EXPERIMENTAL AND NUMERICAL SIMULATION OF DENSE WATER OVERFLOWS ON A CONTINENTAL SLOPE

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Summary We study a gravity current flowing down a uniform slope in a stratified or homogeneous media with rotation. Experiments performed on the large Coriolis turntable (Grenoble) are used to determine the stabilization depth of the main current, to measure the mixing and friction effects in a rotating system and to observe developments of instabilities. Experiments are used to test different turbulent mixing parameterization in numerical models used in oceanography.

Oceanic context

Dense overflows on a continental slope play an important role in renewing deep water as part of the global thermohaline convective cycle. Cold water from Nordic seas or salty water from the Mediterranean Sea descent into the Atlantic ocean over a sill, resulting in mass exchange with high density gradient, instabilities and mesoscale vortices creation. The main objectives of this study are to determine experimentally the principal characteristics of the gravity current (its position, width, thickness, velocity or development of instabilities), to measure the effects of bottom friction, mixing and entrainment in a rotating system and to test the influence of turbulent mixing parameterization in numerical models used in their oceanic configuration.

Experimental simulation

The experiments are performed on the large Coriolis turntable (Grenoble) with the experimental setup described in figure 1. The gravity current is created by salty water injected with a constant flux, which then flows down the incline slope (2m wide, 10m long, 15^o of inclination) with intense turbulent mixing occurring at the interface. In cases of homogeneous media the initial density differences are of 0.75%, 1.5% or 3.0%; and in cases of uniformly stratified environment, the density of the incoming fluid is that of the bottom water. The gravity current is deviated under Coriolis forces along the slopping bottom. The dimensions of the experiment permit to obtain a gravity current both turbulent and strongly influenced by rotation, and allow a good similarity with the oceanic scale with Rossby and Burger numbers conserved. For instance a continental slope of 122km wide and 3km deep can be reproduced. Earlier experiments were done either without rotation (Baines), or in a quasi-laminar regime (Etling).

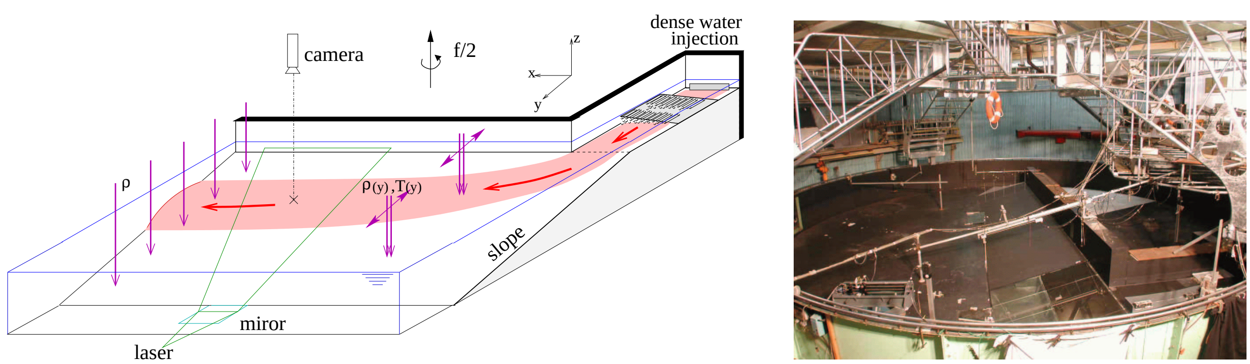

Figure 1. Schematic representation and picture of the experimental setup, with the position of the probes and laser

Velocity fields are measured by particle image velocimetry (PIV). The current is seeded with particles illuminated by a laser sheet directed along the slope at different heights. Probes are also used to record density variations at different locations (Fig 1).

This experimental study allowed trajectory visualisation of the gravity current (Fig 2). From the inlet, the current first flows down the slope as a usual turbulent gravity current, mixing with the ambiant fluid. It is then deflected by the Coriolis force and reaches an equilibrium depth, in a state of geostrophic balance. However a small part of the fluid is moving downward in the bottom viscous boundary layer. It is subject to a friction driven instability, as seen in figure 2a. Another instability, of baroclinic kind, is observed on the main current, generating large vortices stretching over the whole water depth (Fig 2a).

The position of equilibrium can be measured from velocity fields obtained by PIV, as shown on figure 3 in the main current. Density profiles also permit to determine the width, thickness and position of the gravity current, and to measure the mixing occurring mainly at the beginning of the descent. The geostrophically balanced jet flowing along the slope suffers very little mixing.

A global assessment of mixing is obtained 24 hours after an experiment, once the fluid particles of different densities reach their rest state. The global distribution of density probability is calculated from vertical density profiles as shown in figure 4. The initial density excess of the current in this experiment is 1.5% while the maximal density measured in the main current after mixing is 0.4%,corresponding to the observed peak. The occurrence of higher densities can be attributed to the downward flow in the viscous boundary layer protected from mixing.

Numerical modelling

Global oceanic models don't succeed at representing correctly those dense overflows. The main problem is often due to an excessive mixing of the deep water masses. Models have trouble treating topography, coarse vertical resolutions,and inadequate parameterization of bottom friction and turbulent mixing, especially when rotation is important. These laboratory experiments can be used as test cases to compare the performance of different parameterizations. An isopycnal coordinate model, MICOM, is used here because diapycnal mixing (between layers of different densities) is introduced only by the turbulence parameterization, without numerical contributions. Mixing between the different layers is represented by Hallberg's parameterization (2000) which is based on Turner's turbulent entrainment scheme (1986).
The main features of the gravity current are well reproduced by numerical simulations, but velocities obtained are too high while the current thickness is too small. A thorough analysis of the turbulence parameterization influence is in progress.

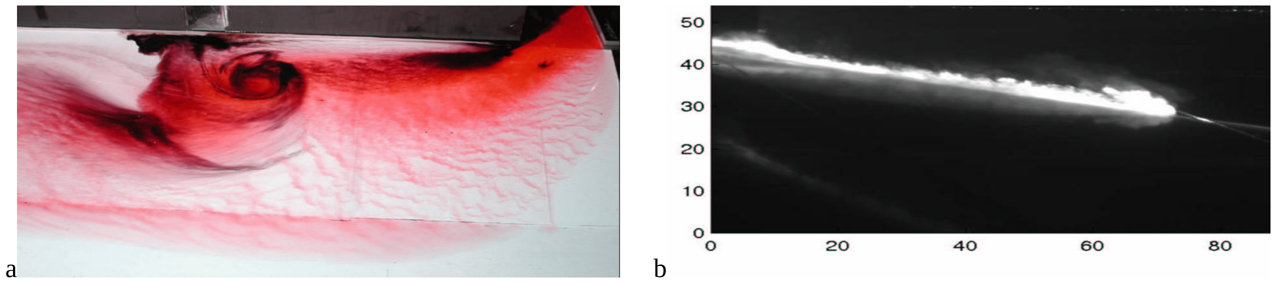

Figure 2. Visualisation of the gravity current behaviour. **a.** The current (red dye) splits into a geostrophically balanced jet flowing along the slope and a thin layer slowed down by viscosity descending the slope. The main current is subject to baroclinic instabilities which induce cyclonic vortices over the gravity current seen by injection of black dye. **b.** The vertical cut (fluorescine illuminated by a vertical laser sheet) shows that the current thickness decreases at the beginning of the slope before growing because of turbulent mixing.

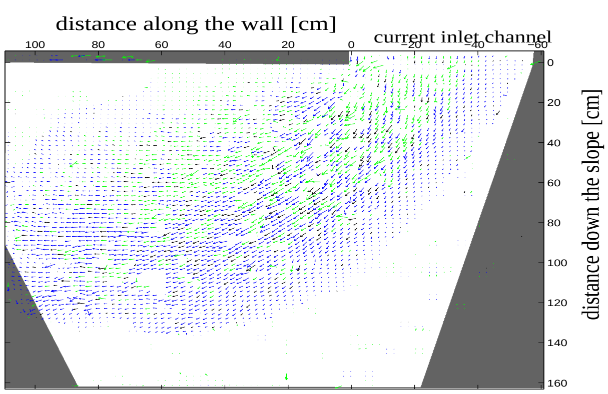

Figure 3. Example of velocity field obtained for the main current by PIV with a laser sheet parallel to the slope at a distance of 2cm.

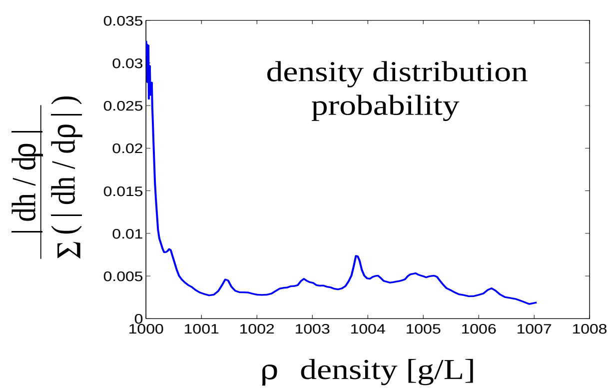

Figure 4. Global density distribution probability obtained by mixing for a current of 1.5% of initial density excess. A peak at 0.4% and A nearly uniform distribution is observed with a peck at 0.4%, the main current density after mixing.

Conclusions

The dynamics of a dense water overflow on a continental slope has been reproduced in laboratory for the first time: effects of rotation and density stratification are reproduced in dynamical similarity, and the gravity current is fully turbulent. The mixing of this current with the surrounding fluid has been characterized, providing support for modelling of turbulence in such systems.

References

[1] Baines P.G.: Mixing in flows down gentle slopes into stratified environments. *J. Fluid Mech.* **443**, 237-270, 2001.
[2] Etling D. et al.: Experiments with density currents on a sloping bottom in a rotating fluid. *Dyn. Atmos. Oceans* **31**, 139-164, 2000.
[3] Hallberg R.: Time integration of diapycnal diffusion and Richardson number dependent mixing in isopycnal coordinate ocean models. *Mon. Wea. Rev.* **128**, 1402-1419, 2000.
[4] Turner J.S.: Turbulent entrainment: the development of the entrainment assumption, and its application to geophysical flows. *J. Fluid Mech.* **173**, 431-471, 1986.