DIRECT NUMERICAL SIMULATION OF PARTICLE EROSION

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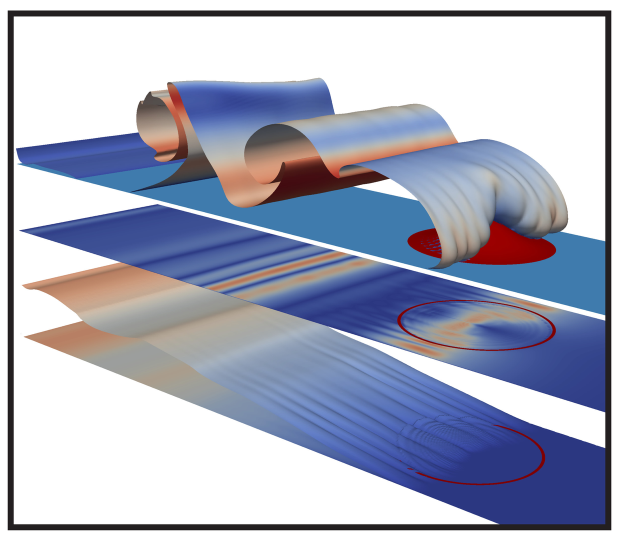
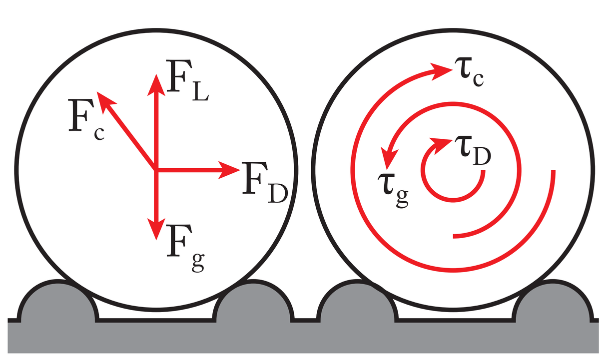
HERE IS OUR PROBLEM



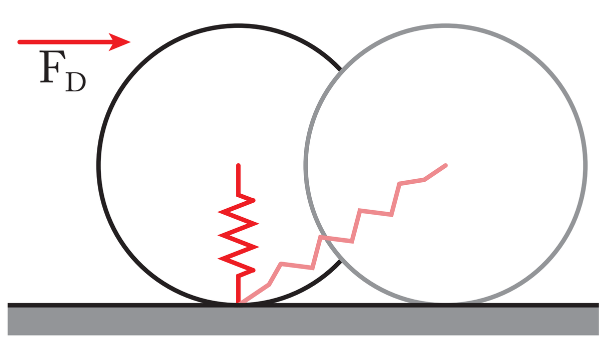
To realistically simulate geophysical flows over complex topography, you need an accurate erosion model. But despite decades of research, the most commonly used model of erosion, the Garcia-Parker model, is just an empirical fit to experimental data.

An accurate analytical model would be desirable, because then you could understand the model's limitations and under what circumstances it could be applied. To develop such an analytical model, one needs to understand how a few particles interact as they are eroded, and then use statistical techniques to scale up to a large scale continuum model. Our research will focus on understanding the mechanisms underlying the resuspension of a few particles.

CURRENT ANALYTICAL MODELS



There are two ways the resuspension of a single particle is typically modeled. First, one can set up a force and moment balance between the fluid forces pulling the particle away from a surface, and the gravitational or adhesive forces keeping it attached. If the lift force or drag moment becomes great enough, the particle will be entrained.



Another way of modeling particle liftoff is with an energy balance. A damped spring, which can be either linear or non-linear, holds a particle to a fixed point on the substrate. If the length of the spring ever exceeds some critical breaking length, the particle will become entrained. These kinds of models typically predict more particle erosion than force balance models because small amounts of energy added at a resonant frequency can have more of an effect here.

WHAT WE PROPOSE TO DO

To develop an analytical erosion model, we need to know which mechanisms play an important role in erosion, and which ones don't. This is where simulations become useful. We can setup various flow scenarios, and then directly observe the flow field before and after particle liftoff. We can also directly measure the forces on a particle, and decompose them into pressure, viscous, and contact forces.

1 We're going to start small, and try and fully understand the mechanisms behind the liftoff of a single particle in two dimensions and how they are affected by various fluid parameters such as the Reynolds number, density ratio, particle spacing, and shear velocity.

2 Next, we'll increase the complexity and study the erosion of a single layer of particles.

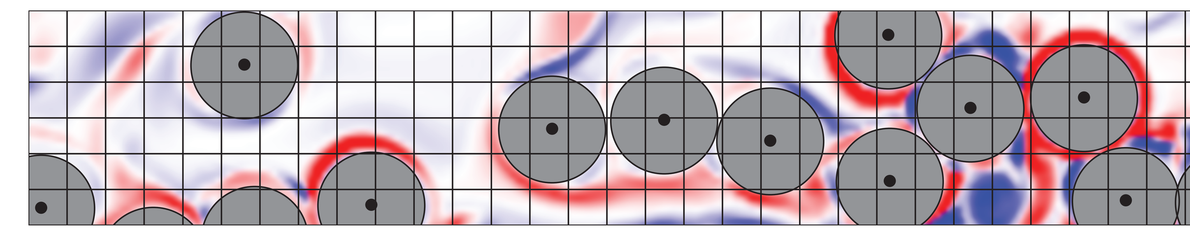
3 Then, we would progress to many rows of particles. The packing of the particles becomes important in this case. We will start with regularly packed sediment beds, but can also generate randomly packed ones.

4 There are many directions we could take the research at this point, we could study systems with two different particle sizes, non-spherical particles, or adhesive particles.

5 Once we are satisfied with our two-dimensional results, we will move on to three dimensional simulations (our code can already do this). In three dimensions, the packing of particles becomes even more important.

HOW THE CODE WORKS

Our code uses a Lagrange multiplier method to enforce the correct no-slip boundary condition over the surface of the particles. It works in either two or three dimensions.



1 First, we project the particles onto the Eulerian fluid grid using a volume fraction, which ranges between 0 if the grid cell is completely outside any particles, and 1 if it completely inside.

2 Next, we solve the Navier-Stokes equations on the Eulerian grid. We neglect the presence of the particles, except for their density.

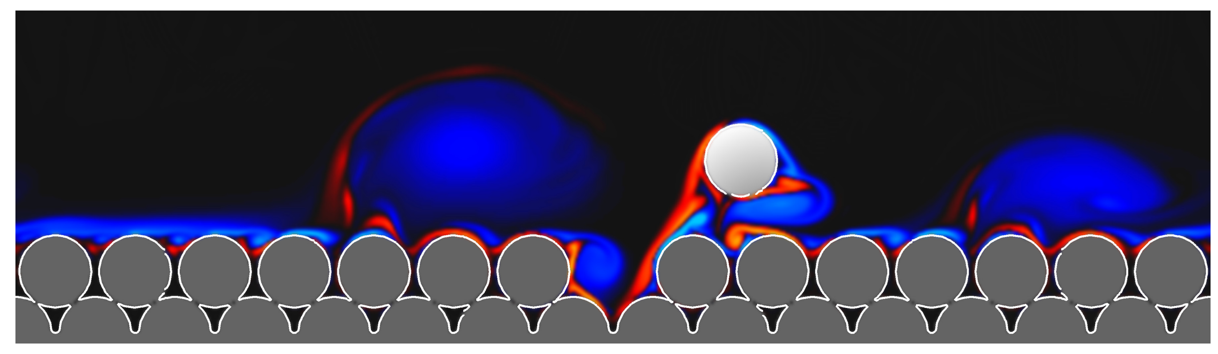
$$\nabla \cdot \mathbf{u} = 0$$
$$\rho\left(\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u}\cdot\nabla)\,\mathbf{u}\right) = -\nabla P + \mu\nabla^2\mathbf{u} + \rho\mathbf{g} + \mathbf{f}$$

3 We enforce rigid body motion on the particles by taking the average translational and rotational velocities within each particle region, and setting it equal to the particle's Lagrangian velocity. The velocity at each Eulerian grid point is updated accordingly.

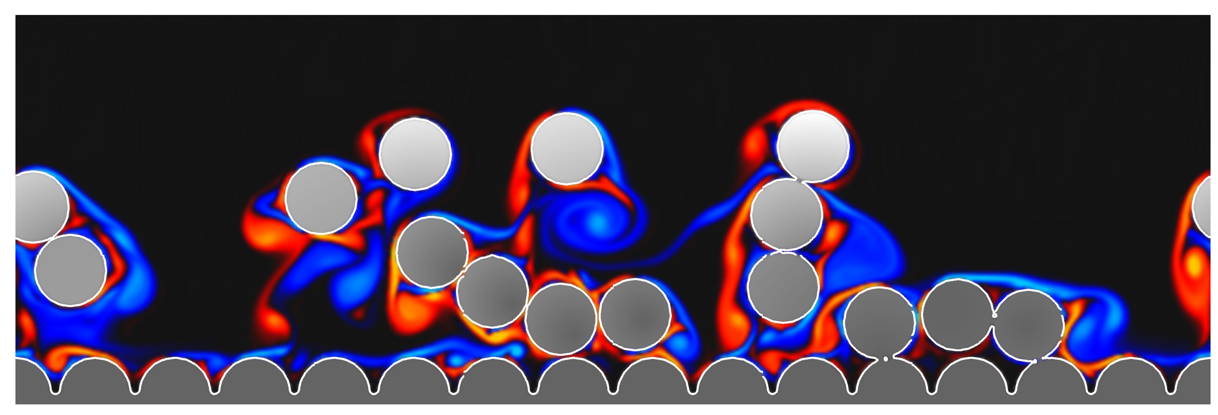
4 If at this point, the volume fraction in a grid-cell is greater than one, a collision has occurred. We use a visco-elastic collision model to apply appropriate forces to each particle involved in a collision, and then update their velocities appropriately.

5 Finally, we update the Lagrangian position of each particle and begin again for the next timestep.

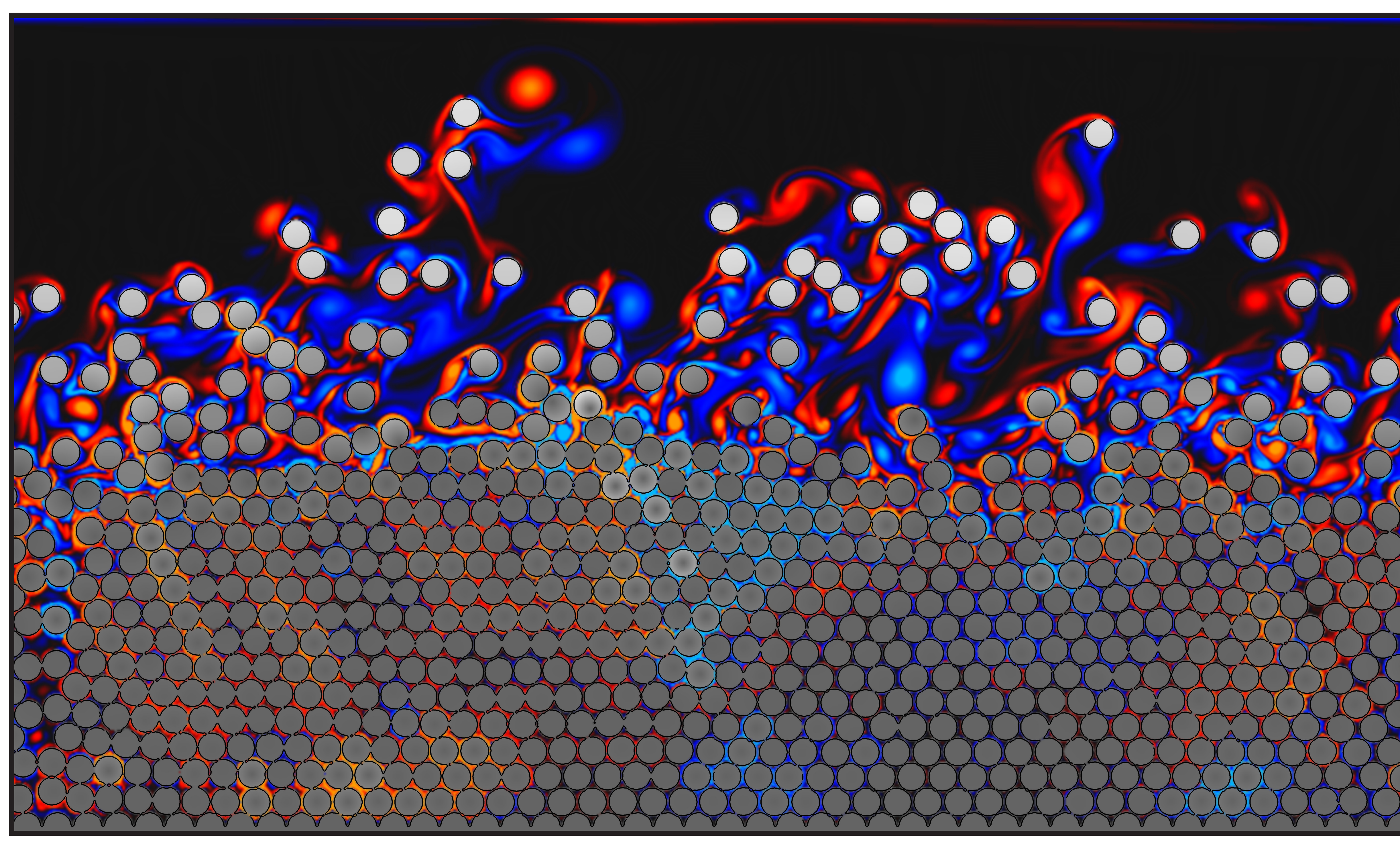
ONE FREE PARTICLE



ONE FREE ROW



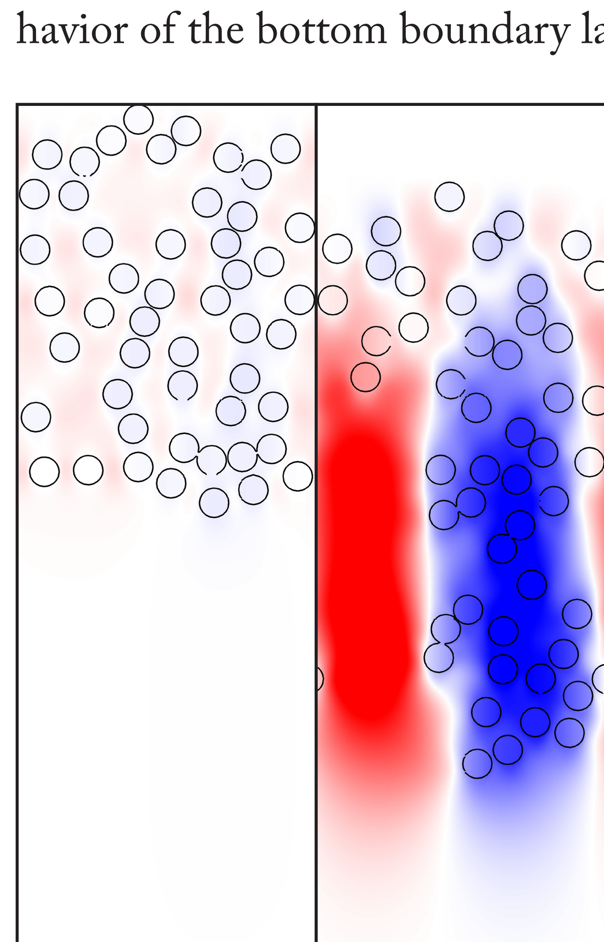
SIXTEEN FREE ROWS



OTHER APPLICATIONS OF OUR CODE:
HINDERED SETTLING

Another graduate student in our group is using this code to study flow dynamics in the bottom layer of a turbidity current. In this bottom layer, the particle concentration becomes high enough such that they affect the overall flow properties.

First, at very high particle concentrations, the effective viscosity of the fluid increases, which will in turn increase the thickness and behavior of the bottom boundary layer.



Second, and more importantly, interactions between particles cause their settling velocity to decrease as particle concentration increases. This happens for two reasons. First, conservation of mass dictates that if the particles settle down, fluid rises up. Second, the vorticity of each particle slows those around it.

This code will be used to study these how the particle concentration affects these two phenomena, especially in conditions similar to the bottom layer of turbidity currents.

OTHER APPLICATIONS OF OUR CODE:
CUTTINGS IN BOREHOLES

Our code is also relevant for many industrial applications. As oil companies drill a new well, they pump drilling fluid down the center of the drill string. The fluid emerges from at drill bit, and flows back up and out of the well between the drill string and the sides of the well. One purpose of this fluid is to bring the rock cuttings produced by the drill bit up to the surface.

Recently, oil companies have developed the ability to steer their drills and create large horizontal sections in their wells. The cuttings have a tendency to settle out of the drilling fluid in these horizontal sections and clog up the well. Our code could be used to simulate the flow in horizontal well sections in order to cheaply find the best combination of fluid properties that would minimize the loss of cuttings. This would require the ability to simulate non-spherical particles and non-newtonian fluids, both of which are being added to the code.