GRAVITY-DRIVEN FLOWS IN STRATIFIED FLUIDS)

Paul F. Linden [a)] & Benjamin D. Maurer
Department of Applied Mathematics and Theoretical Physics, University of Cambridge, Cambridge, UK.

Summary We describe the flow generated by horizontal density differences between two stably stratified fluids. These gravity-driven flows are extensions of classical gravity currents that occur between two unstratified fluids of different densities, and which have successfully been described in terms of transfers of available potential energy to the kinetic energy of the flows. Using a combination of lock exchange laboratory experiments and numerical simulations we examine the case of layered stratification. In the case when the two fluids have the same average densities the flows are symmetrical and are given by the individual intrusions along the interfaces. When the average densities are different a mean shear develops and the intrusion speeds vary with depth. We show that these two flows can be decoupled and their speeds determined by the available potential energy of the system.gy.

INTRODUCTION

We are interested in determining the role of ambient stratification in the density-driven exchange of two fluids. For this purpose we have carried out experiments and numerical simulations on a stratified version of the classical 'lock exchange' experiment which has been used to study gravity currents in unstratified fluids [2]. Recently, this has been extended to the case of two continuously stratified fluids but restricted to the case where the average densities of the two fluids are the same [1].

The purpose of this paper is to examine the effects of different average densities on the lock exchange flow. We do this by considering the case of layered stratifications.

THE INITIAL CONFIGURATION

Equal initial average densities

We consider two fluids initially at rest and separated by a vertical lock gate. The fluids are stably stratified in the vertical and the stratification takes the form of a set of vertical layers separated by sharp density interfaces. We consider the case where the density difference $\Delta\rho$ between each layer on both sides of the lock is the same, and apart from the top most layer on the left and the bottom most layer on the right, which have depths d the other layers all have equal depths $2d$ (Figure 1). In this case the average densities of the two fluids are equal and the flow is symmetrical about the initial position of the lock.

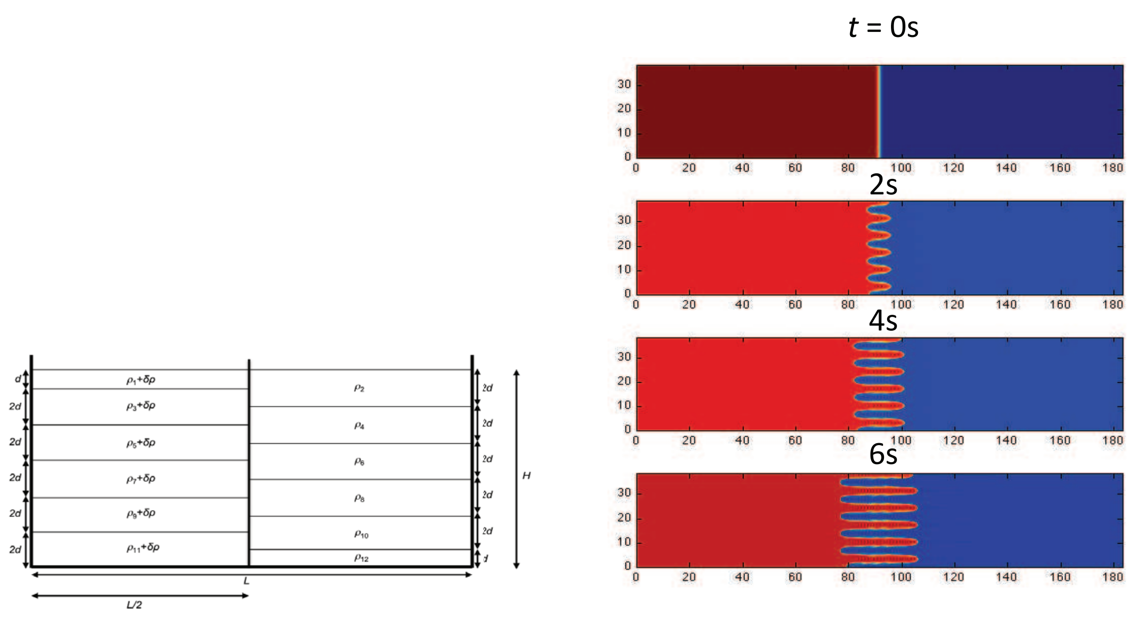

Figure 1. The initial configuration before the lock is released (left) and numerical simulations for 10 layers with equal average densities on both sides of the lock ($\delta\rho = 0$).

Different initial average densities

We then consider the effects of increasing the density of the fluid on the left by and amount $\delta\rho$ relative to the fluid on the right. In order that the layers intrude sequentially on both sides it is necessary that $\delta\rho/\Delta\rho < 0.5$

[a)] Corresponding author. E-mail: P.F.Linden@damtp.cam.ac.uk

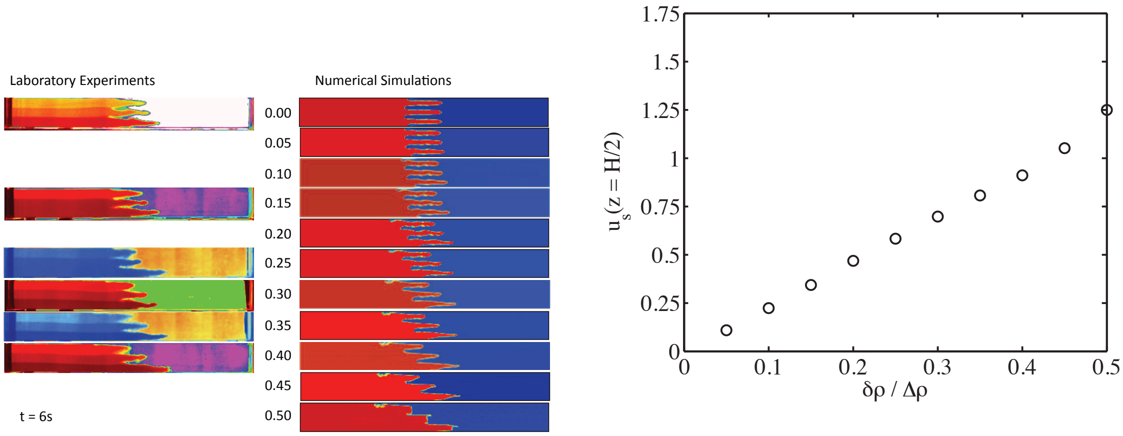

Figure 2. Experiments and numerical simulations (left) for increasing values of $\delta\rho/\Delta\rho$, and the resulting speeds.

As can be seen in figure 2, the effect of a larger average density on the left produces a shearing of the layers, with those on near the bottom travelling faster to the left than those on the top. This is consistent with a shear flow is driven by the average density difference $\delta\rho$, but surprisingly is increase in shear shows a linear dependence.

AVAILABLE POTENTIAL ENERGY

Because of the symmetry of the layer depths, each there is no change in potential energy of the any of the layers except for the depth layers at the top and bottom. consequently, the shear flow is driven entirely by these layers. A calculation shows that the shear flow then decreases as $\Delta\rho^{-1/2}$ as shown in figure 3, while the individual intrusions travel as predicted by the dashed curve.

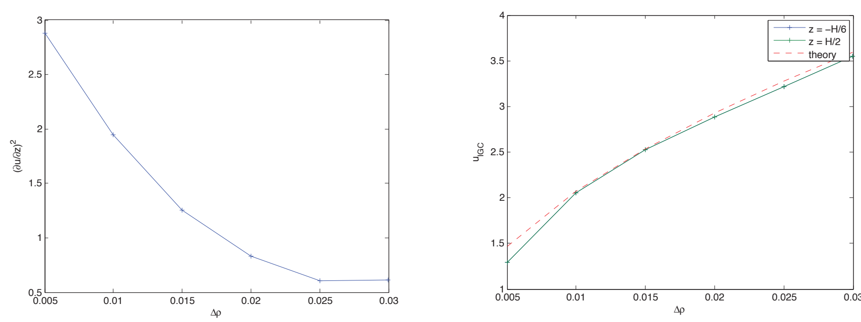

Figure 3. The mean shear (left) and the intrusion speeds (right) plotted against $\Delta\rho$.

We thus conclude the the effects of the stratification and the different average densities can be treated separately and are determined by the available potential energy of the system.

Acknowledgements

This work was supported by the National Science Foundation under grant CTS 0756396.

References

[1] B. D. Maurer, D. T. Bolster, and P. F. Linden. Intrusive gravity currents between two stably stratified fluids. *J. Fluid Mech.*, 647:53–69, 2010.
[2] J. O. Shin, S. B. Dalziel, and P. F. Linden. Gravity currents produced by lock exchange. *J. Fluid Mech.*, 521:1–34, 2004.