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High-resolution numerical simulation of turbidity currents

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Introduction

Gravity currents are driven by hydrostatic pressure gradients caused by differences in temperature, salinity, or particle concentration. These currents occur when denser fluid intrudes into a lighter one. In this context, turbidity currents are responsible for sediment transport processes in lakes, reservoirs, and the ocean. These flows can travel hundreds to thousands of kilometers and last for extended periods, reshaping the seafloor through erosion and deposition. Over geological times, this activity leads to the formation of turbidites, which may act as reservoir rocks containing hydrocarbons. Turbidity currents also pose engineering risks by threatening underwater infrastructure such as pipelines, wellheads, and telecommunication cables. In the context of CO_2 storage, the injected carbon dioxide into reservoirs spreads as a gravity-driven plume beneath impermeable rock layers.

We investigate flows associated with these processes by conducting high-resolution numerical simulations and analyzing differences between two-dimensional and three-dimensional turbidity currents, and their interaction with the bottom topography. Also, we present preliminary results regarding the influence of a concentration-dependent viscosity field. This matters because, even though these flows depend on sediment concentration, most modeling approaches consider constant viscosity. So, we are interested in investigating how the presence of viscosity gradients will impact these buoyancy-dominated flows.

Numerical Method

Under the Boussinesq approximation, we employ direct numerical simulations of the three-dimensional Navier-Stokes equations with variable viscosity that includes a superimposed settling velocity to investigate the evolution of turbidity currents that originate from the lock-exchange configuration, in which a finite volume of dense fluid is released. The numerical algorithm combines several finite difference schemes with direct cosine transformations under the projection method that enforces incompressibility. The code employs domain decomposition in its parallelization and uses immersed boundary methods for the bottom topography.

Results and Conclusions

By comparing two-dimensional and three-dimensional flows, we highlight the influence of spanwise instabilities on deposit profiles, front velocity, and energy balance. In addition, we analyze the interaction of turbidity currents with seafloor topography in the form of Gaussian bumps. We compare the results for two different bump elevations with those for currents moving over a flat bed. The bump heights are selected so that the current mostly passes over the lower bump, whereas it diverts around the higher one. The influence of the bottom topography on the front velocity is found to be much weaker than the influence of the particle settling velocity. In addition, we discuss how the presence of a variable viscosity field, which depends on sediment concentration, will modify some of these findings.

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