Background Motivation

Density currents are primarily horizontal flows generated by horizontal density gradient. Thunderstorm outflows and sea breezes, amongst the others, have been shown to resemble density currents features. The interaction and collision of these flows can trigger severe convection and lead to severe weather.

Why this study?

- Convective initiation and cold pool parametrization has not received a lot of attention in the prior literature. Parametrization is needed since GCM are too coarse to capture cold pool processes.
- Reproduce numerically the recent laboratory experiments of colliding density currents by van der Vellet et al. (2017) in an idealized setup.
- Better understanding the dynamics of the collision, in particular two features: maximum height reached by the fluid after collision and the interface angle between the two fluids. The latter in particular is relevant for the position and strength of collision-induced convective triggering.
- Predict this interface angle, prior to the running of the numerical model, based on the density ratio of the two fluids.

Numerical model

Initial conditions and setup

2D rectangular tank with height H and length L, with the two fluids with depth D at the two sides with buoyancies $b_1$ and $b_2$. Using the numerical software package called Hydra (http://www.vortex.mcs.st-and.ac.uk) we solve the Boussinesq approximation of the vorticity equations. The numerical solution will depend on some dimensionless parameters (aspect ratio $\frac{H}{L}$, buoyancy ratio $\frac{b_1}{b_2}$, depth ratio $\frac{D}{H}$). Therefore we have run several experiments varying these parameters.

Numerical simulations

Animations of the simulations can be downloaded scanning the QR code provided.

Theoretical model for interface angle

The aim is to understand the role of vorticity field (plot shown on the left for $r_0=0.33$). The denser current (marked by red vorticity field) intrudes underneath the less dense current (in blue). This dynamic can be described by the angle that the interface between the two fluids form with the horizontal bottom line. Formation of vortices with opposite sign circulation at the head of current can be seen. Therefore we have modelled the collision dynamics as a vortex pair system. This analysis gives us a predictive formula for the angle with the horizontal line.

The theoretical value for the angle agrees well with numerical values for all buoyancy ratios (see figure 4). However this model is approximate, and is only expected to apply for a short interval during the collision. Nonetheless, it has two implications. The first, from is that, at a given dimensionless time after collision, the angle is proportional to the net circulation in the collision zone. The second, from is a parabolic dependence of the measured angle on the buoyancy ratio, with a vertical interface in the case $r_0=1$.

Highlights, conclusions and future work

- The numerical simulations in idealized setup carried in this study represent a first step towards convective cold pool parametrization.
- The vorticity Boussinesq model is able to capture the essential features of the collision dynamics.
- The predictive formula for the interface angle agrees well with numerical simulations values.
- The present study could be relevant only to daytime well mixed boundary layers. Therefore more simulations are needed to explore more realistic situations (stratification and wind shear).

References


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