Computational Investigations of Turbidity Currents in Complex Topographies*

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Abstract

We consider turbidity currents interacting with complex seafloor topographies, such as mini-basins, ridges, and curved or meandering channels. Both two- and three-dimensional Navier-Stokes simulations are employed in order to investigate the dynamics of the currents, along with their erosional and depositional behavior for a range of flow parameters and topographical shapes.

For mini-basin topographies, we observe that coherent vortical structures generated by topographical effects can result in the formation of strong local variations in the sediment deposit. Reflections of the current, as well as the formation of internal bores, are seen to be influential as well. Results from a parametrical study are discussed, based on two- and three-dimensional simulations of depositing currents, in order to quantify the effects of the geometrical parameters and grain-size on the sediment deposit fields.

For continuous inflow turbidity currents propagating through bends and meandering channels, the amount of over-spill is investigated as a function of the governing geometrical and flow parameters. Particular emphasis is placed on the influence of the secondary flow induced by the channel curvature.

References

Ermanyuk, E.V. and N.V. Gavrilov, 2005a, Interaction of an internal gravity current with a submerged circular cylinder: J. Appl. Mech. Tech. Phys., v. 46/2, p. 216–223.

Ermanyuk, E.V. and N.V. Gavrilov, 2005b, Interaction of an internal gravity current with an obstacle on the channel bottom: J. Appl. Mech. Tech. Phys.v. 46/4, p. 489–495.

Härtel, C., E. Meiburg, and F. Necker, 1999, Analysis and direct numerical simulation of the flow at a gravity-current head. Part I: Flow topology and front speed for lip and no-slip boundaries: Journal of Fluid Mechanics, v. 418, p. 189-212.

Necker, F., C. Haertel, L. Kleiser, and E. Meiburg, 2002, Simulation of sedimentation and mixing in deeply-submerged gravity currents, *in* A. Gyr and W. Kinzelbach, (eds.), Sedimentation and sediment transport; proceedings, p. 195-200.

 de Rooij, F. and S.B. Dalziel, 1998, Time and space-resolved measurements of the deposition under turbidity currents, *in* W.D. McCaffrey, B. Kneller, and J. Peakall, (eds.), Particulate Gravity Currents: International Association of Sedimentologists, Special Publication, v. 31, p. 207-215.

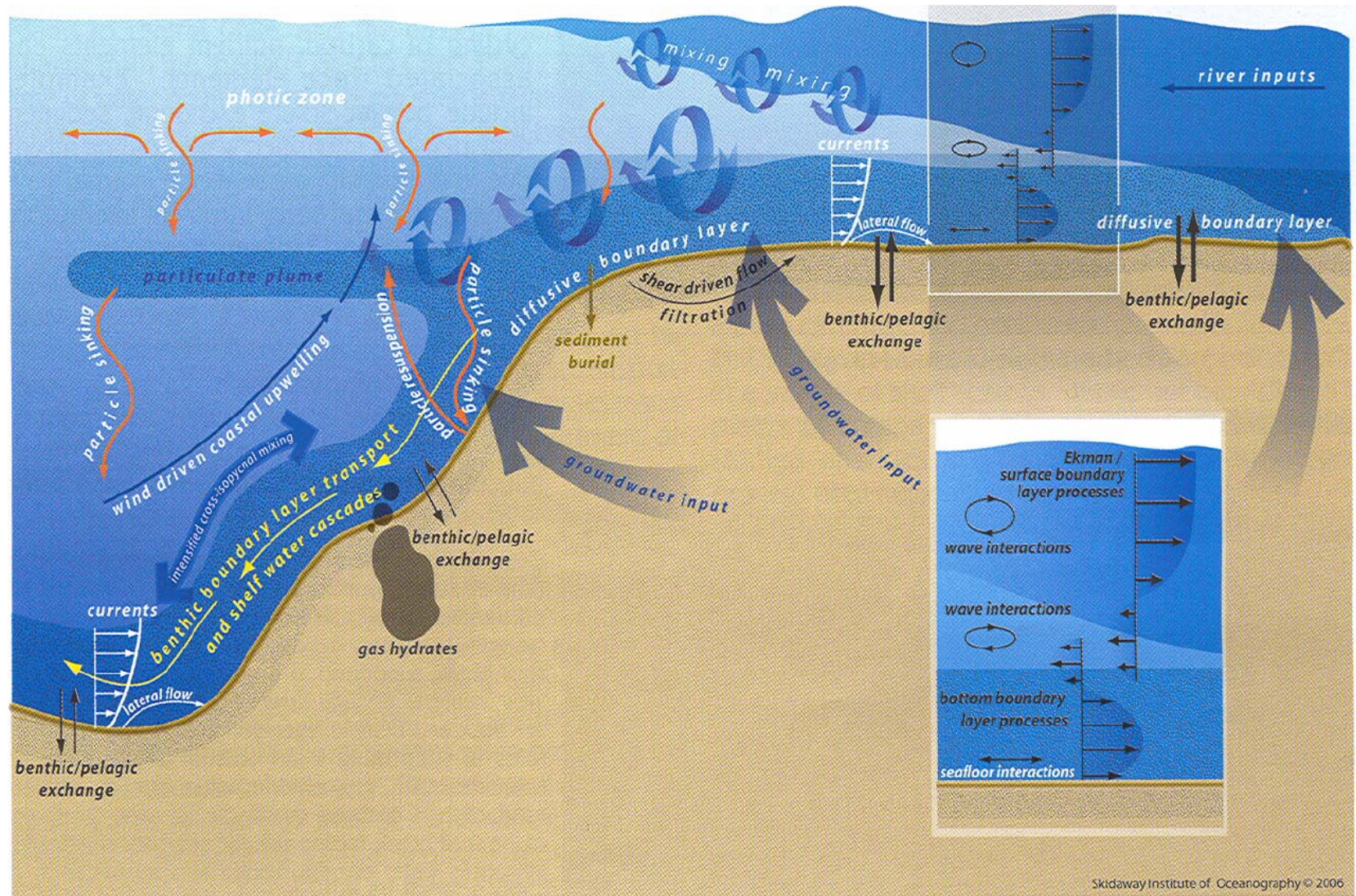# Computational Investigation of Turbidity Currents in Complex Topographies

M. Nasr, S. Saegeler, M. Zoellner, E. Meiburg (UCSB)

B. Kneller (U. Of Aberdeen)

- *Motivation*
- *Governing equations / computational approach*
- *Results*
  - *mini-basins*
  - *sinusoidal channels*
- *Summary and outlook*

UCSB

Coastal margin processes

Turbidity current

- *Underwater sediment flow down the continental slope*
- *Can transport many km³ of sediment*
- *Can flow O(1,000)km or more*
- *Often triggered by storms or earthquakes*
- *Repeated turbidity currents in the same region can result in the formation of hydrocarbon reservoirs*
- *Properties of turbidite:*
  - *particle layer thickness*
  - *particle size distribution*
  - *pore size distribution*

Turbidity current.
(University of Florida)

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*

→ *don't resolve small-scale flow field around each particle,
but only the large fluid velocity scales*

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
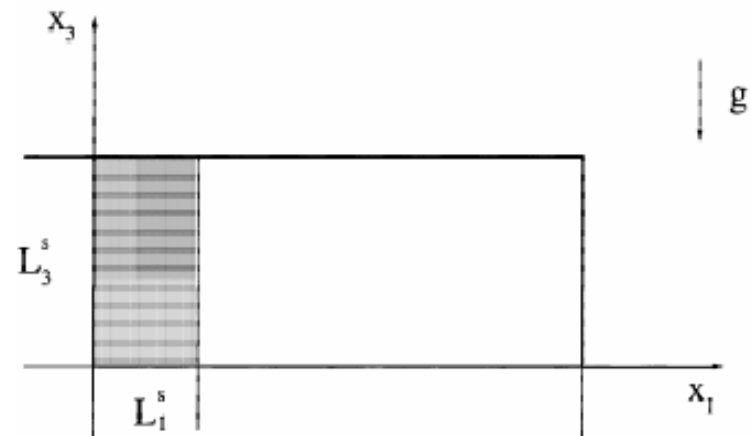
Dense front propagates along bottom wall

Light front propagates along top wall

Results: 3D turbidity current – Temporal evolution

## *DNS simulation (Fourier, spectral element, $7x10^7$ grid points)*
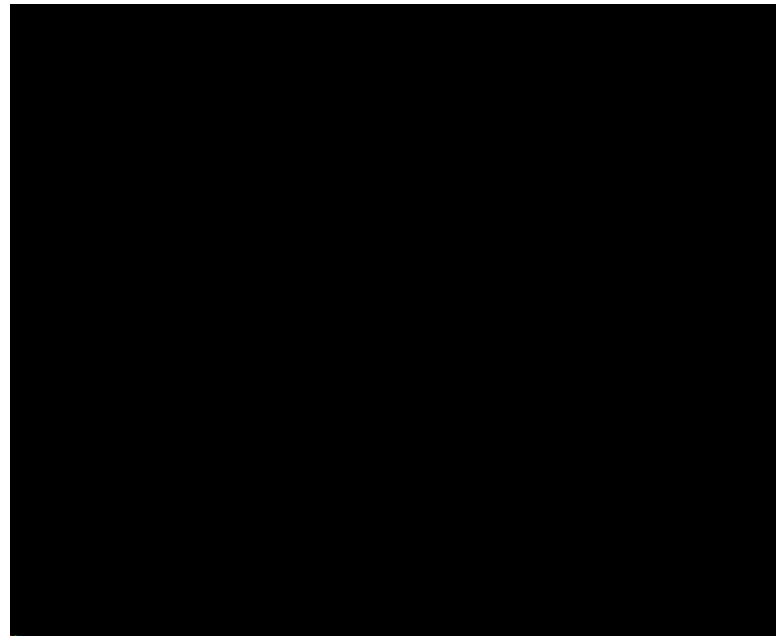
Necker, Härtel, Kleiser and Meiburg (2002a,b)

- *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)

- - - *Experiment*
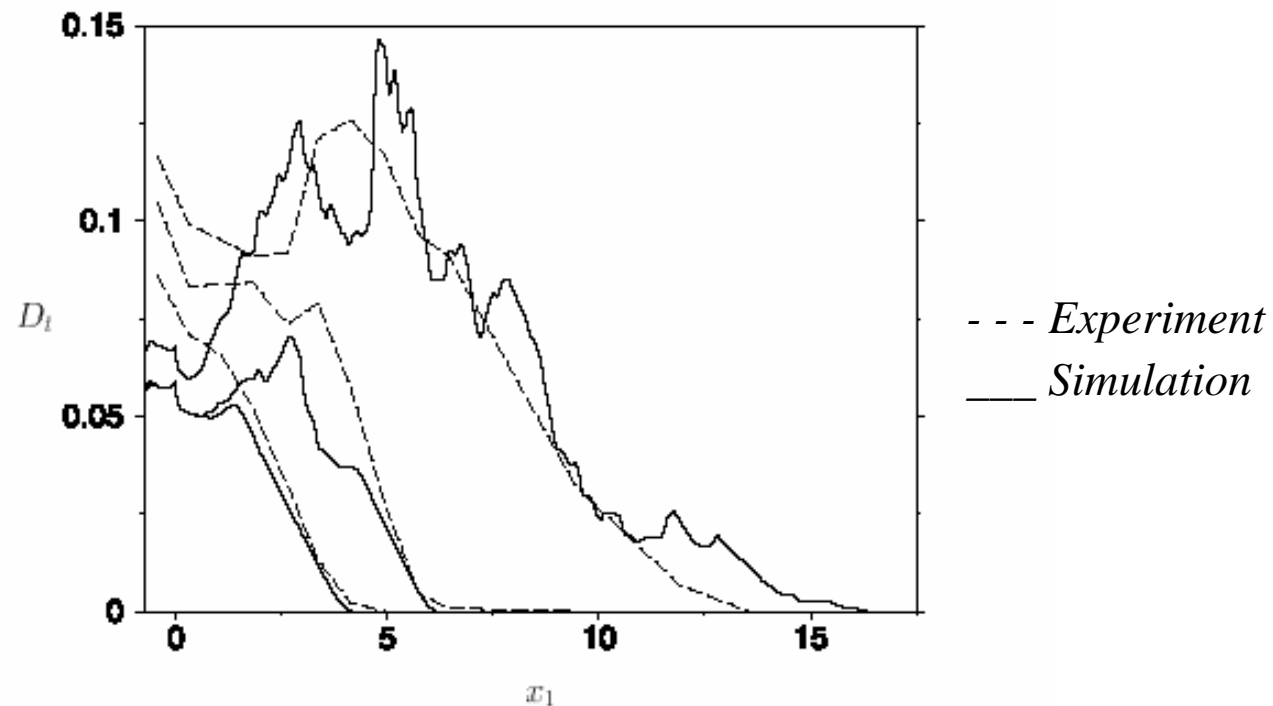
___ *Simulation*

• *simulation reproduces experimentally observed sediment accumulation*

Filling of a minibasin

Interaction of gravity currents with submarine topography:
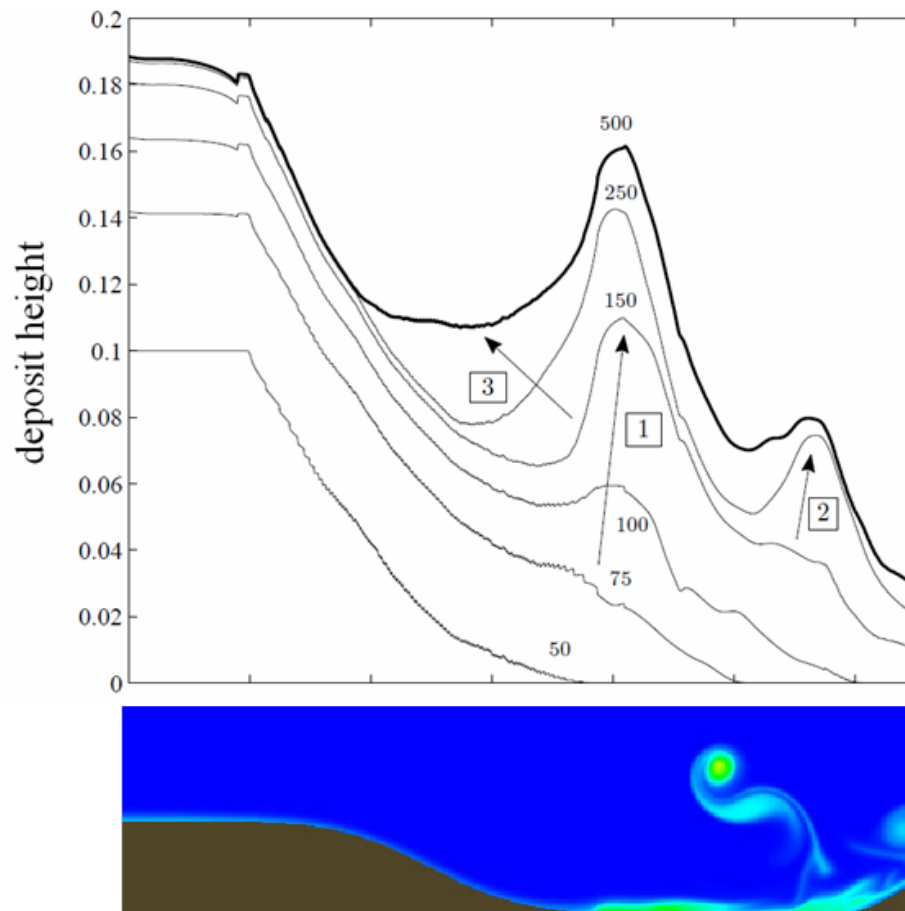
Filling of a minibasin

Deposit profiles

1. Accumulation by dumping after the front travels down the slope.
2. Current is reflected at the hump.
3. Secondary current travels upstream and deposits on the slope.
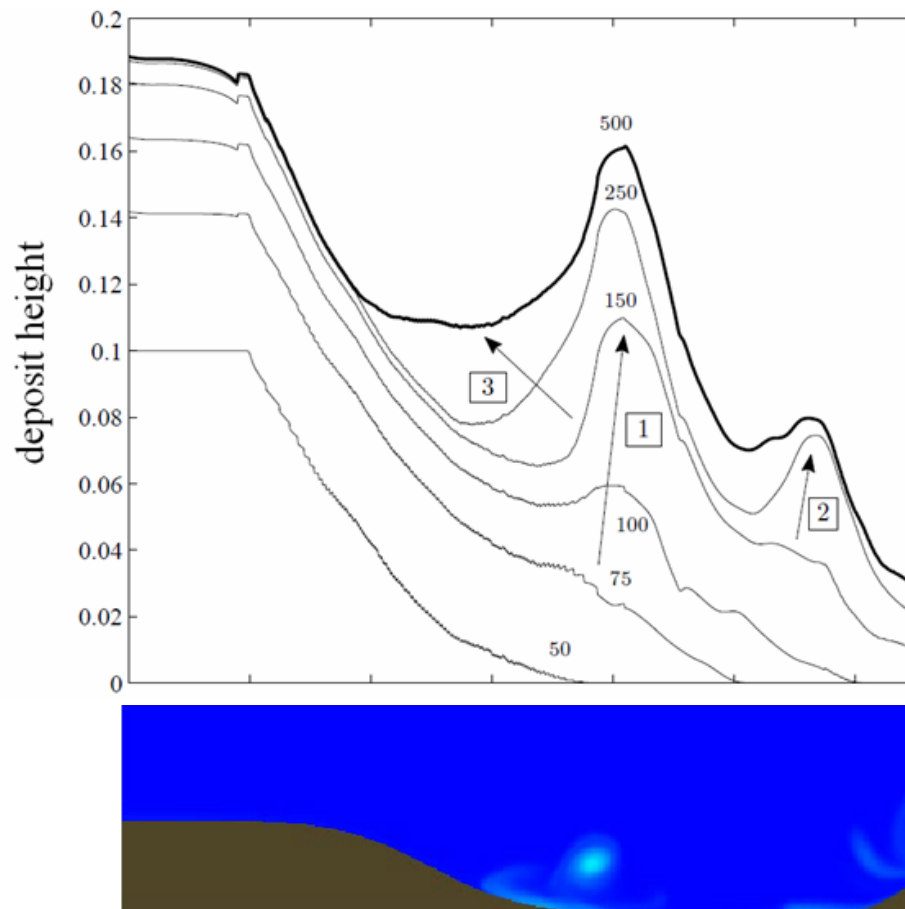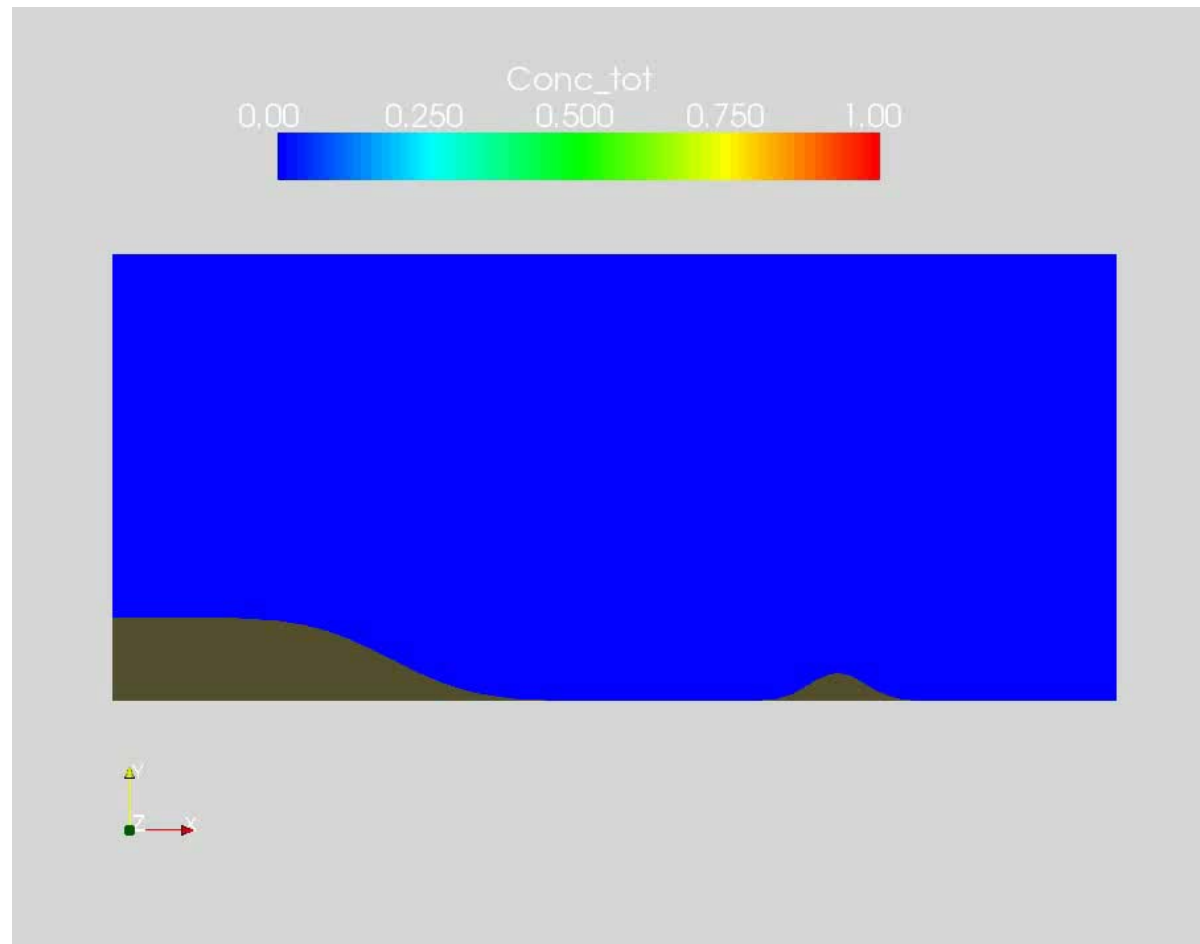
Filling of a minibasin

Deposit profiles

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Filling of a minibasin

Interaction of gravity currents with submarine topography:

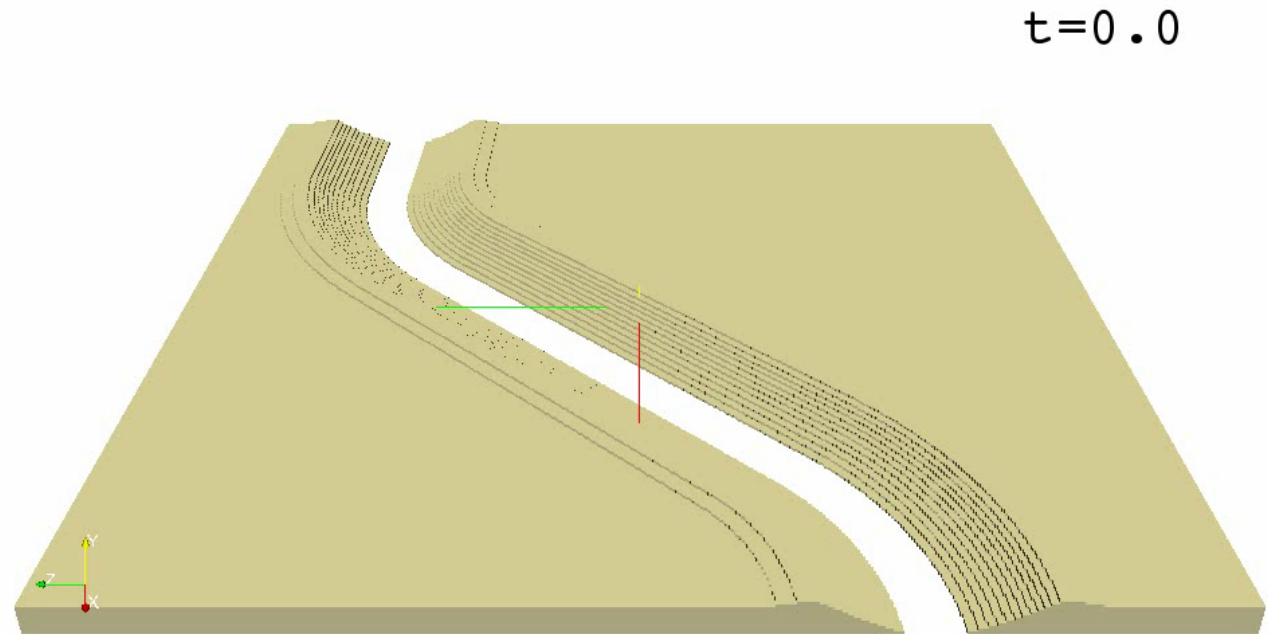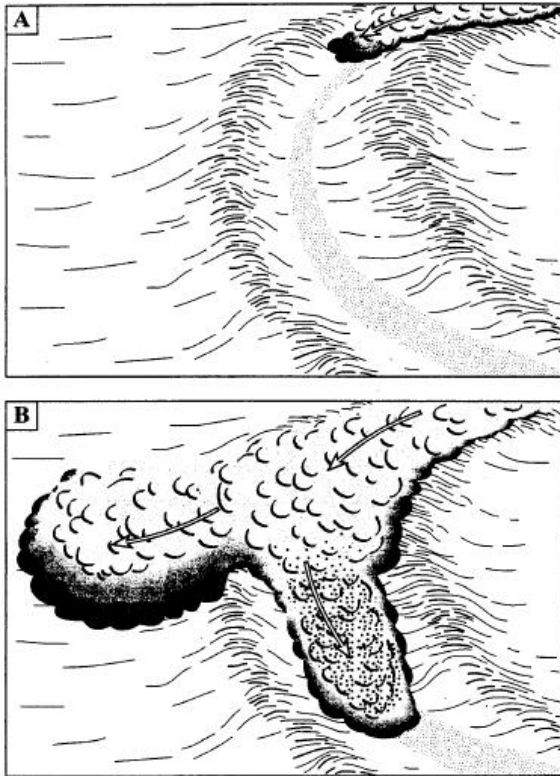# Turbidity current propagating along submarine channel

Formation of submarine channel-levee systems
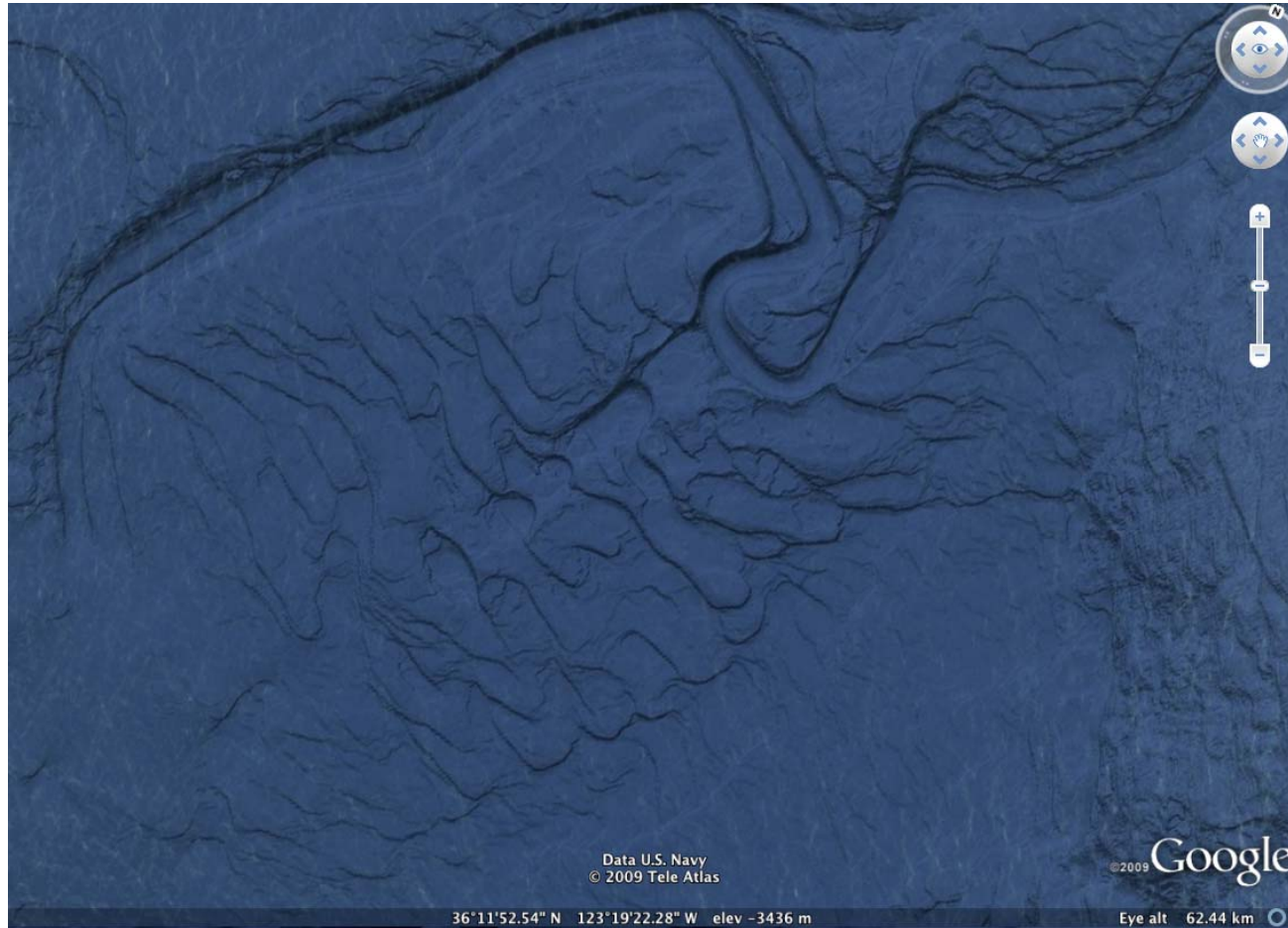
Monterey Canyon fan

Turbidity current propagating along submarine channel
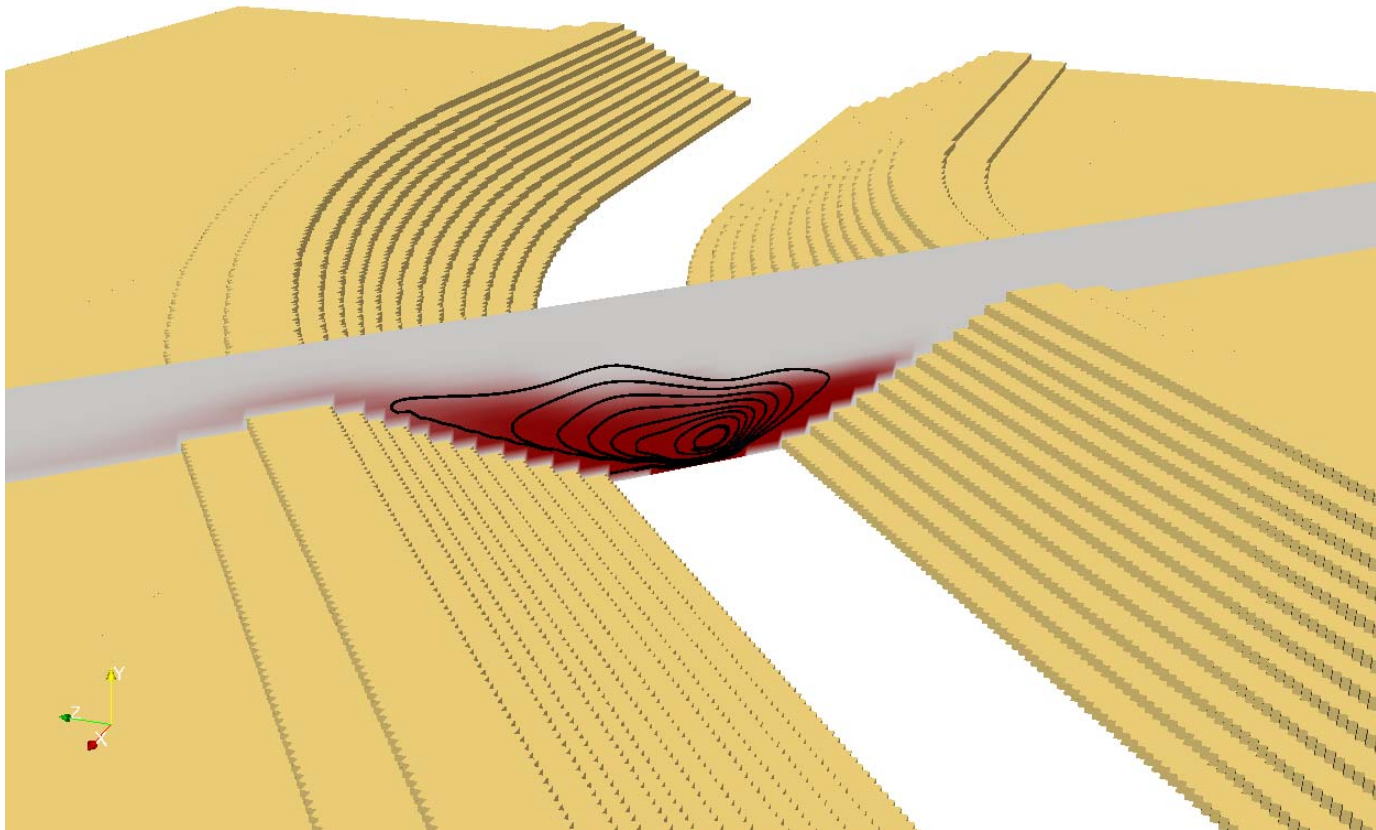
'Flow stripping' in channel turns: lateral overflows

t=0.0

Turbidity current/sediment bed interaction

Secondary flow in submarine canyon bends

  • *creates bed shear stress that causes lateral sediment transport*

Further development: Next steps

- *Implementing and validating LES and RANS models, so that the code runs efficiently at large Reynolds numbers*

- *Coupling to larger-scale simulators, such as ROMS (Regional Ocena Modeling System), so that we can simulate the interaction of turbidity currents and river outflows with tidal flows, internal waves, along-shore flows, Coriolis effects etc.*

- *Refine particulate models to account for such effects as flocculation, etc.*

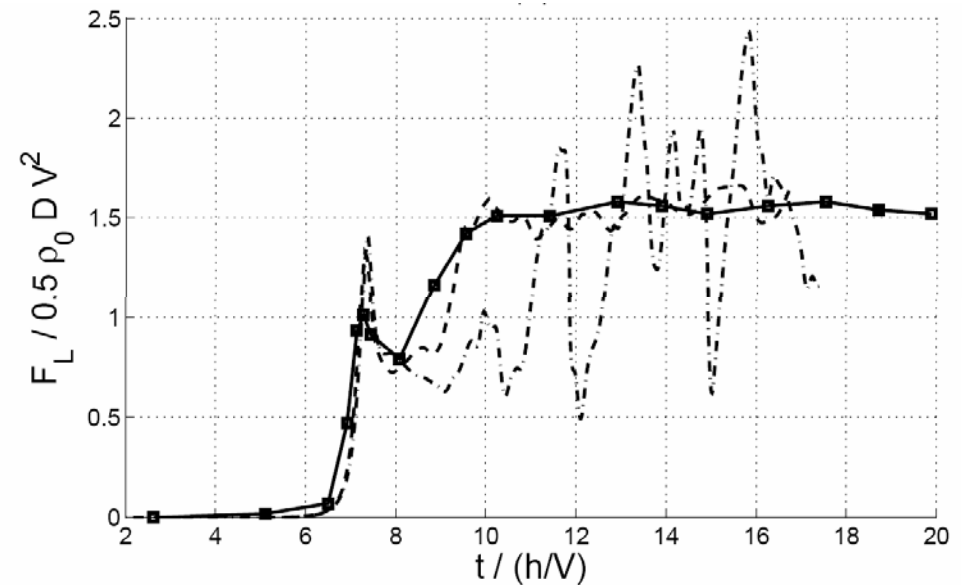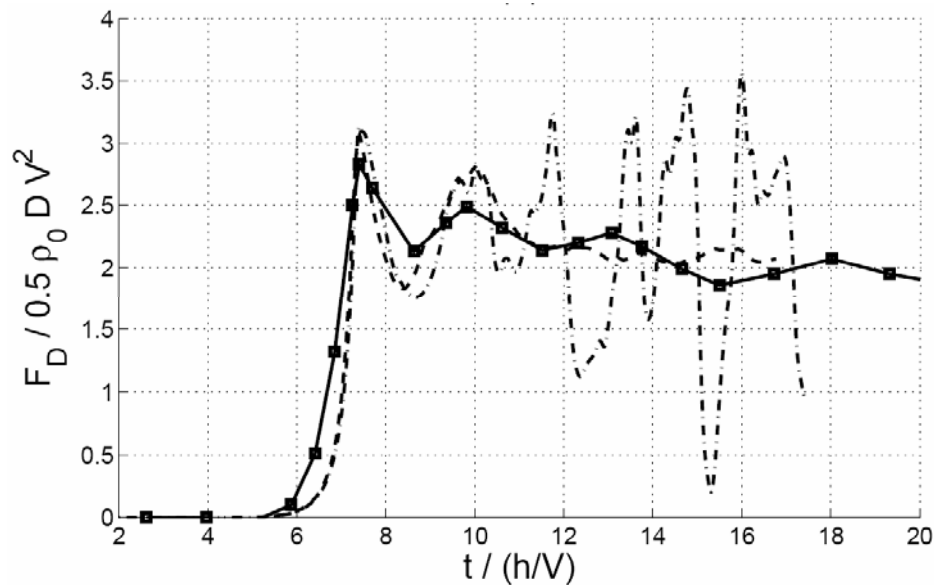# *Gravity current flow over elevated circular cylinder*

Vorticity and shear stress:
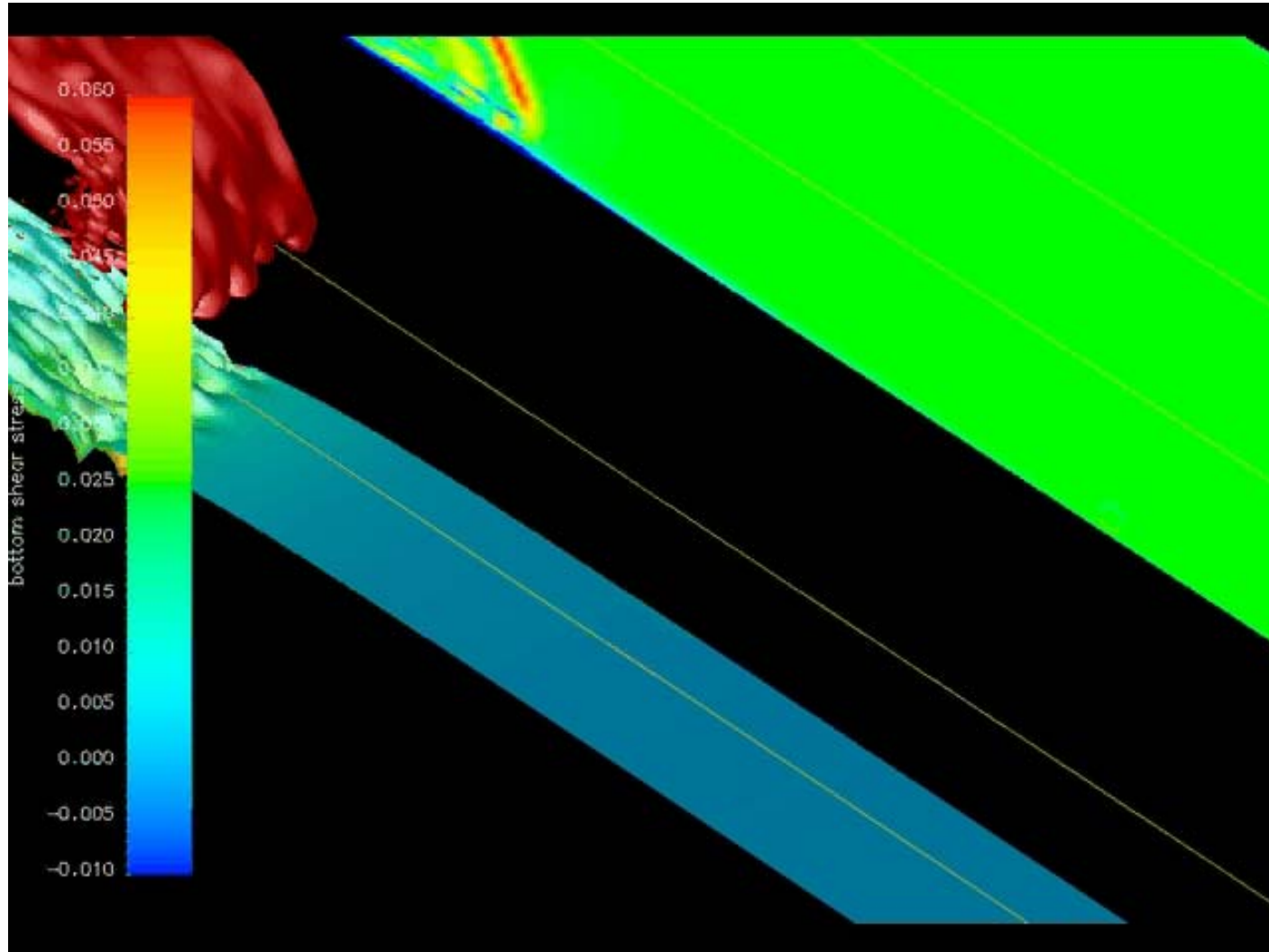
- *important for the prediction or erosion and scour*

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

Comparison with experiments by Ermanyuk and Gavrilov (2005):

_____ *experiment*

. - . - . *2D simulation*

- - - - *3D simulation*

- *2D simulation captures impact, overpredicts quasisteady fluctuations*
- *3D simulation captures impact and quasisteady stages well*

Summary

- *high resolution 2D and 3D simulations of gravity currents*

- *detailed information regarding sedimentation dynamics, energy budgets, mixing behavior, dissipation...*

- *important differences between 2D and 3D simulation results*

- *extension to gravity currents flowing down a slope, complex geometries, erosion and resuspension, submarine structures, levees*