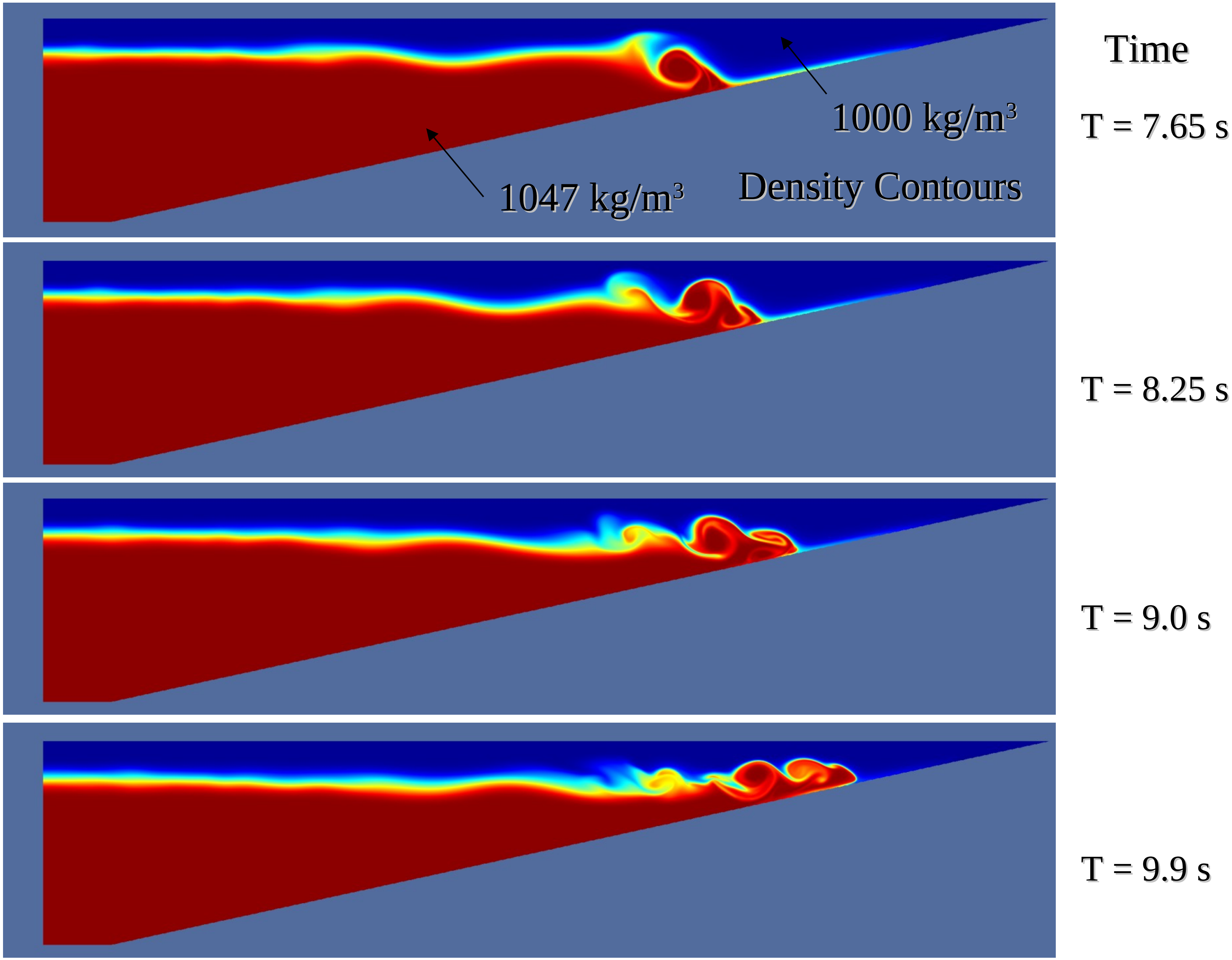
Example : Modelling of Breaking of Internal Solitary Waves at Laboratory Scales



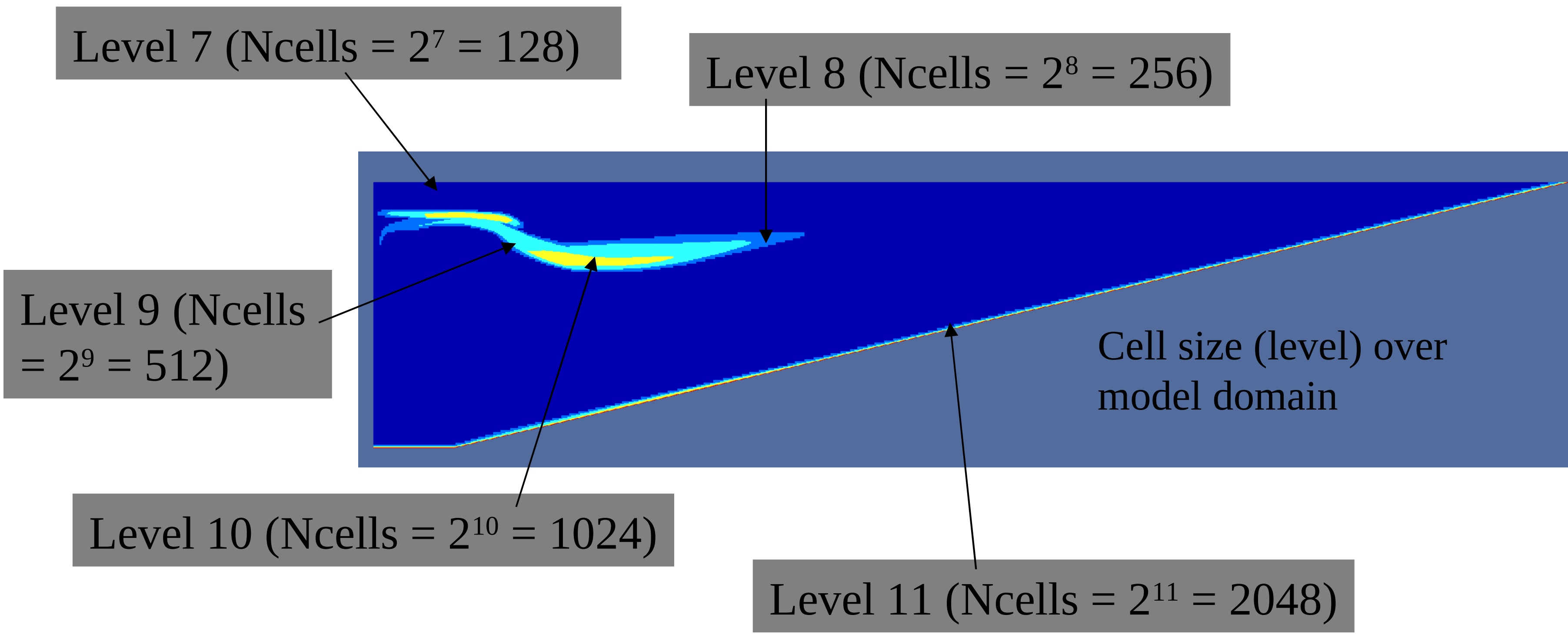


Time
T = 7.65 s
1000 kg/m3
1047 kg/m3
Density Contours
T = 8.25 s
T = 9.0 s
T = 9.9 s

For viscosity ~ 1.e^{-6} m^2/s find viscous sub-layer

Lvisc ~ 9.e^{-5} m

So that L_{ext}/L_{visc} ~ 0.15/9.e^{-5} ~ 1667



Adaptive Convergence Test

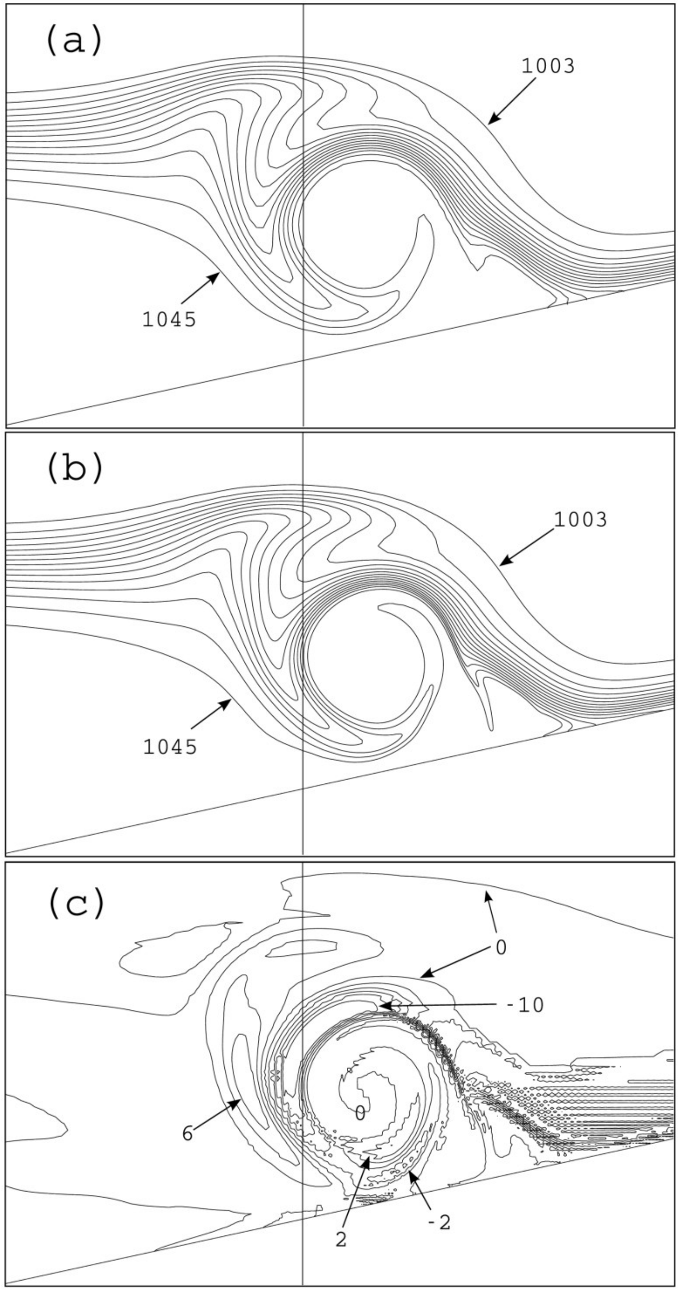
Density contours in the (x, z)-plane at time 7.5 s for:

(a)standard run with a maximum level of 9,

(b)adapting to a maximum level of resolution of 12,

(c) frame(b) - frame(a).

The height of each frame is 0.075m.



Multi-Bolus Generation

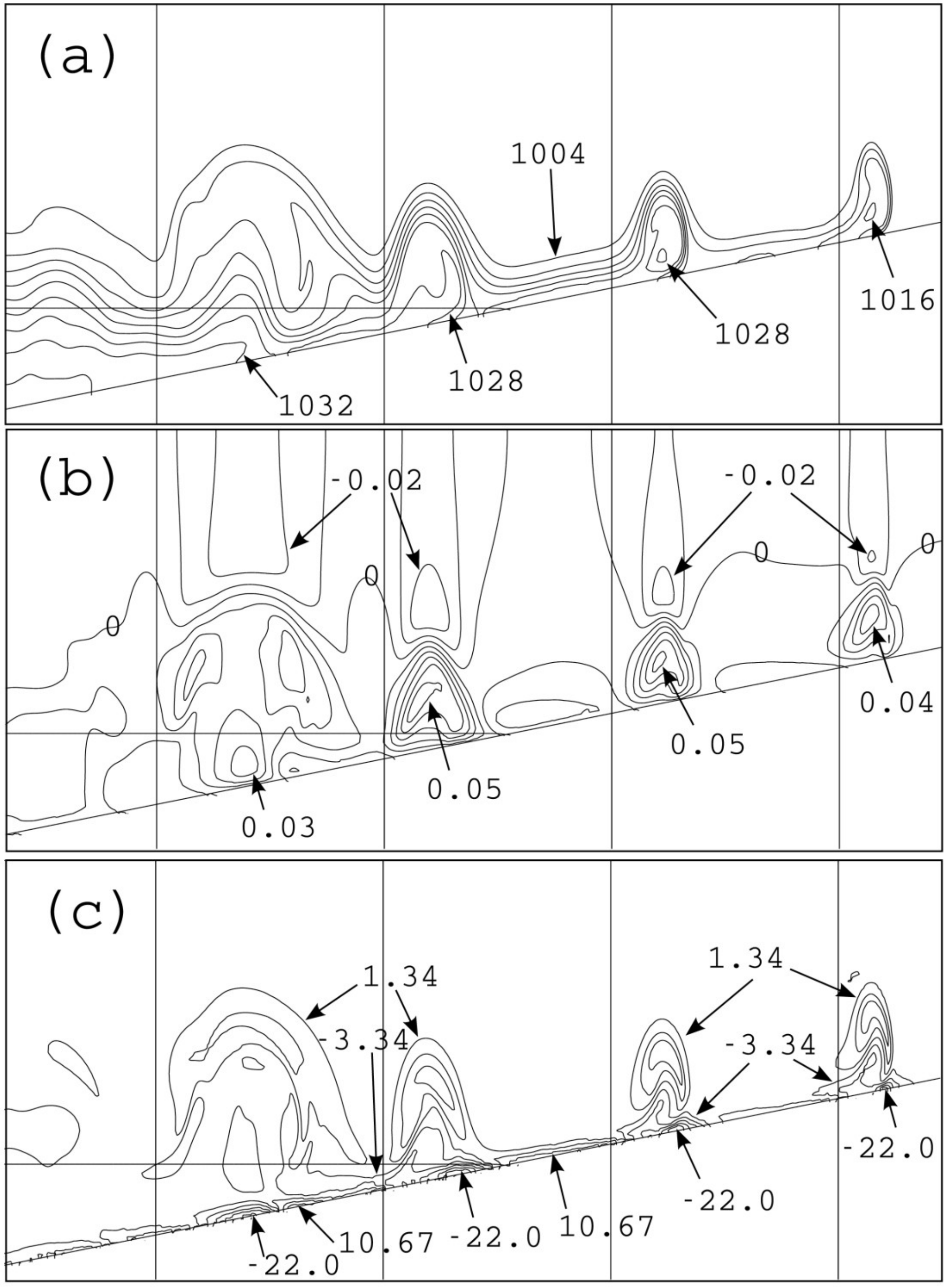
Contours in the (x, z)-plane at time 37.5 s for model experiment 2 in Table 1 of:

(a) Density

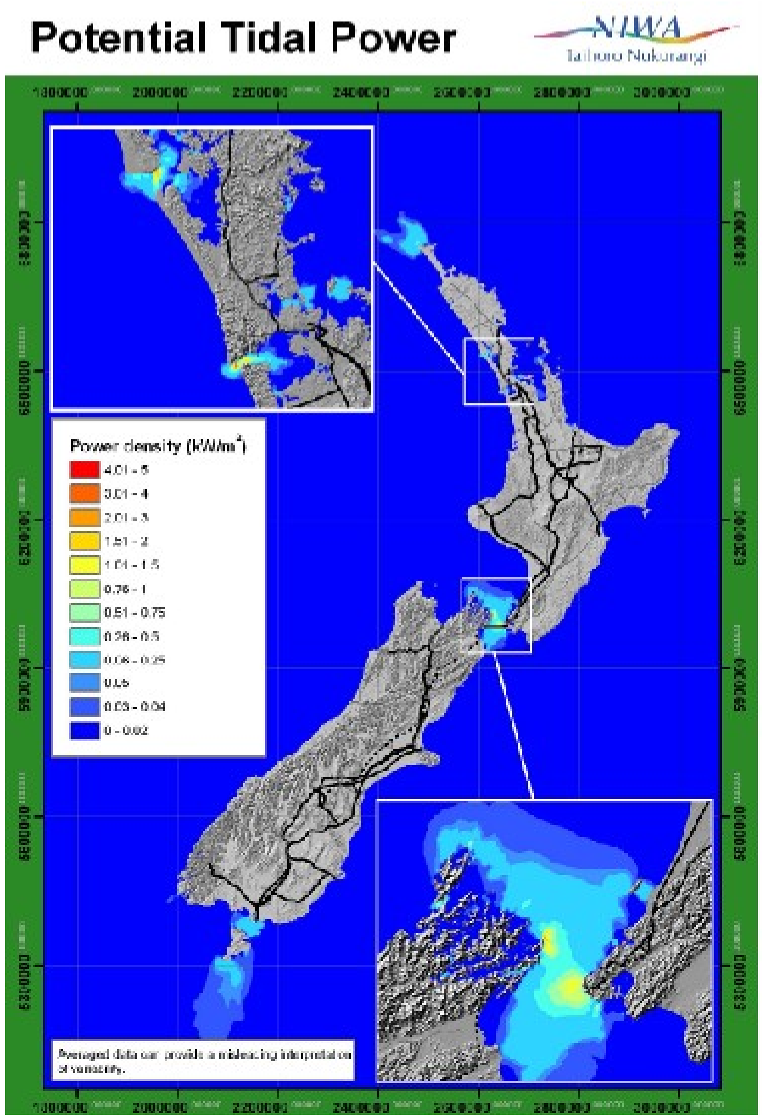
(b) x component of velocity,

(c) vorticity

The height of each frame is 0.072m. Vertical scale is four times the horizontal scale for clarity. Horizontal line inside model domain locates initial undisturbed pycnocline.



Tidal energy and optimisation of turbine arrays



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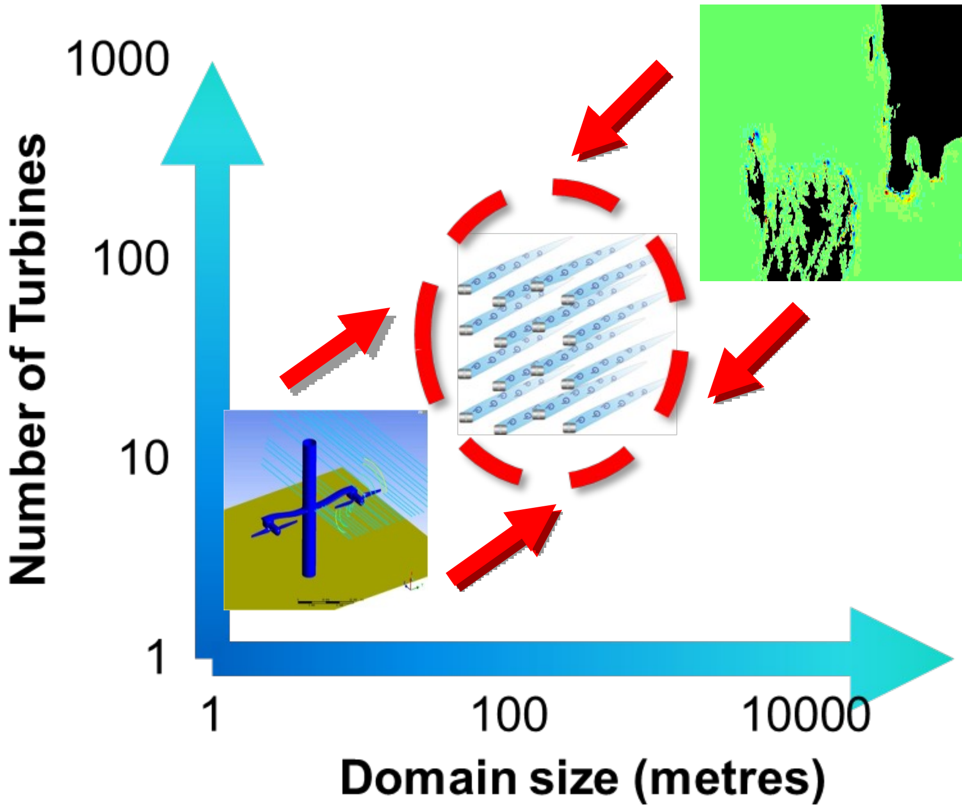
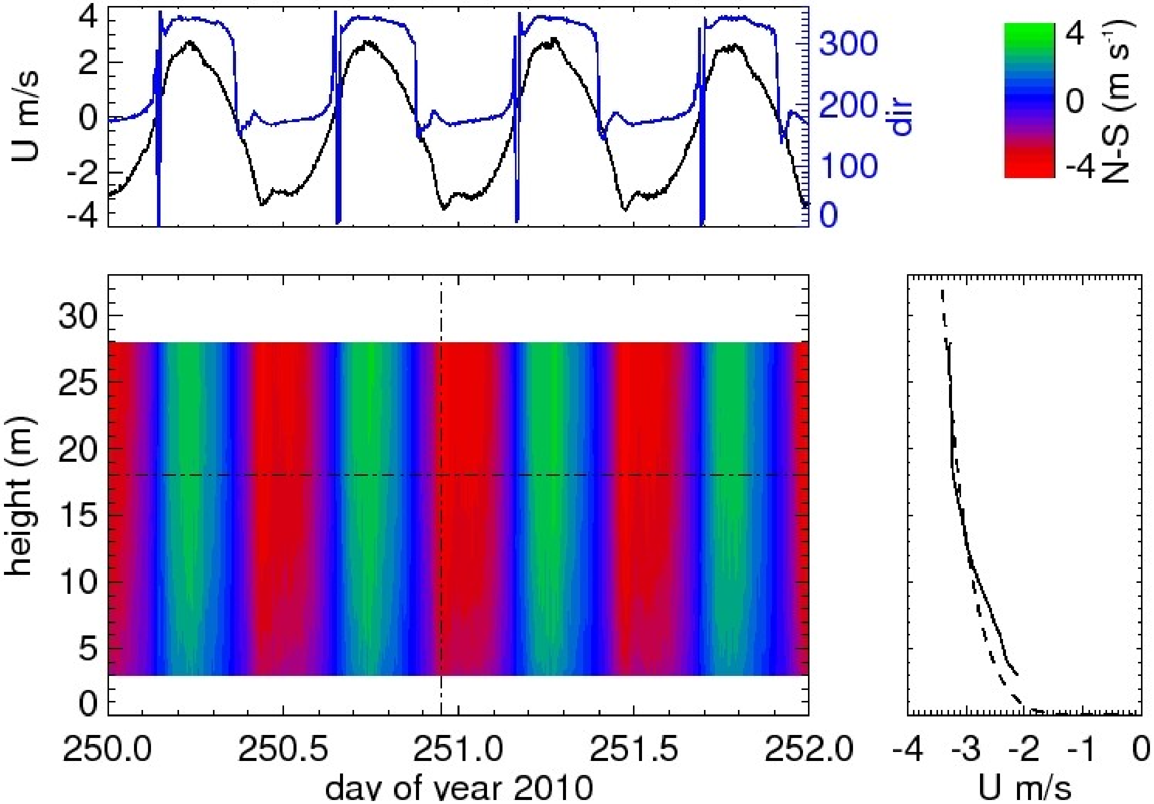


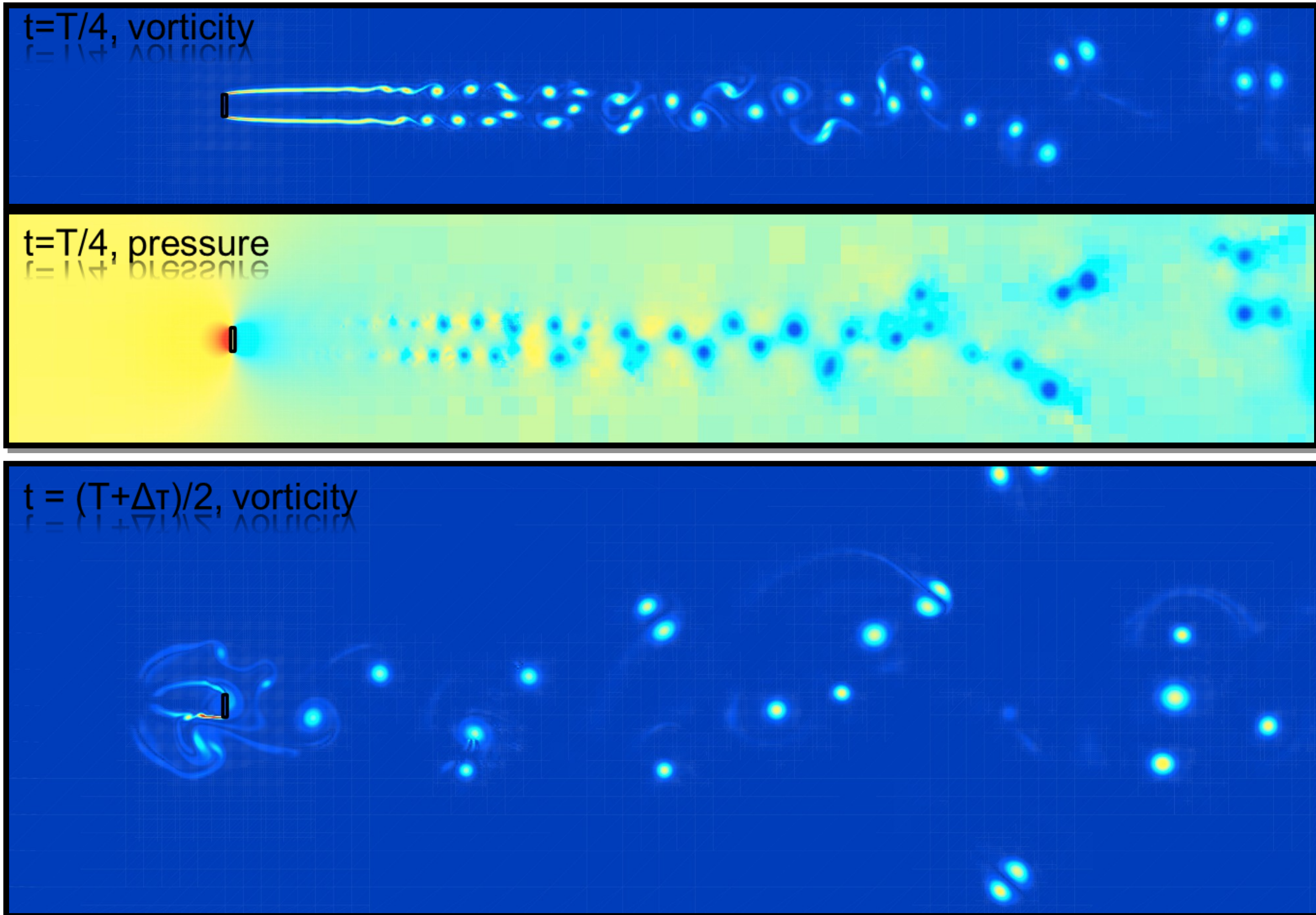
- Gerris is an adaptive grid flow solver
- Shallow water equations with linear free surface
- Turbines: rectangular step of increased bottom friction
- Start with single turbine
- Build up to an array

Current at Cape Terawhiti, Cook Strait

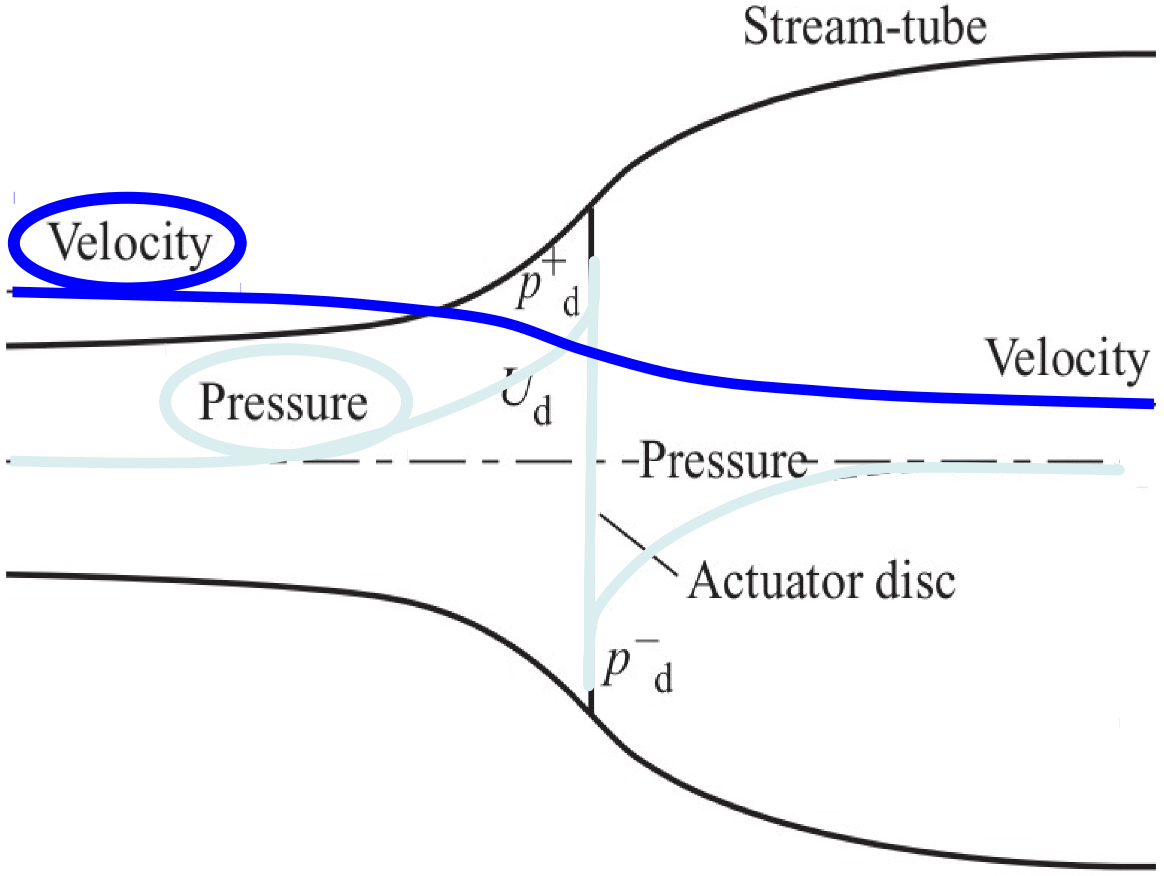


Strong bidirectional, boundary layer flow up to 3.4 m s^{-1}

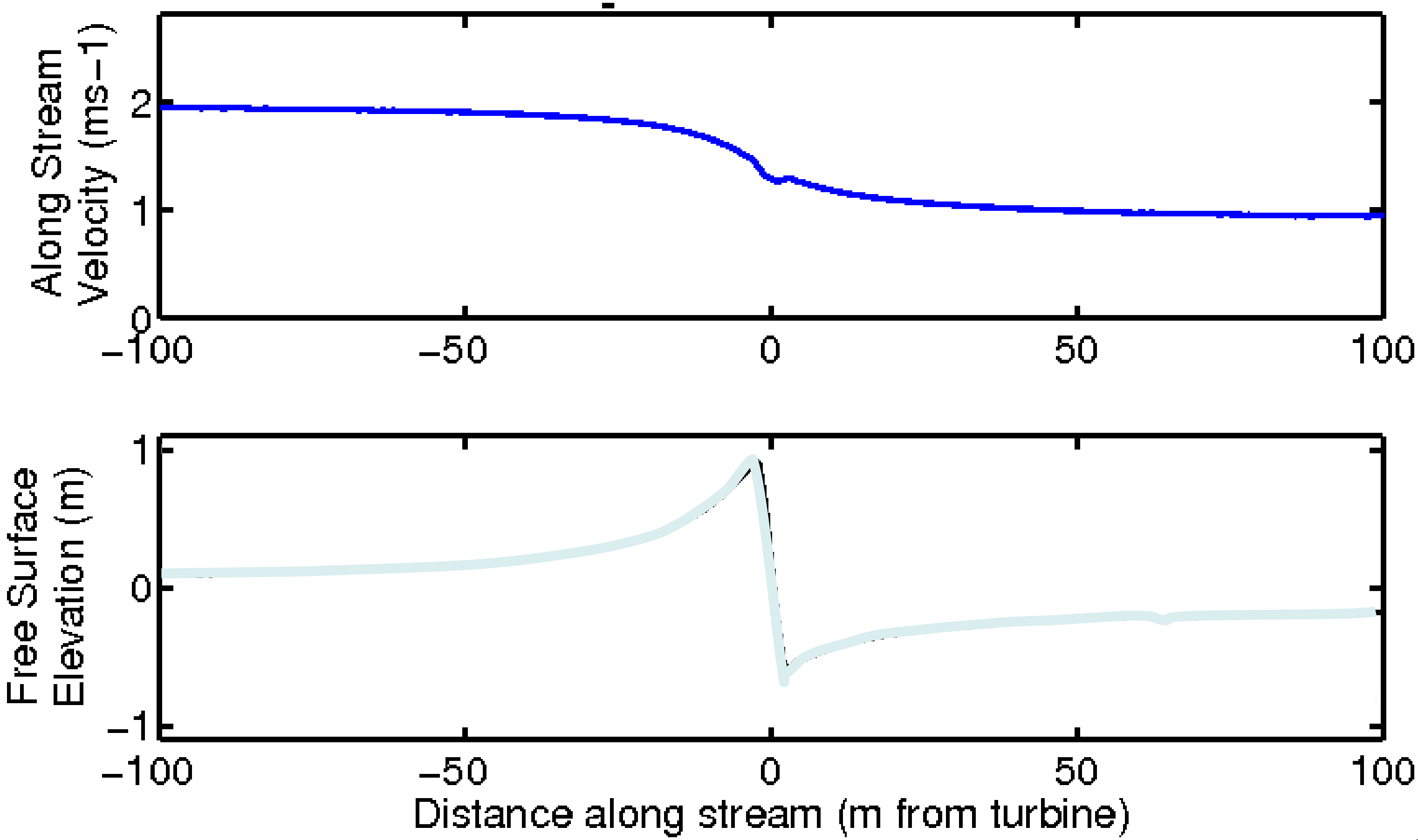
Results: Single Turbine at Optimised Drag

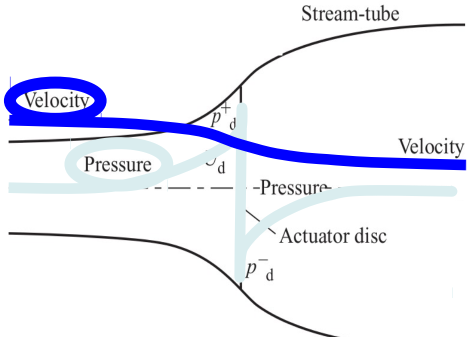


Actuator disc theory predicts a sharp pressure drop and a gradual velocity drop across the turbine



Results: turbine compares qualitatively well with actuator disc





Future scope

- Capturing stratification at coastal scales. Progressing plume simulations to real systems and include wind stress.
- Flow through fish cages with the intention of high resolution dissolved oxygen modelling.
- Rickard et al, Ocean Modelling, 30, 2009
- O'Callaghan et al, Journal of Geophysical Research, 115, 2010