High-resolution simulations of down-slope turbidity currents into a stratified saline ambient

R. Ouillon[1], S. Radhakrishnan[1], E. Meiburg[1], B. Sutherland[2]
[1]Department of Mechanical Engineering
UC Santa Barbara
Santa Barbara, CA 93106, USA
Email: ouillon@engineering.ucsb.edu

[2]Department of Physics
University of Alberta
Edmonton T6G 2E1, Canada

Abstract

We explore the properties of turbidity currents down a slope into a stratified saline ambient through highly resolved direct Navier-Stokes simulations, and compare our results to experimental results and analytical scaling arguments. Turbidity currents are buoyancy-driven flows where a denser fluid, charged with suspended particles, propagates through a lighter fluid under the effect of gravity. Three-dimensional simulations are conducted to investigate the properties and behaviour of these flows in various stratification and particle settling velocity configurations when they are moving down a slope. The unstable nature of the flow can be examined through three-dimensional representations of isosurfaces of constant particle concentration, as shown in figure 1.

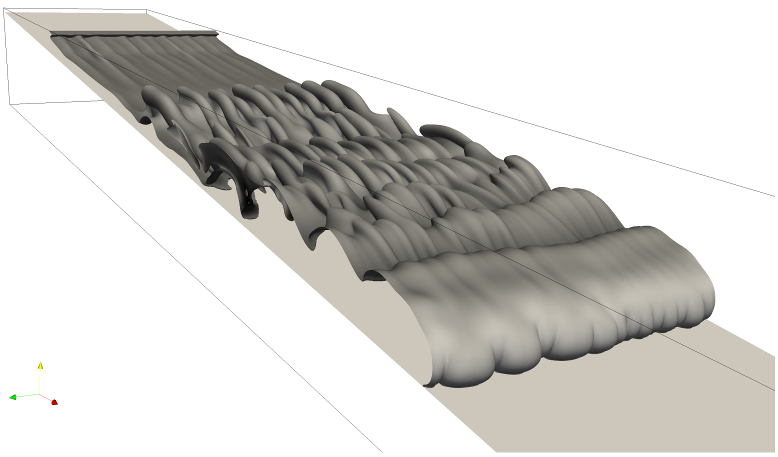

Figure 1: Downslope turbidity current as it destabilizes into a three-dimensional turbulent flow.

The lobe and cleft instability plays a key role in the transition from two-dimensional Kelvin-Helmholtz instabilities to a fully developed three-dimensional turbulent flow. The instability is described in terms of wavelength and sensitivity to the Reynolds numbers. The adequate width of the domain is chosen accordingly. The front velocity is then computed for various configurations of stratification and particle settling velocity. The results are compared to experimental data and a simple scaling law, with very good agreement, confirming the ability of highly resolved numerical simulations to capture the physics of such flows. The particle settling behaviour is then discussed and the relation between the sedimentation rate and the settling velocity is monitored. Numerical simulations yield comprehensive information on the flow field and particle and salinity distribution. This is used to compute a time and space dependent entrainment velocity of the ambient into the current and proves the case-sensitive and highly variable nature of entrainment.

Being able to accurately estimate the intrusion depth - the depth at which the current lifts from the slope and enters the ambient - is paramount as it corresponds to the point where the turbidity current loses its destructive potential with regard to engineering infrastructure on the seafloor. It also strongly affects the dynamics of settling by driving the particle-laden current away from the slope. This intrusion into the ambient is thus numerically investigated and compared to experimental results, existing scaling laws and a new simple model for low entrainment and long descent cases, with good agreement with literature. The intrusion phenomenon, illustrated in figure 2, depends on the kinematic and dynamic features of the flow and is influenced by the combined effects of particle settling, stratification and mixing with the ambient through entrainment.

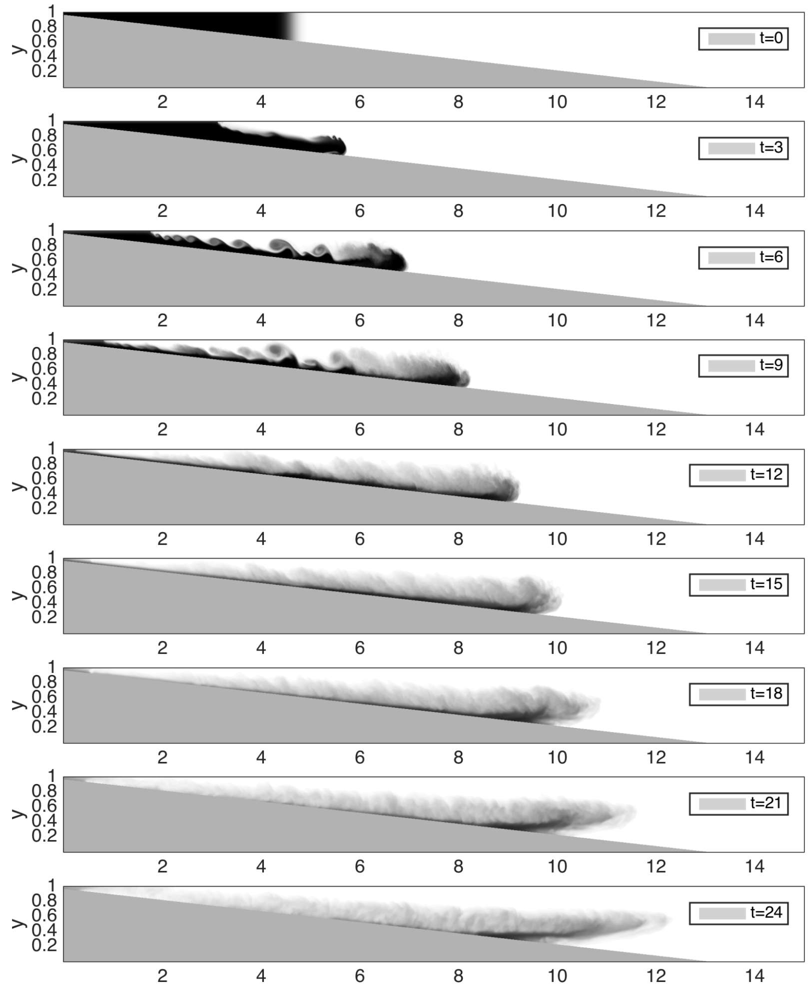

Figure 2: Evolution of a downslope turbidity current intruding in the ambient as its density matches the density of the ambient.

We analyze the energy budget of the flow to build on our understanding of energy transfers in turbidity currents, with a special focus on energy losses and potential to kinetic energy transfers. We finally describe the generation and propagation of internal waves by down-slope turbidity currents and briefly investigate their properties.