TURBINS: A computational tool for three-dimensional, high-resolution simulations of particle-laden flows

Mohamad M. Nasr-Azadani and Eckart Meiburg

UC SANTA BARBARA engineering

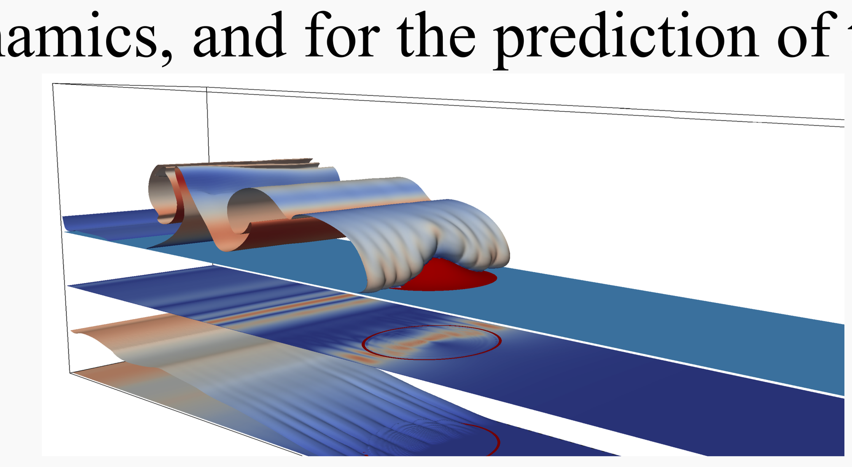
CSDMS COMMUNITY SURFACE DYNAMICS MODELING SYSTEM

Introduction

Turbidity currents are underwater avalanches traveling along the seafloor, as a result of the density difference between the suspension and ambient water. They play an important role within the global sediment cycle, and in the formation of deep-sea hydrocarbon reservoirs.

Left: A turbidity current traveling down the continental slope into the deep-sea regions. Sediment is both eroded and deposited as the current interacts with the seafloor topography (http://www.clas.ufl.edu/).

Due to the infrequent and unpredictable occurrence of turbidity currents in remote areas, and their destructive nature, field data regarding their structure and evolution are very difficult to obtain. Consequently, high resolution simulations have become an important tool for the exploration of their dynamics, and for the prediction of the deposit properties.



Right: Particle concentration isosurface for a turbidity current interacting with a Gaussian bump. Transient bottom shear stress contours (middle) and deposit profiles (bottom) can be studied via TURBINS.

TURBINS (**TURB**idity currents via **I**mmersed boundary **N**avier-**S**tokes simulations) is a highly parallel three-dimensional DNS based code developed to simulate gravity and turbidity currents propagating over complex topographies.

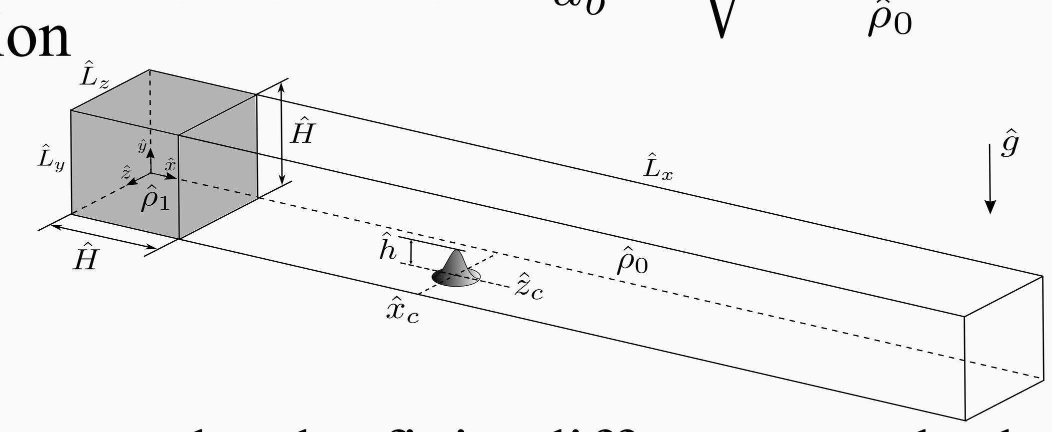
Modeling approach

- Divergence free velocity field $\nabla \cdot \mathbf{u} = 0$
- Incompressible Navier-Stokes equations (Boussinesq). $\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} = \frac{1}{Re}\nabla^2 \mathbf{u} - \nabla p + c\mathbf{e}^g$
- Transport equation for describing particle motion $\frac{\partial c}{\partial t} + (\mathbf{u} + u_s \mathbf{e}^g) \cdot \nabla c = \frac{1}{ScRe}\nabla^2 c$
- Constant settling velocity

$$Re = \frac{\hat{u}_b \hat{H}}{\hat{\nu}}$$

Characteristic velocity: buoyancy velocity $\hat{u}_b = \sqrt{\frac{\hat{H}\hat{g}(\hat{\rho}_1 - \hat{\rho}_0)}{\hat{\rho}_0}}$

- Lock-exchange configuration



Numerical Method

Viscous terms: fully implicit second order finite difference method.

Convective terms: explicit third order Essentially Non-Oscillatory (ENO) scheme.

Projection method: impose incompressibility condition.

Time integration: third order TVD Runge-Kutta method.

Immersed boundary method: accurate treatment of complex geometry.

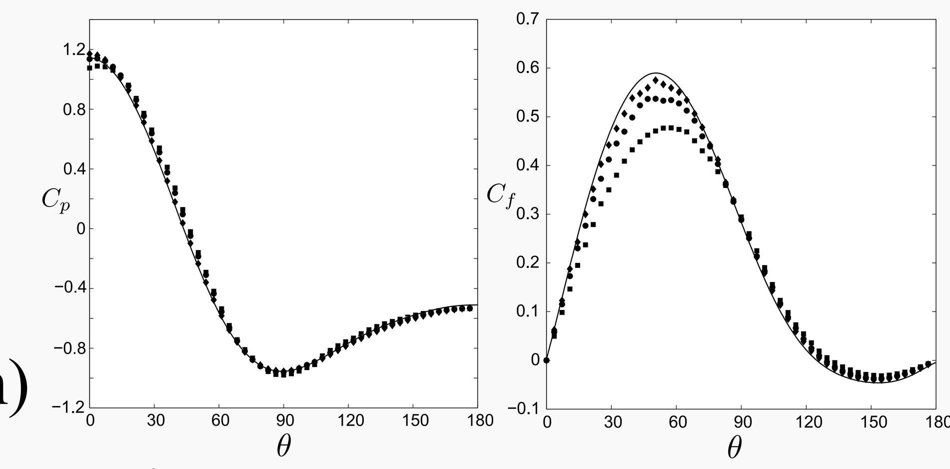
Parallelism

Domain decomposition approach is adopted to parallelize TURBINS. PETSc is used to distribute data among processors, update ghost nodes, and solve the linear systems via parallel Krylov solver (e.g. GMRES). HYPRE is incorporated to solve pressure Poisson equation via Algebraic MultiGrid preconditioner: *BoomerAMG*.

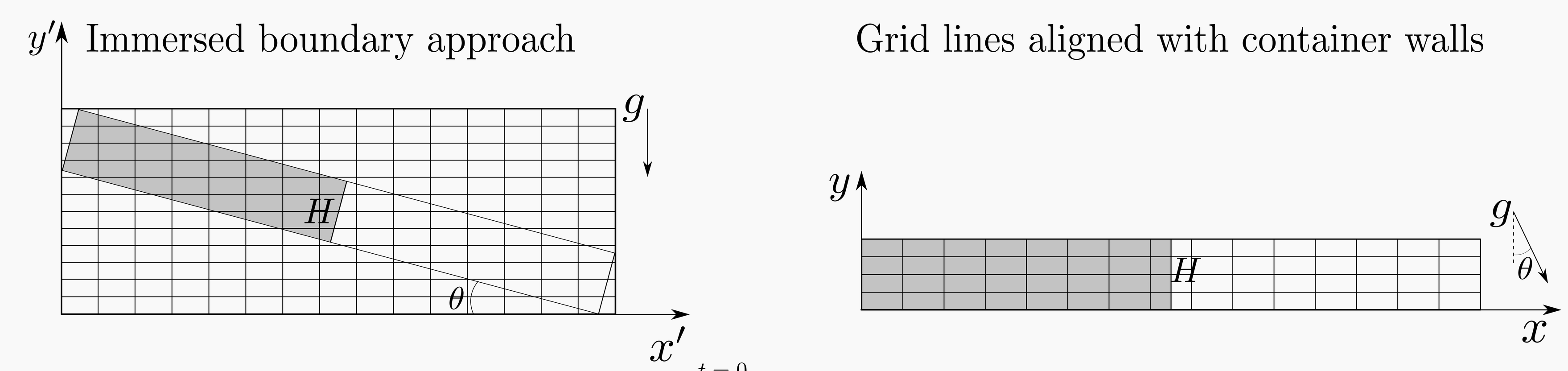
Results

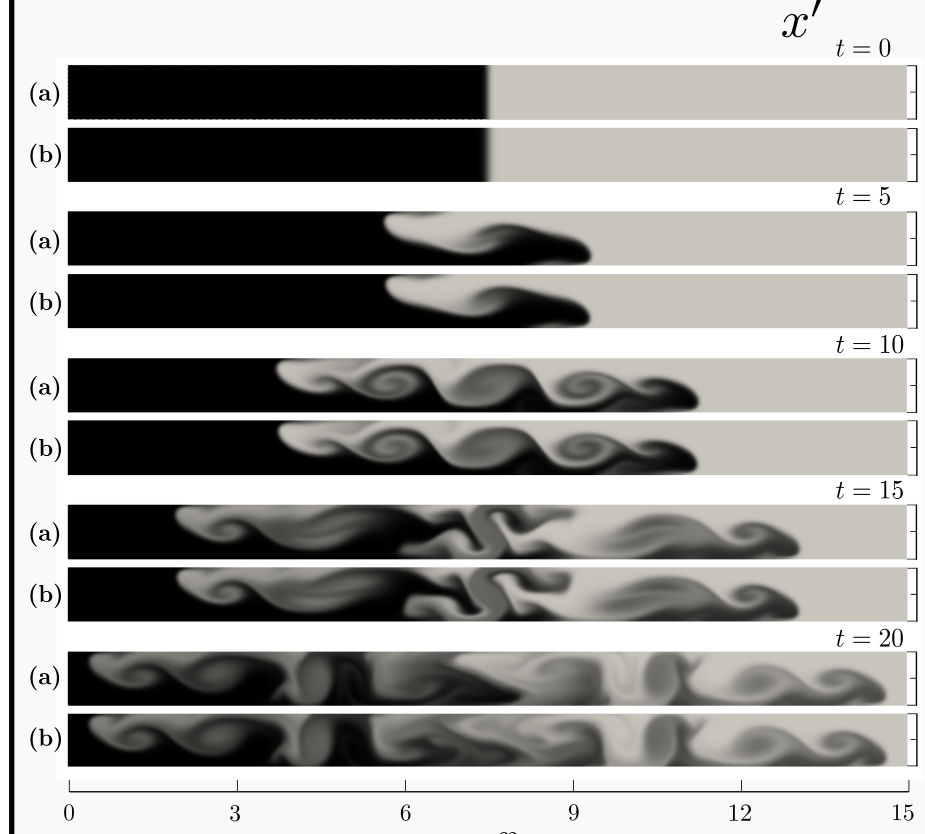
Validation

1) Uniform flow over a cylinder: Surface pressure and wall shear stress are calculated very accurately (important for erosion)



2) Gravity current in a sloping channel:

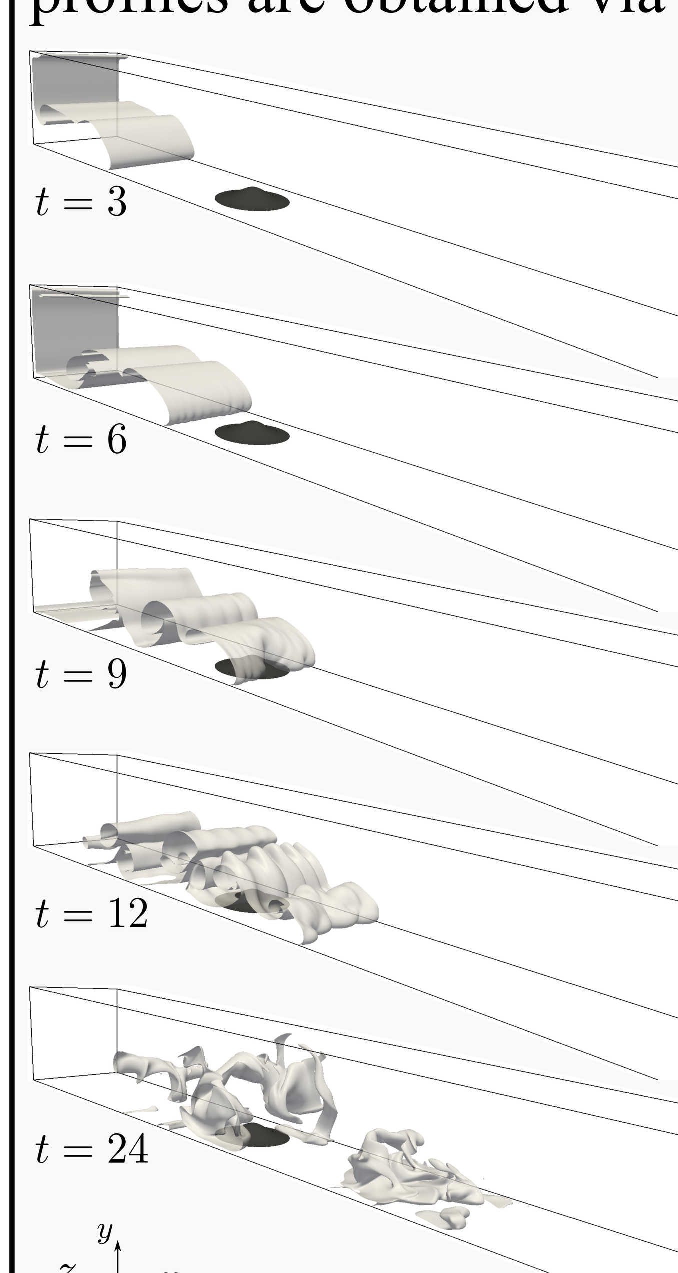




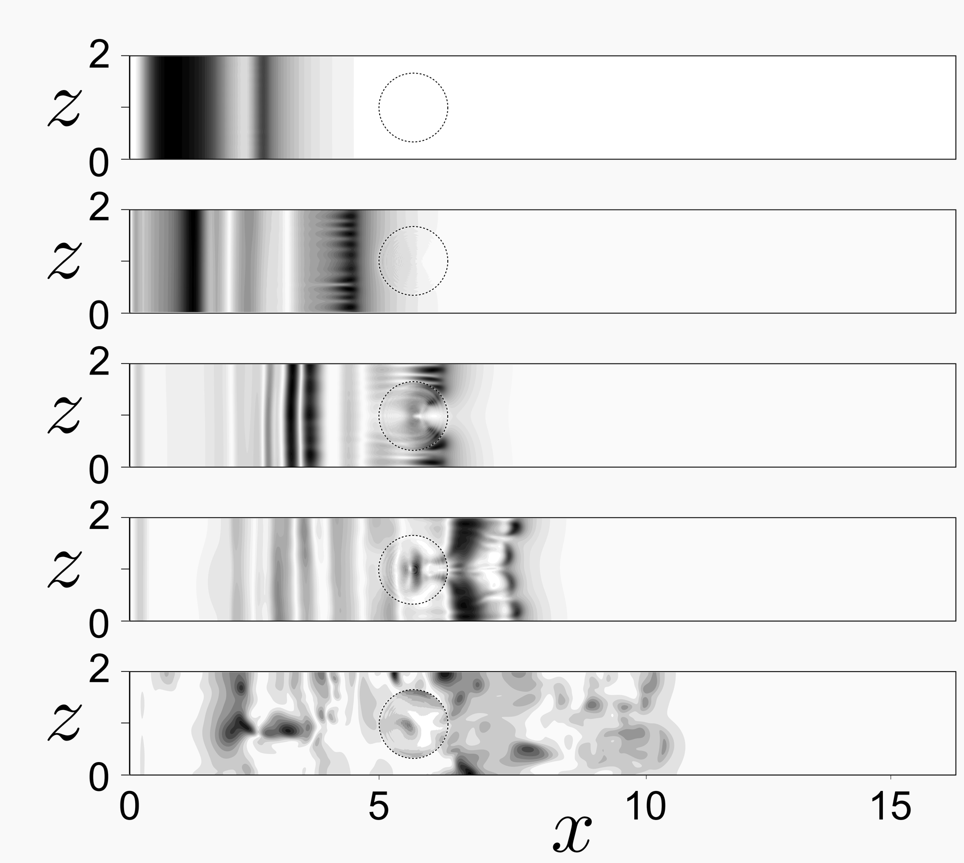
Left: Comparison of the gravity current concentration fields (white corresponds to $c = 0$ and black to $c = 1$) in a sloping channel with $\theta = 15^o$ and $Re_H = 750$, obtained via two different numerical approaches. a): present immersed boundary approach, b): coordinates aligned with container walls.

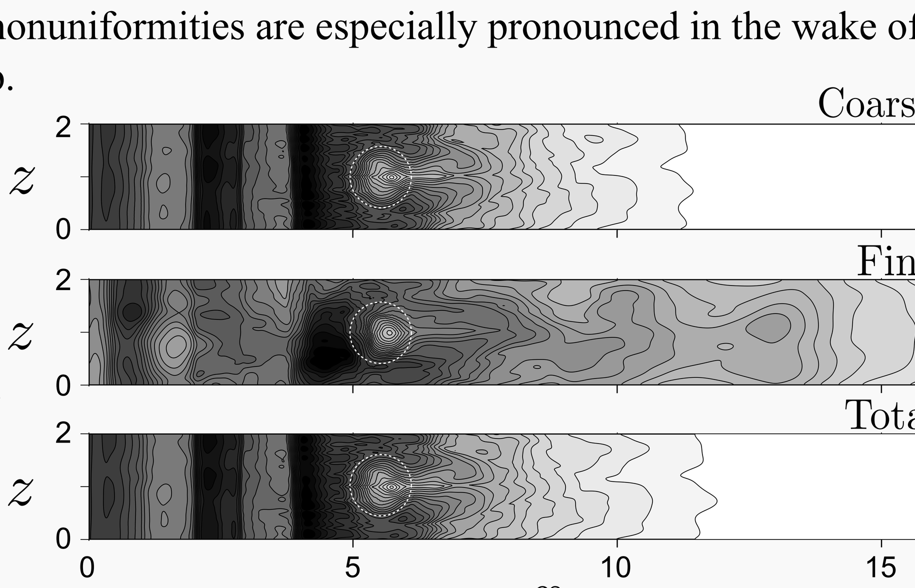
Bidisperse turbidity current interacting with a bump

Deposit profiles of fine and coarse particles demonstrate the non-linear coupling between particles of different sizes. Information such as runout length, instantaneous bottom shear stress and final deposit profiles are obtained via depth-resolved simulations by TURBINS.



Top: Time evolution of the c = 0.1 concentration isosurface for a lock-exchange turbidity current interacting with a Gaussian bump for Re = 2, 000. The suspension contains a mixture of two particle sizes, with nondimensional settling velocities equal to 0.035 and 0.0035, and initial mass fractions of 90% and 10%, respectively.





Top: Time evolution of bottom shear stress for the flow shown in the left figure. The interaction of the current with the Gaussian bump leads to the emergence of pronounced features in the shear stress distribution. **Bottom:** Final deposit profiles for the same bidisperse turbidity current. The nonuniformities are especially pronounced in the wake of the bump.

Acknowledgement

MN was funded via research support to Prof. Kneller's group from BG Group, BP, ConocoPhillips, DONG, GDF Suez, Hess, Petrobras, RWE Dea, Total, and Statoil. EM acknowledges financial assistance through NSF grant CBET-0854338. The three-dimensional simulations were carried out at the Community Surface Dynamics Modeling System (CSDMS) high-performance computing facility at the University of Colorado in Boulder. We would like to thank CSDMS director Prof. James Syvitski and the technical staff at CSDMS for their support.