Understanding Ocean Circulation using Open-Ended Experiments in an Introductory Class

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Want to run this activity yourself – find it on Teach the Earth
https://serc.carleton.edu/teachearth/activities/181203.html

1. INTRODUCTION

Density-driven flow is major driver of ocean circulation, and key to understanding thermohaline circulation and ocean overturning. In an introductory earth systems course, we use quantitative tank experiments to investigate the effects of salinity (and thus density) on the flow of ocean water.

During a 2 hour laboratory, students perform two activities, a set of quantitative experiments to explore density driven flows, and an open-ended experiment to replicate an ocean process of their choice. Applications include convergence of currents, ocean stratification, geostrophic flow, the effects of bathymetry and complex water flow off Antarctica. These experiments provide practice in data recording, writing scientific reports, defining and testing hypotheses, and fitting equations using a spreadsheet.

In preparation for the laboratory, students are required to watch a video that explains the aims of the activity and explains how to perform the quantitative experiments. Since introducing this video, we have found that students arrive much better prepared for the class and start working sooner.

Watch the introduction video
https://www.youtube.com/watch?v=5NpYKpI-p8U

2. EQUIPMENT

For this activity, we use custom-made acrylic tanks that contain a removable barrier which isolates part of the tank. The tanks have internal dimensions of 80 mm (W) x 200 mm (H) x 800 mm (L), and are constructed from 10 mm thick clear rigid plastic, as shown in Figure 1. The barriers are made from the same materials, and sized to provide a watertight fit once inserted (Figure 1). They feature a cut-out handle, and have a rubber door seal around the edge, on occasion silicone grease may be needed to allow easy removal. Other equipment includes: salt, food dye, density meter, balance, spoon and measuring jug. For the open-ended activity, we also supply ice, rocks, fans and extra barriers.

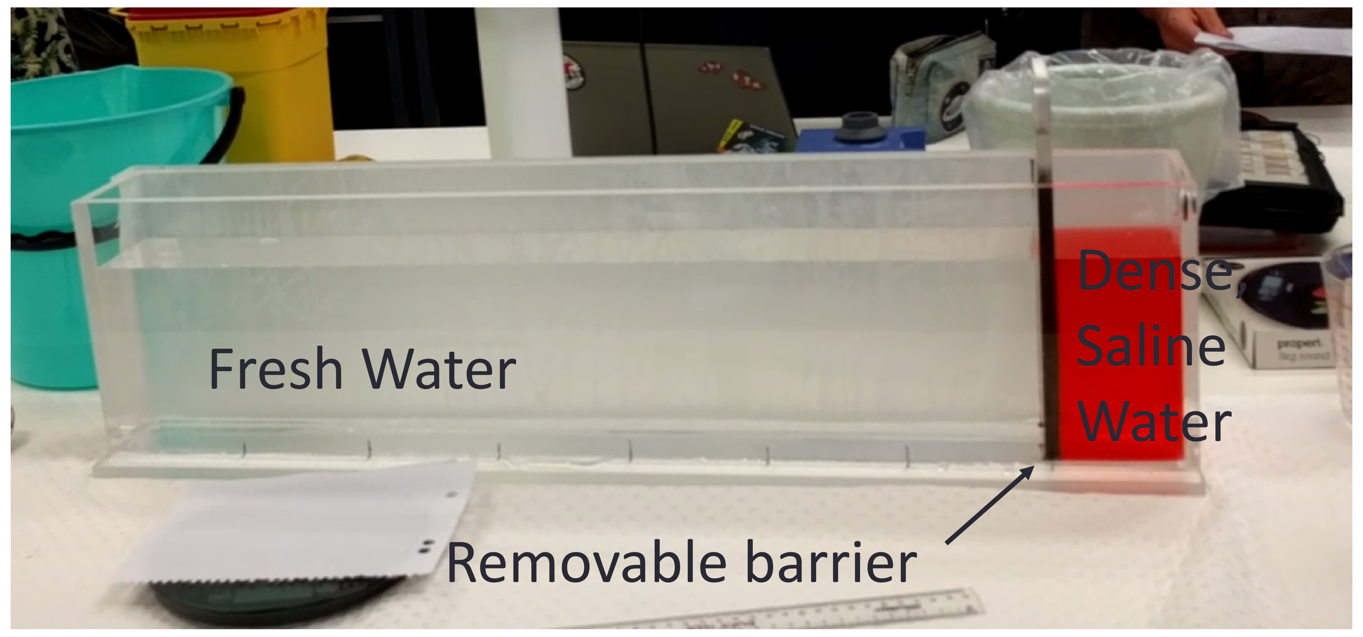
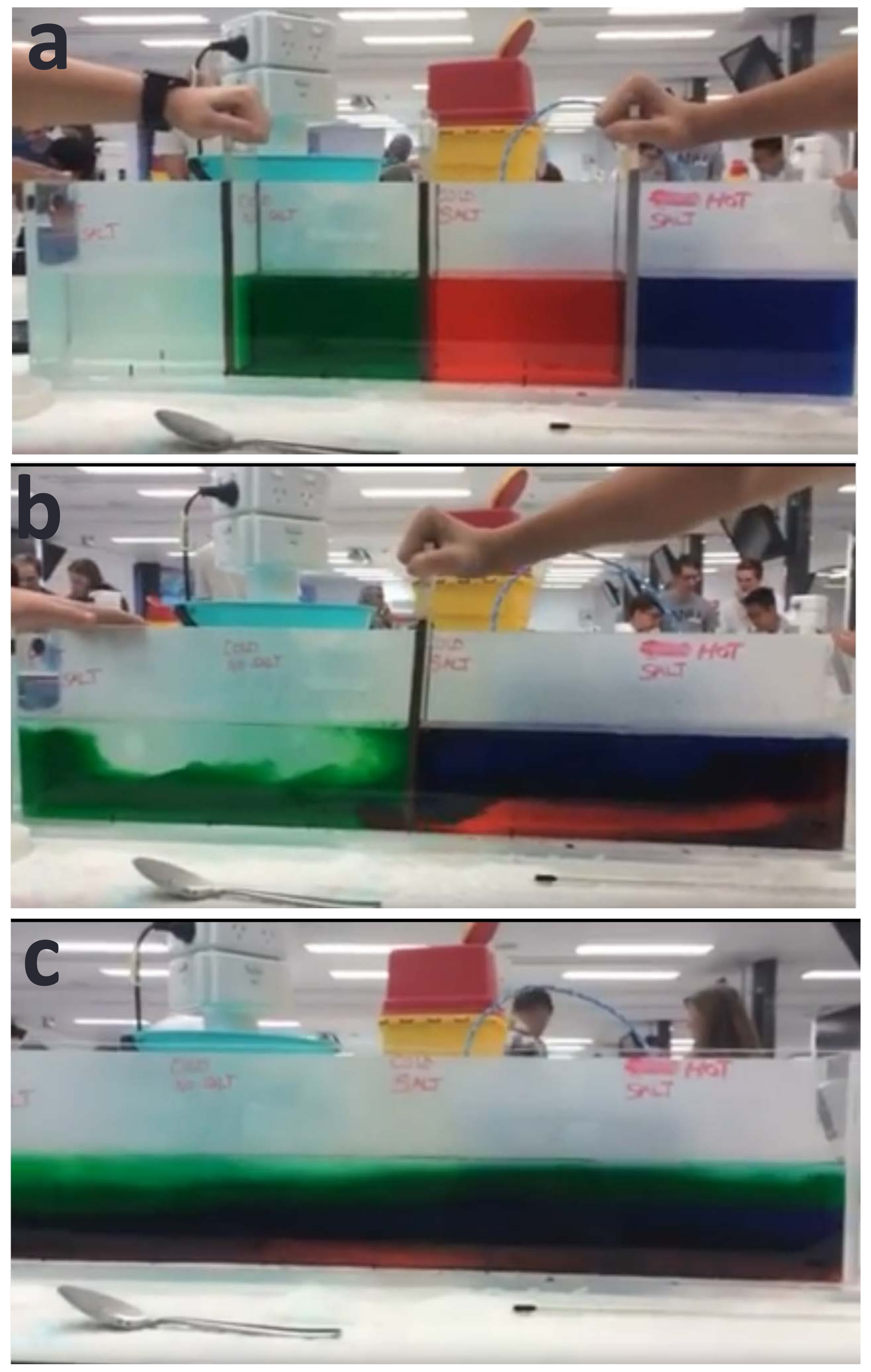


Figure 1: Tank set-up just prior to the commencement of a quantitative experiment. The small compartment (red) is higher in density (salinity).

3. OPEN-ENDED EXPERIMENTS

Students are invited to design and conduct an experiment to replicate an ocean process of their choice, based on what they have learned in preceding lectures/workshops. They are provided with materials including salt, ice, warm water, additional barriers, obstacles and fans. This leads to a vibrant engaged class as students attempt to replicate processes such as the convergence of currents, ocean stratification, geostrophic flow, the effects of bathymetry and the complex water flow off Antarctica (Figures 2-4). .Many students record their experiments as videos or photos, some of which are high-quality demonstrations of science communication and may be used as an advertisement for the course.



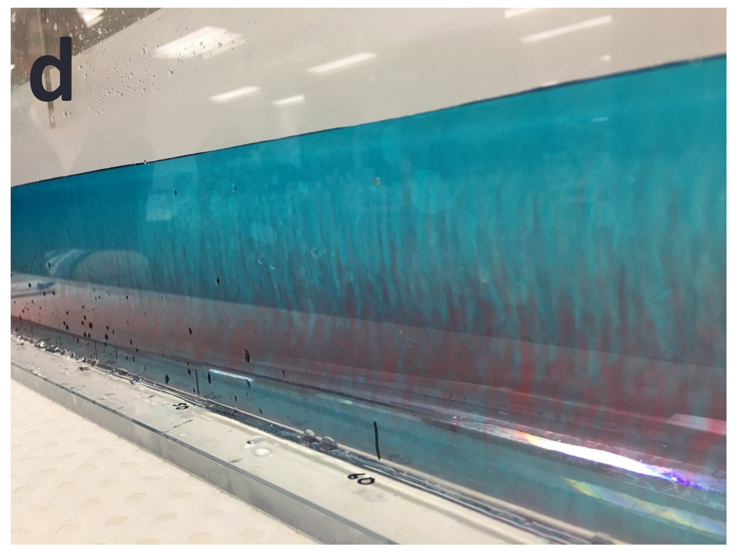


Figure 2: a-c – Three stages of a experiment investigating the mixing fresh water (clear – cold, green – hot) and salt water (red – cold, blue – hot), to determine the final layering. (Photos: Margot Schneider). **d** – Salt fingering – formed when the warm salty water (blue) diffuses into the cold fresh layer (red), losing heat and sinking. Warm, salty blue fingers sink, whilst cold, fresh red fingers rise. (Photo – Fletcher Howell)

Watch Videos

4. QUANTITATIVE EXPERIMENTS

Prior to the open-ended experiments, students perform a series of experiments with increasing density, timing the flow of the density current. The tanks are filled with fresh water and the barrier is used to isolate a small portion. A known amount of salt and dye is added to this volume, creating a more saline, denser water mass (Figure 1). Students, working in teams of ~4, remove the barrier between the water volumes, observing and timing the progress of the dense salty water as it flows along the base of the tank, to determine the flow velocity. After performing multiple experiments with increasing density, students calculate a constant that allows for the determination of flow velocity as a function of water height and the density contrast between water masses.

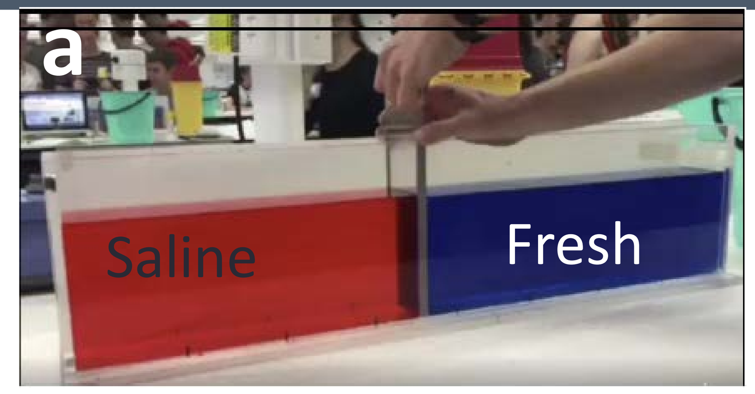
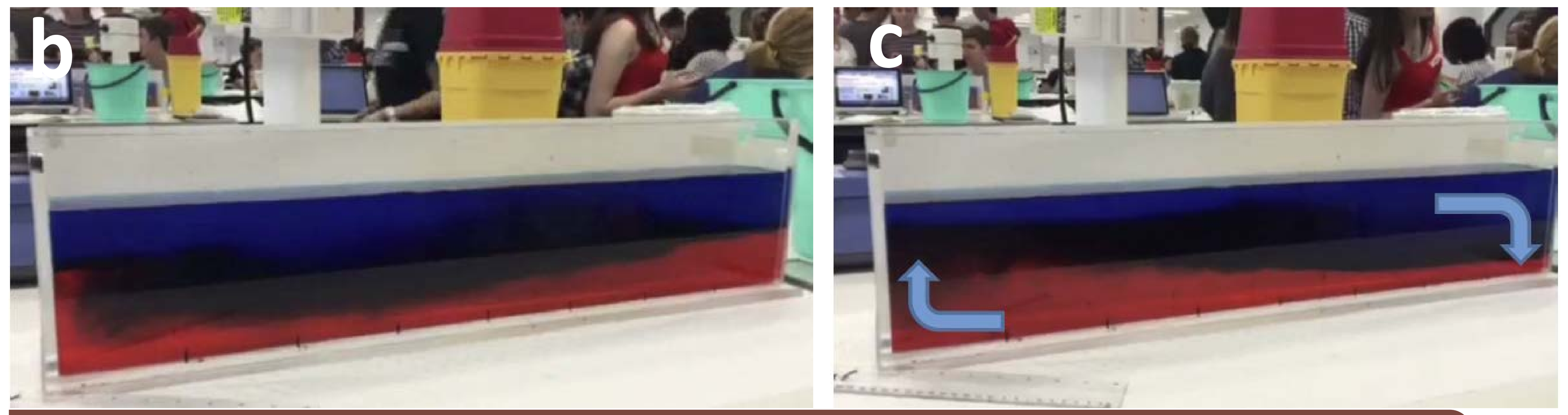


Figure 3: Three stages of an experiment aiming to create a simple circulation system with both upwelling and downwelling. When the current reaches the end of the tank upwelling or downwelling occurs. (Photos: Zoe Esplin)

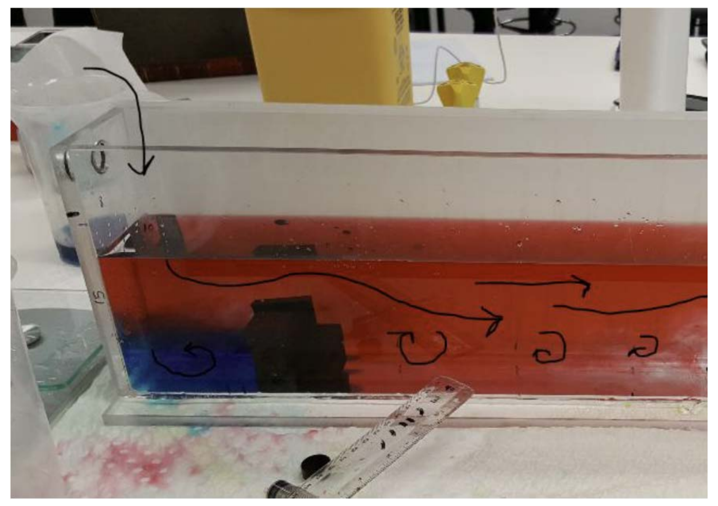


5. ASSESSMENT

Assessment for this activity varies year to year, but generally consists of two parts. One part of the assessment involves performing data analysis for the quantitative experiments. This involves entering the timing and density data into a spreadsheet (or similar), and then plotting the results. Once this is done, curve fitting is used to obtain a constant for an equation that can predict the current velocity when the density difference is know.

The assessment for the open-ended experiments involves writing a simple laboratory report (aim, methods, results, discussion), teaching students how to communicate what they did, and to interpret their results. The results section of the report often includes high quality images or videos that show the experiments, along with an involved discussion of what they aimed to achieve, and if it succeeded.

Figure 4: An annotated image from an experiment exploring whether an agitated surface ocean (red) is able to mix with dense deep ocean water (blue). The blue dense water was emplaced using a syringe, and the surface layer agitated by stirring, with an aim to replicate how the wind mixes the surface layer. The students found that the deep ocean water was too dense to mix with the surface water. (Photo: Lachlan O'Reilly)



6. OUTCOMES

This activity is frequently rated as one of the highlights of the semester for both students and teaching staff, and has very high levels of student engagement. Over the last three years the range of experiments conducted by students has broadened, and we see a definite link in the quality of experiment between those who have attended lectures, and those that did not. We also perceive an increase in student understanding of the drivers for ocean circulation since adding the open-ended experiment. Overall, the activity teaches students the link between observations, theory and experimental modelling of oceanographic processes.

We wish to thank all the students and teaching assistants involved in the course over the last three years, in particular those providing or appearing in videos and photos.