Computational Investigations of Gravity and Turbidity Currents

Eckart Meiburg
UC Santa Barbara

- *Motivation*
- *Governing equations / computational approach*
- *Results*
  - *2D/3D turbidity currents*
  - *inversion: reconstruction of turbidity current*
  - *current/sediment bed interaction*
  - *current/submarine structure interaction*
- *Summary and outlook*

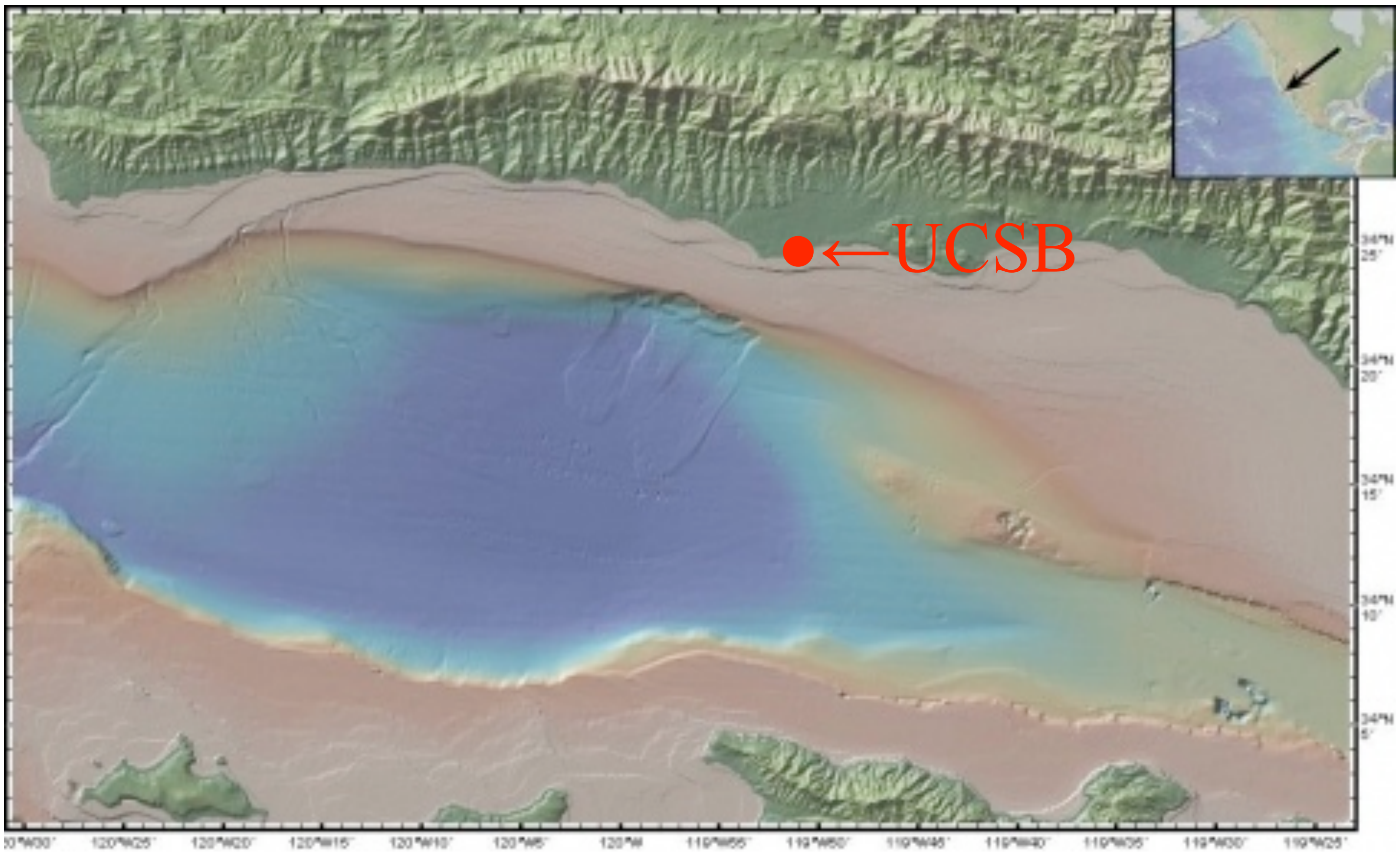
UCSB

Turbidity current

- *Underwater sediment flow down the continental slope*
- *Can transport many km^3 of sediment*
- *Can flow O(1,000)km or more*
- *Often triggered by storms or earthquakes*
- *Repeated turbidity currents in the same region can lead to the formation of hydrocarbon reservoirs*
- *Properties of turbidite:*
  - *particle layer thickness*
  - *particle size distribution*
  - *pore size distribution*

Turbidity current.
http://www.clas.ufl.edu/

Turbidity current (cont'd)



Off the coast of Santa Barbara/Goleta

Framework: Dilute flows

Volume fraction of particles of $O(10^{-2} - 10^{-3})$:

- *particle radius « particle separation*
- *particle radius « characteristic length scale of flow*
- *coupling of fluid and particle motion primarily through momentum exchange, not through volumetric effects*
- *effects of particles on fluid continuity equation negligible*

Moderately dilute flows: Two-way coupling

Mass fraction of heavy particles of O(10%), small particle inertia (e.g., sediment transport):

- *particle loading modifies effective fluid density*
- *particles do not interact directly with each other*

Current dynamics can be described by:

- *incompressible continuity equation*
- *variable density Navier-Stokes equation (Boussinesq)*
- *conservation equation for the particle concentration field*

$\rightarrow$ *don't resolve small scale flow field around each particle, but only the large fluid velocity scales ('SGS model')*

Moderately dilute flows: Two-way coupling (cont'd)

$$\nabla \cdot \vec{u}_f = 0$$

$$\frac{\partial \vec{u}_f}{\partial t} + \left(\vec{u}_f \cdot \nabla\right) \vec{u}_f = -\nabla p + \frac{1}{Re}\nabla^2 \vec{u}_f + c\,\vec{e}_g$$

effective density

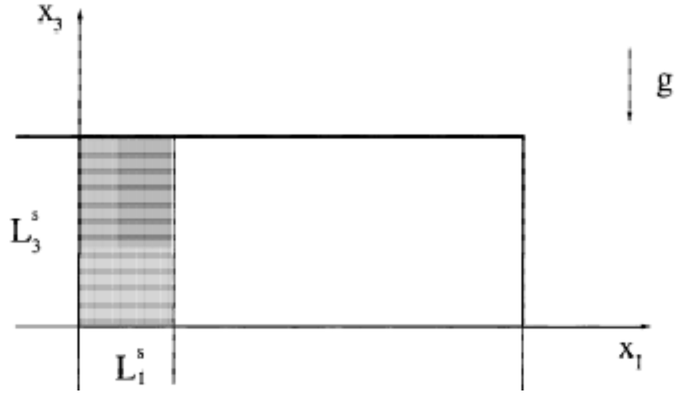
$$\frac{\partial c}{\partial t} + \left[\left(\vec{u}_f + \vec{U}_s\right)\nabla\right] c = \frac{1}{Sc\,Re}\nabla^2 c$$

settling velocity

$$Re = \frac{u_b\,L}{\nu} \quad , \quad Sc = \frac{\nu}{D} \quad , \quad U_s = \frac{u_s}{u_b}$$

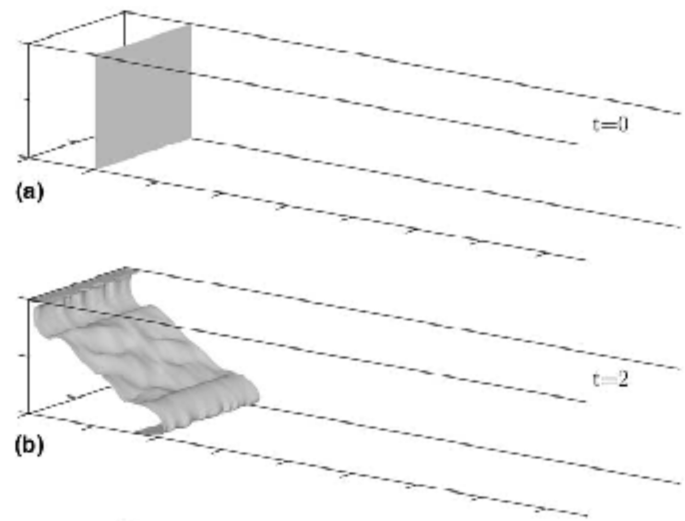
Model problem (with C. Härtel, L. Kleiser, F. Necker)

Lock exchange configuration



Dense front propagates along bottom wall

Light front propagates along top wall



Numerical method

- *Fourier spectral method in the streamwise and spanwise directions*
- *sixth order compact finite difference method or spectral element method in the vertical direction*
- *third order Runge-Kutta time stepping*
- *mostly equidistant grids*
- *up to 70 million grid points*

Results: 3D turbidity current – Temporal evolution

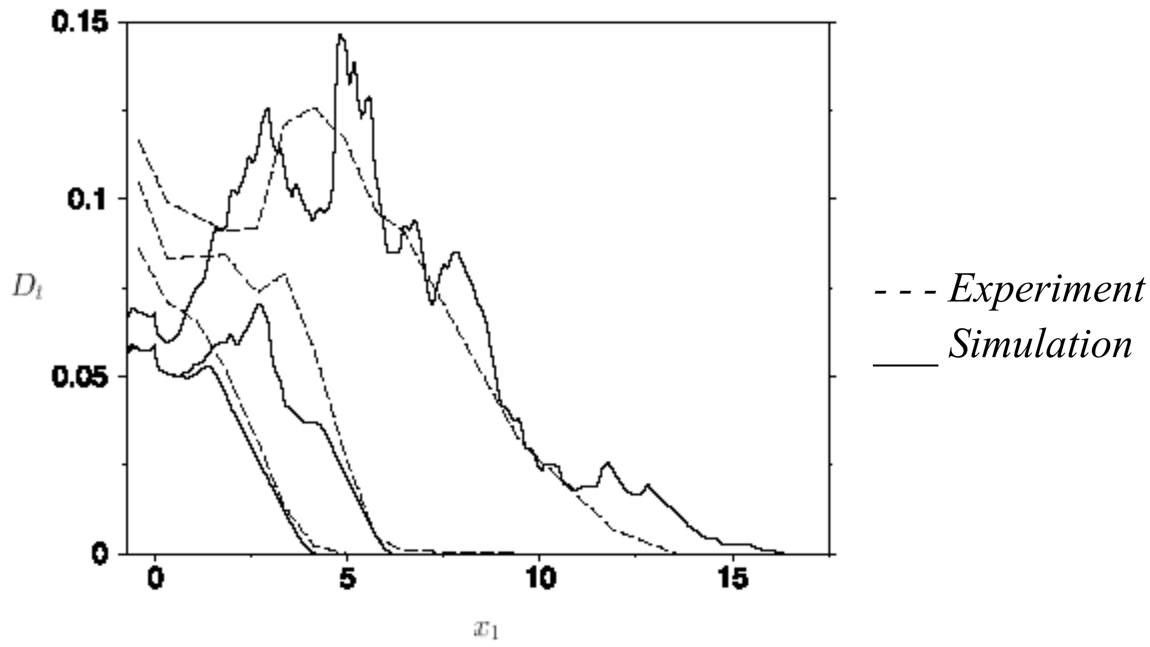
DNS simulation (Fourier, spectral element, 7x10^7 grid points)

Necker, Härtel, Kleiser and Meiburg (2002a,b)

- *turbidity current develops lobe-and-cleft instability of the front*
- *current is fully turbulent*
- *erosion, resuspension not accounted for*

Results: Deposit profiles

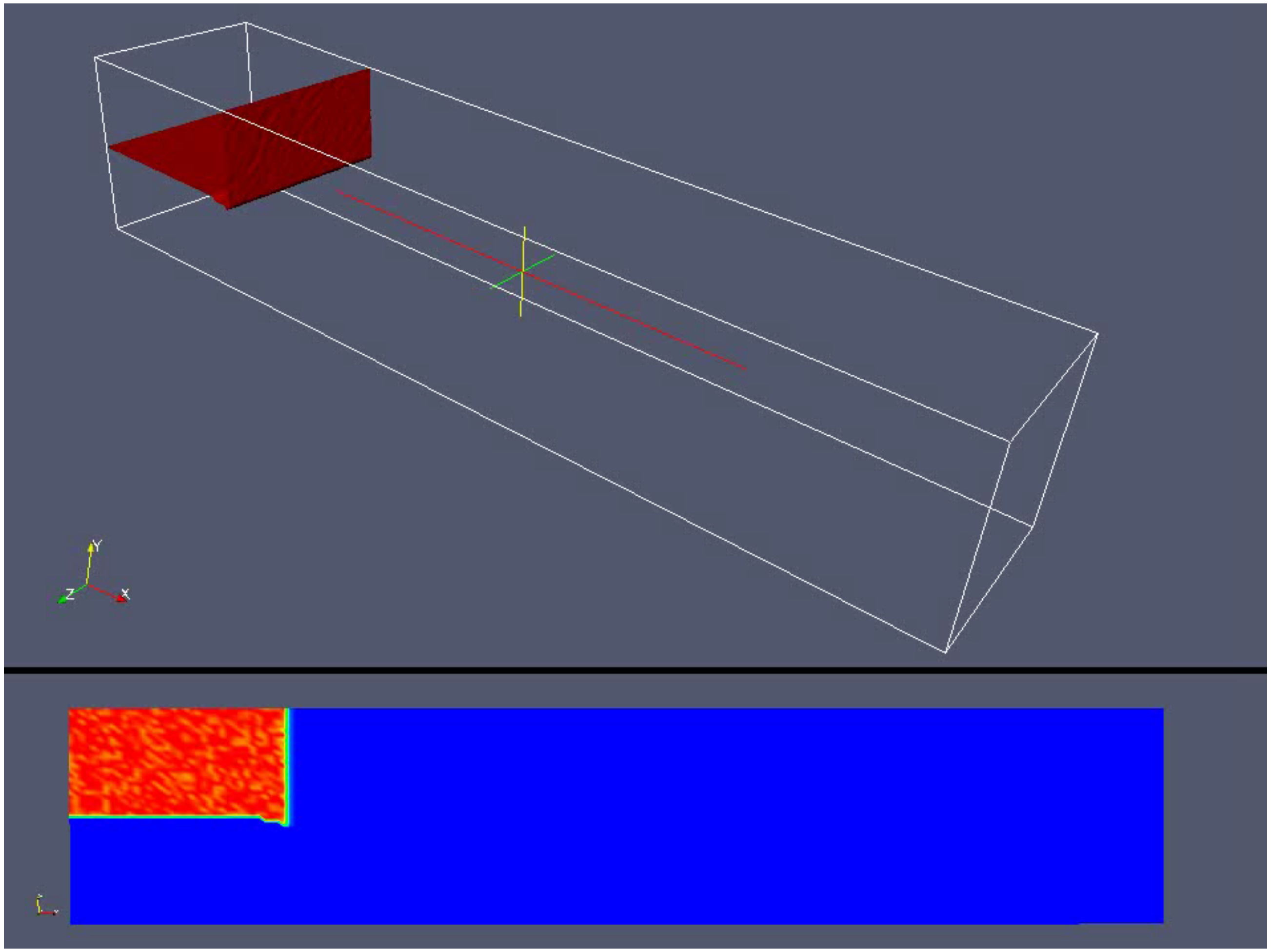
Comparison of transient deposit profiles with experimental data of de Rooij and Dalziel (1998)



• *simulation reproduces experimentally observed sediment accumulation*

Current extensions: More complex geometry, e.g. filling of a minibasin (w. M. Nasr, B. Hall)

Interaction of gravity currents with submarine topography:



Erosion, resuspension of particle bed (with F. Blanchette, M. Strauss, B. Kneller, M. Glinsky)

Experimentally determined correlation by Garcia & Parker (1993) evaluates resuspension flux at the particle bed surface as function of:

- *bottom wall shear stress*
- *settling velocity*
- *particle Reynolds number*

Here we model this resuspension as diffusive flux from the particle bed surface into the flow

Erosion, resuspension of particle bed (cont'd)

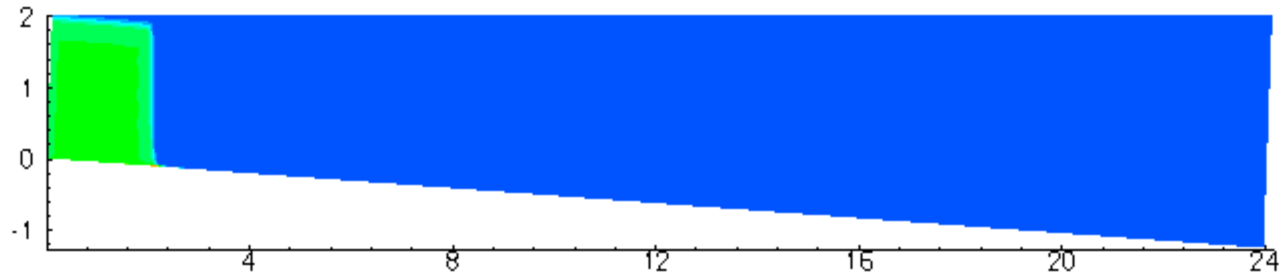
$\rho_p = 1.5 g/cm^3$, $r_p = 50 \mu m$, $\nu = 10^{-6} m^2/s$

current height $= 1.6m$

initial concentration $= 0.5\%$

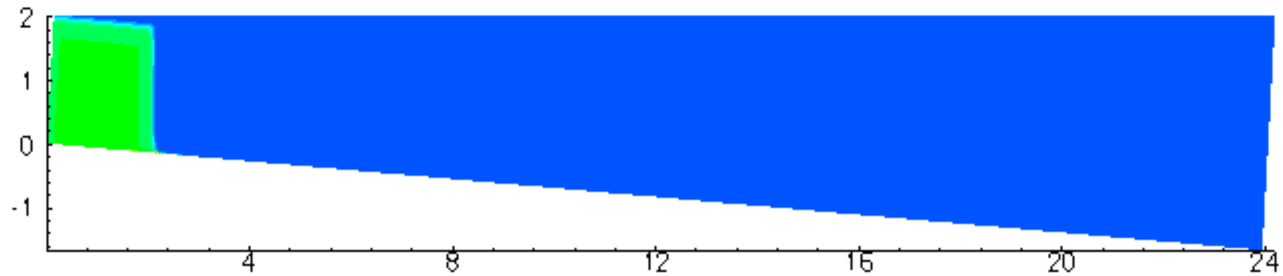
Re $= 2,200$:

slope angle $= 3^o$:



deposition outweighs erosion: decaying turbidity current

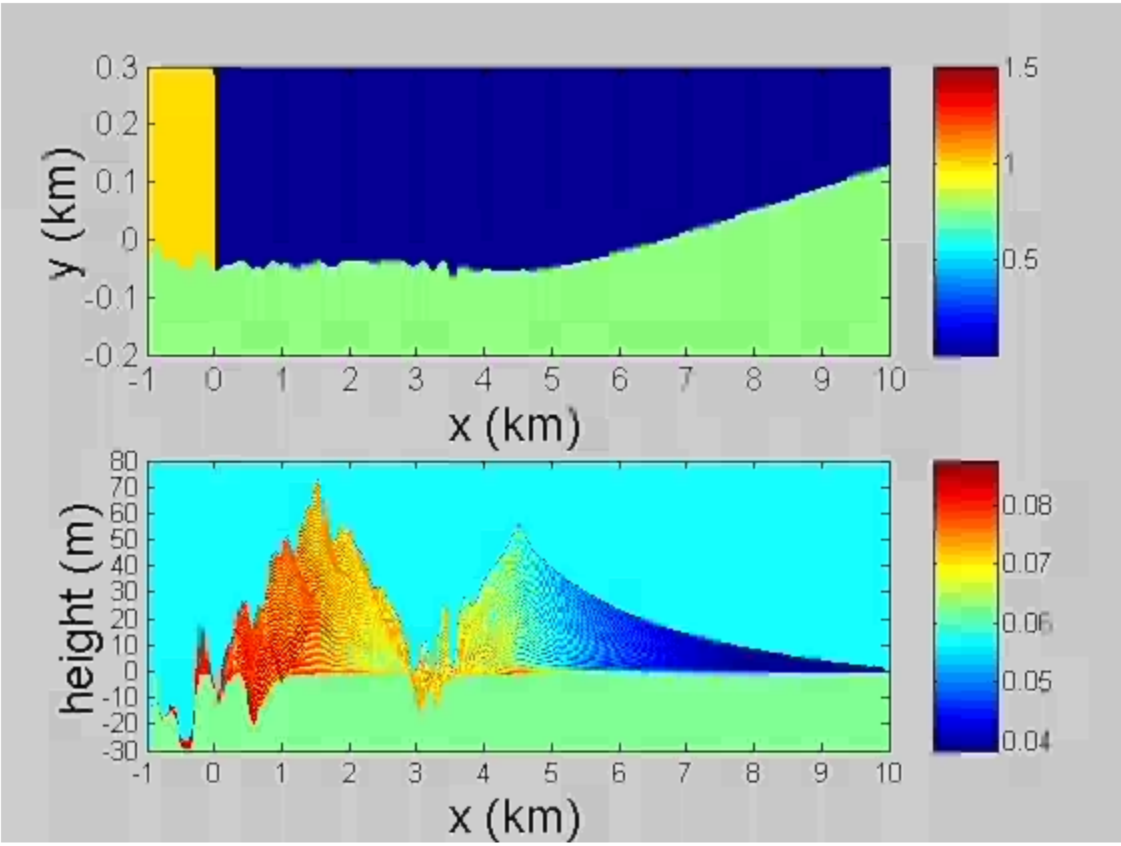
slope angle $= 4^o$:



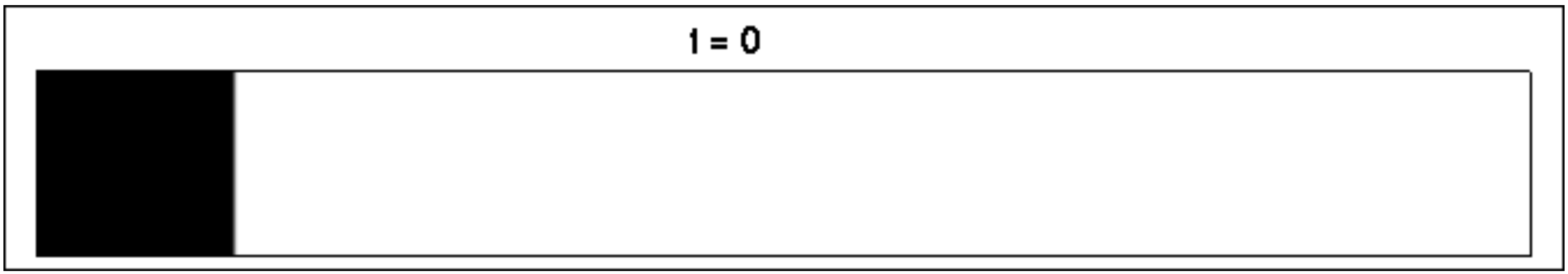
erosion outweighs deposition: growing turbidity current

Erosion, resuspension of particle bed (cont'd)

- *multiple, polydisperse flows*
- *feedback of deposit on subsequent flows*
- *formation of ripples, dunes etc.*



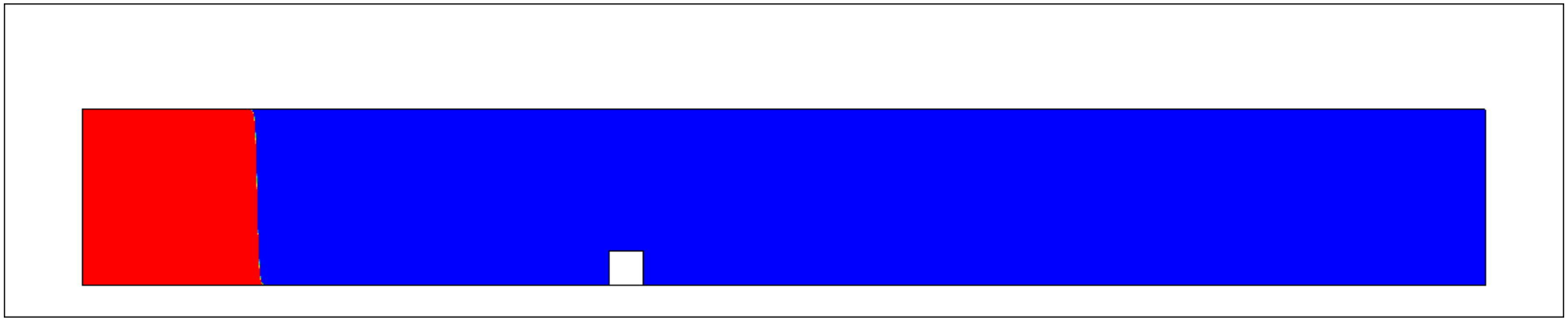
Reversing buoyancy currents (with V. Birman)



- *propagates along bottom over finite distance, then lifts off*
- *subsequently propagates along top*

Hazards posed by gravity and turbidity currents (with E. Gonzales, G. Constantinescu)

Gravity currents may encounter underwater marine installations:

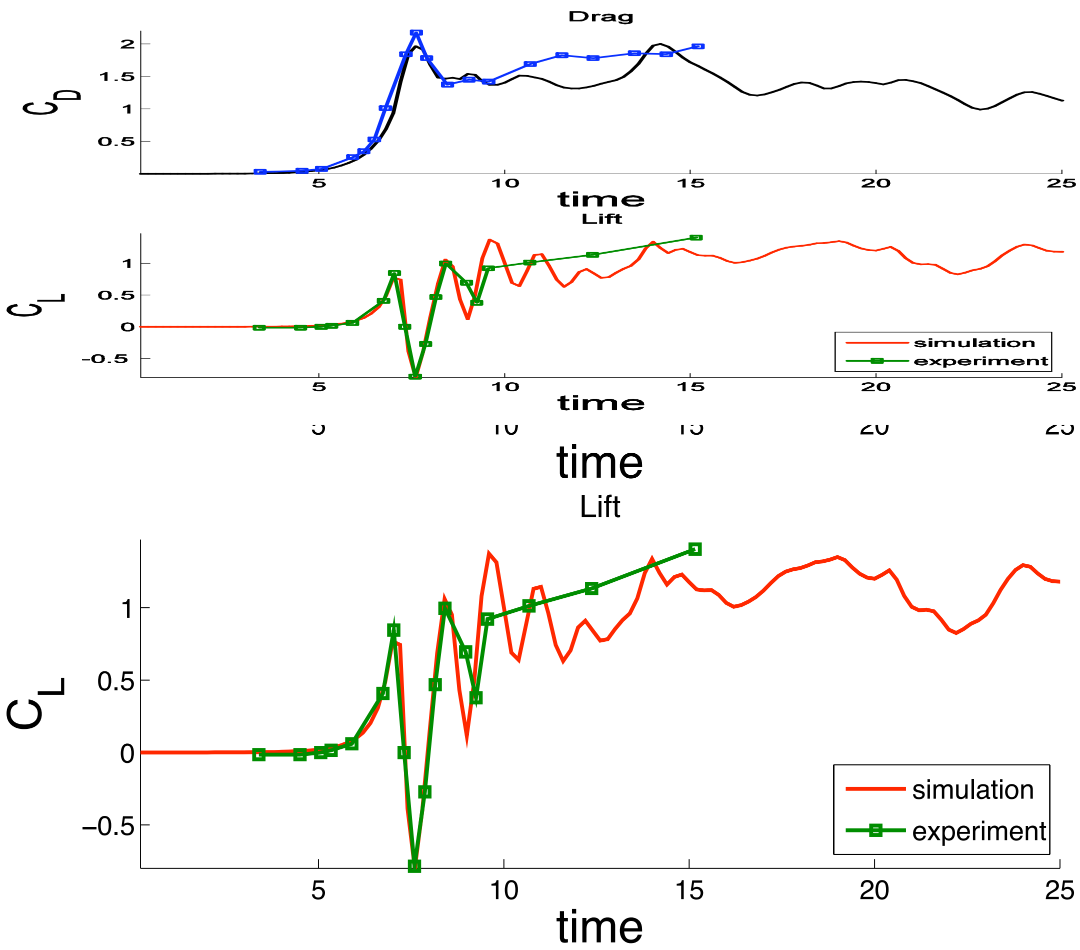


Constantinescu (2005)

- *what forces and moments are exerted on the obstacle?*
- *steady vs. unsteady?*
- *erosion and deposition near the obstacle?*

Hazards posed by gravity and turbidity currents (cont'd)

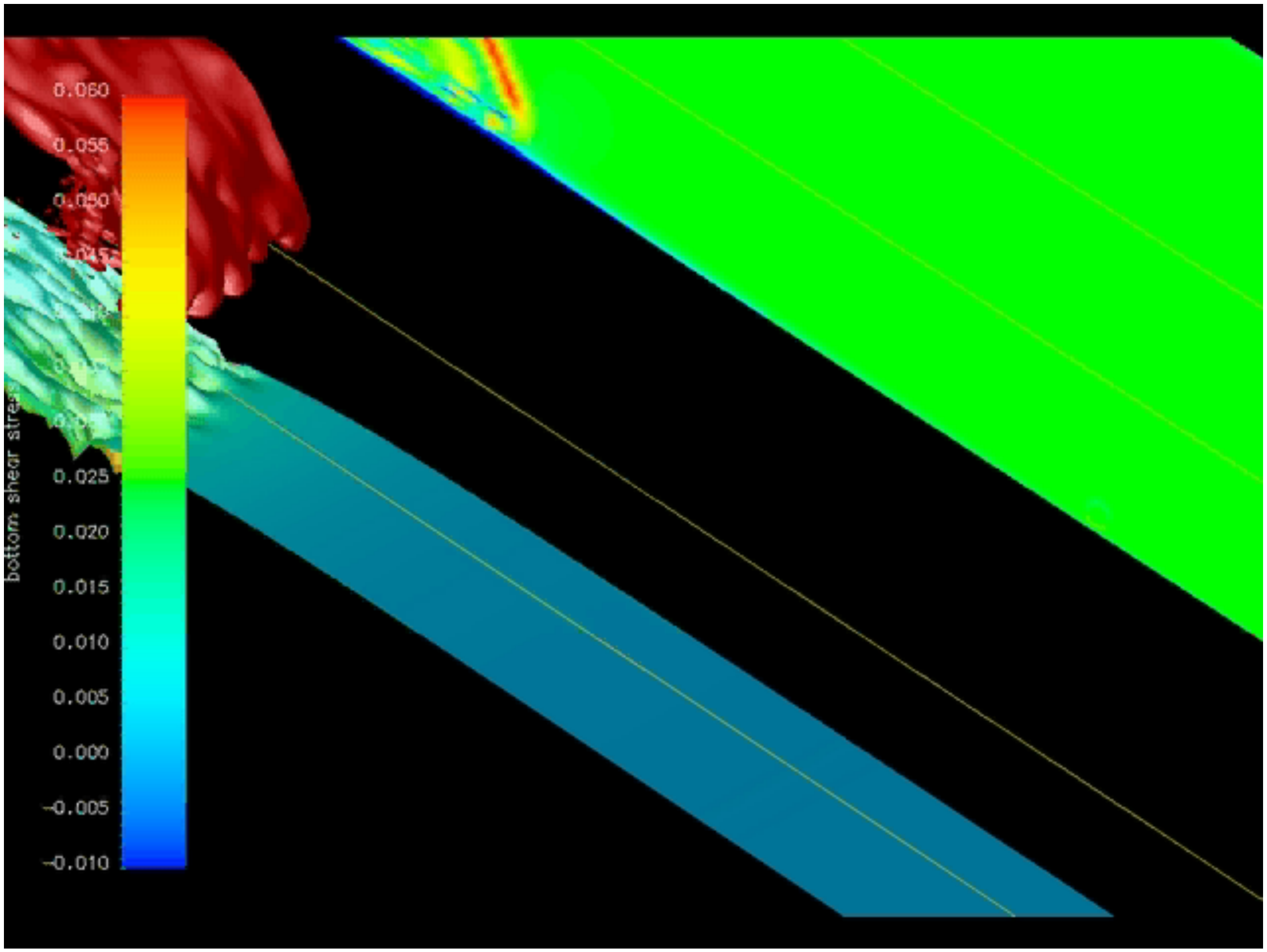
Comparison with experiments by Ermanyuk and Gavrilov (2005):



- *2D simulation captures impact, overpredicts quasisteady fluctuations*

Gravity current flow over elevated circular cylinder

Vorticity and shear stress:



- *important for the prediction or erosion and scour*

Summary

- *high resolution 2D and 3D simulations of turbidity currents*
- *detailed information regarding sedimentation dynamics, energy budgets, mixing behavior, dissipation…*
- *important differences between 2D and 3D simulation results*
- *extensions to complex geometries, erosion and resuspension, reversing buoyancy, submarine structures . . .*
- *inversion: reconstruct current from deposit profiles*
- *linear stability problem of channel and sediment wave formation*