Laboratory simulations of eddy behaviour in the region of an ice front

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Introduction

The eastern side of the Ronne depression is an area where High Salinity Shelf Water (HSSW) formed as a by-product of sea ice formation enters the cavity beneath the Filchner Ronne Ice Shelf system (Makinson and Schroder, 2004). This fluid flows downslope via the Ronne Depression. The production of HSSW also causes the formation of eddies as the HSSW descends through the water column (Nicholls et al., 2003).
Separate related work as part of this project includes an analysis of the FR5 and FR6 mooring records from the Southern Weddell Sea along the Ronne Ice Front. This shows the flow along the ice front to be rich in eddies. These have previously been attributed to baroclinic instability (Nicholls et al., 2003). Our experimental study is to determine if eddies in the southern Weddell Sea could propagate into the cavity beneath the ice shelf taking the additional HSSW with them and also potentially increasing mixing in the cavity.

Methods

The experiments discussed in this paper have been conducted in the School of Mechanical, Aerospace and Civil Engineering, University of Manchester. The apparatus is shown in Figure 1. It consists of a 1.2 m rotating table, a Perspex tank with internal dimensions of 55x55x55 cm, a slope with a fixed angle of 1 in 10, and a gravity fed source. The source fluid densities were varied from 1010 to 1100 kg m^{-3} with an ambient density from 996 to 1000 kg m^{-3}. This produced density differences ranging from 1 to 10 %. The source injector was fixed 10 cm from the top of the slope facing down the slope and fluid exiting the source was dyed for visualisation. The ambient fluid depth was either 2.5 or 5 cm at the top of the slope. Dye was also added to the surface of the ambient fluid during the experiments to visualise the flow in the upper layer. The ice shelf is simulated only through its physical effect on the water column height and the experiments all have an unstratified ambient fluid. The ice shelves used were built from Perspex sheet and are suspended from above the tank with a space between the shelf and slope ranging from 1.25 to 5 cm. Images are recorded from a video camera mounted above the tank. The rotation period was set to 10s in all but 10 experiments. This arrangement consistently produced eddies which are largely barotropic and vortex stretching was the primary mechanism for their formation. The ice shelf and slope were setup in different configurations with an example configuration shown in Figure 2. The ice shelf front could be either perpendicular or parallel to the slope. A solid coast was included at the end of the slope for 25 of experiments and the total number of experiments completed was 84.

Preliminary Results

The work on the data is underway and some preliminary conclusions can be drawn. The production of eddies is similar to that of previous work by other authors (e.g. Lane-Serff and Baines, 1998, Cenedese et al., 2004). The formation of eddies is most likely by the following mechanism. Initially the current adjusts to geostrophic balance causing it to flow along the slope. Ekman drainage occurs in the lower layer producing extra drainage down slope acting to reduce the thickness of the plume. There is a capture or linkage between the lower and upper layer and flow downslope causes an increase in the thickness of the upper layer of fluid which induces vortex stretching and thus a cyclonic eddy through conservation of potential vorticity. Once the eddy has formed it then propagates along the slope. In all experiments the propagation rate of eddies along the slope is an order of magnitude less than the Nof Speed (Nof, 1983). Ekman draining was clearly visible and strongest in the experiments where the source density exceeds 1050 kg m^{-3}.

The size of eddies agrees with previous work (Lane-Serff and Baines, 1998) although there some with a decrease in eddy size observed as the Rossby radius is increased for some of the domain. This could be noise as the eddy size has been shown to vary significantly by previous workers. Also, the time interval between eddies agrees with previous work by Lane-Serff and Baines (1998).

The configuration where the shelf front is perpendicular to the slope, as shown in Figure 2, will be considered first. Once the eddy has formed it propagates along the slope until it reaches the ice front where different behaviours are observed. Eddies may propagate up or down slope upon reaching front or they may enter the cavity. It is found that the stretching parameter ([vortex stretching]=[Rossby radius]×[slope]/[ambient fluid depth at source]) must exceed 0.12 for eddies to enter the cavity. The height of the shelf has been varied in order to determine the critical height at which the eddies are blocked from entering the cavity. This was found to be when the ratio of shelf height to water depth (at the top of the slope) is greater than 1. Thus, for eddies to enter the cavity both the vortex stretching must be greater than 0.12 and the ratio of d/h must be less than or equal to 1. The break up and/or splitting of eddies at the ice front is a common phenomenon and was observed in all configurations. Examples of each of the forms of behaviour are shown in Figure 2.

When the ice shelf is configured with its front parallel to the slope and downslope of the source (not shown in the Figures) an additional flow regime observed. If the distance between the source water injector and the shelf is similar to or less than the diameter of eddies produced in the control experiments then no eddies are produced. Instead a large cyclonic gyre forms between the source water injector and shelf in the ambient fluid layer. The gyre may appear as a dipole but eddies are rarely or never spawned. The effect of the solid coast is to increase the flow down the slope along the coast. Some of the fluid is observed to start to flow upslope following the mean circulation but this eventually flows downslope along the coast.

Discussion

It is clear that the presence of the ice shelf blocks the propagation of eddies unless the water column penetration beneath the surface of the ice shelf is small. Also, altering the shelf configuration so that the shelf is close to the source produces a configuration and result that is unlikely to be observed in the ocean.

These experiments have been conducted in a small tank where the mean circulation is strong which was apparent from the pathways of that the eddies follow. The question of how much of the observed behaviour can be attributed to the size of the tank needs to be addressed. As a result of this the experiments are to be scaled up at the Coriolis-Legi 14 m rotating table facility in France. The aim is to clarify exactly what the effects of the small tank are and how valid these results are when the area of eddy formation in not impeded by the presence of the ice shelf. Planned experiments include the use of stratification to determine if this aids the propagation of eddies into the cavity beneath the ice shelf. PIV will also be used to determine the local velocities within the eddies, enable the calculation of vorticity and to fully visualise flow in the upper layer.

Acknowledgements

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Figures

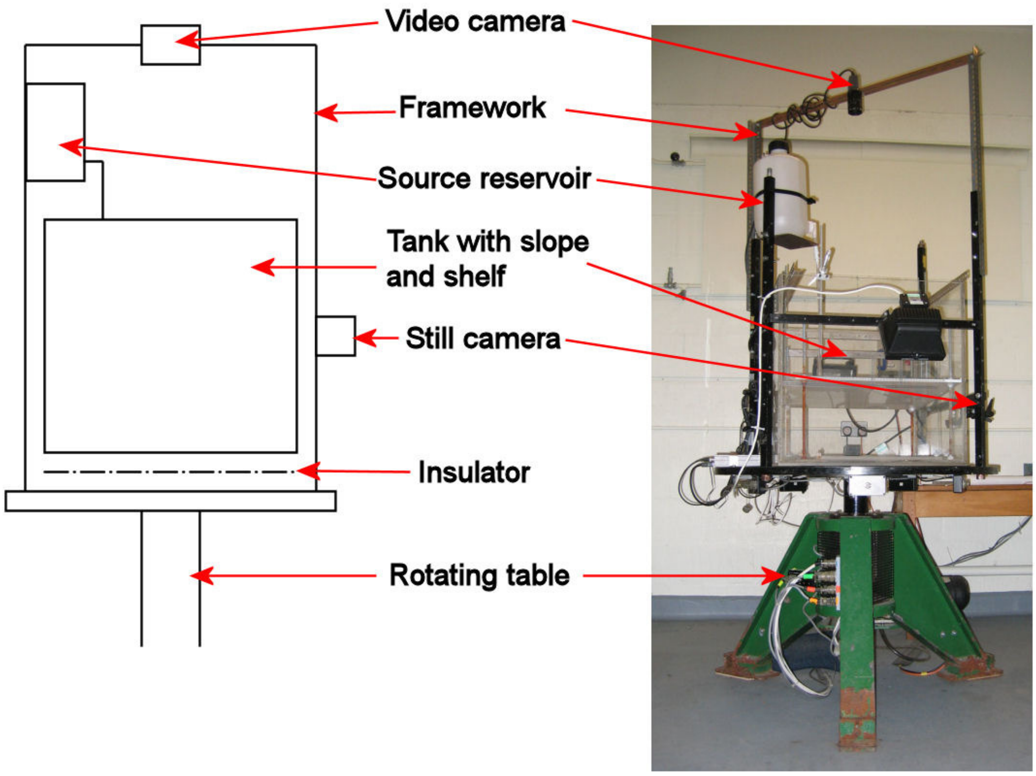
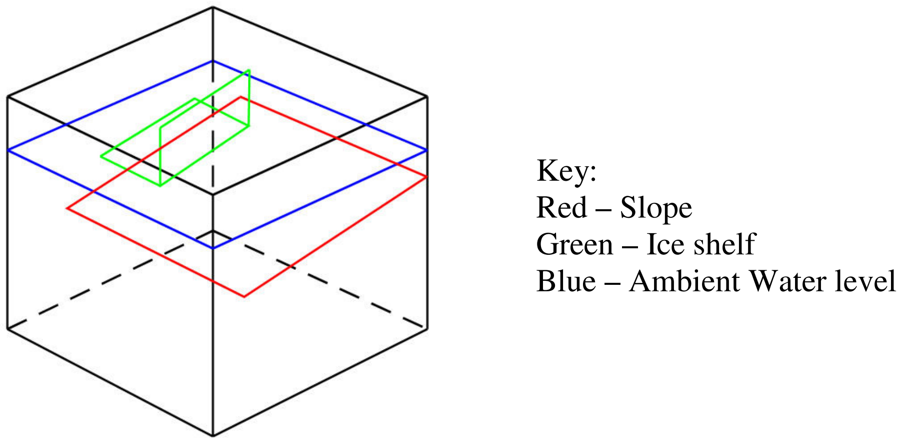
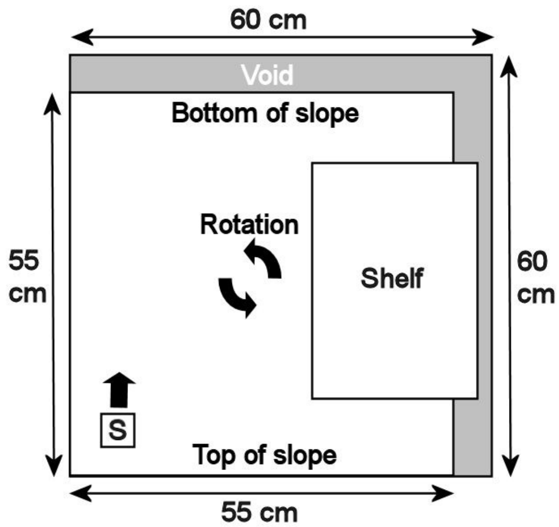


Figure 1: Diagram showing the setup of the laboratory experiments.

a)



b)



c)

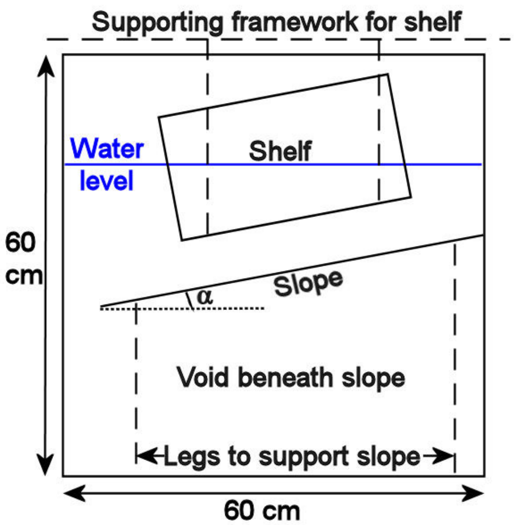
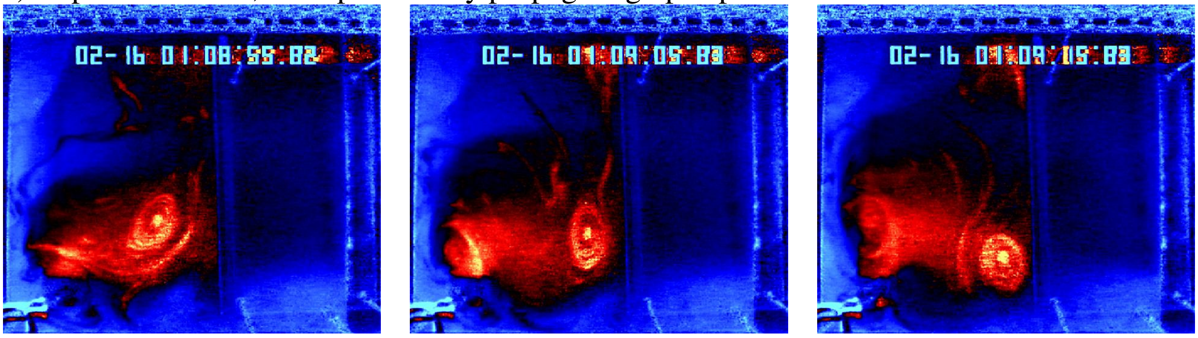
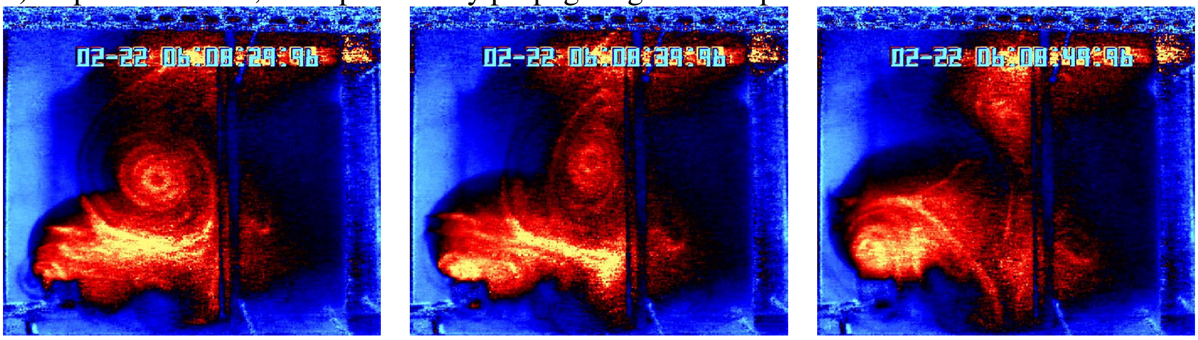


Figure 2: Diagram showing an example configuration from the experiments where the shelf is setup so its front is perpendicular to the slope. The diagrams show a) the isometric view, b) view from above and c) the view from the side.

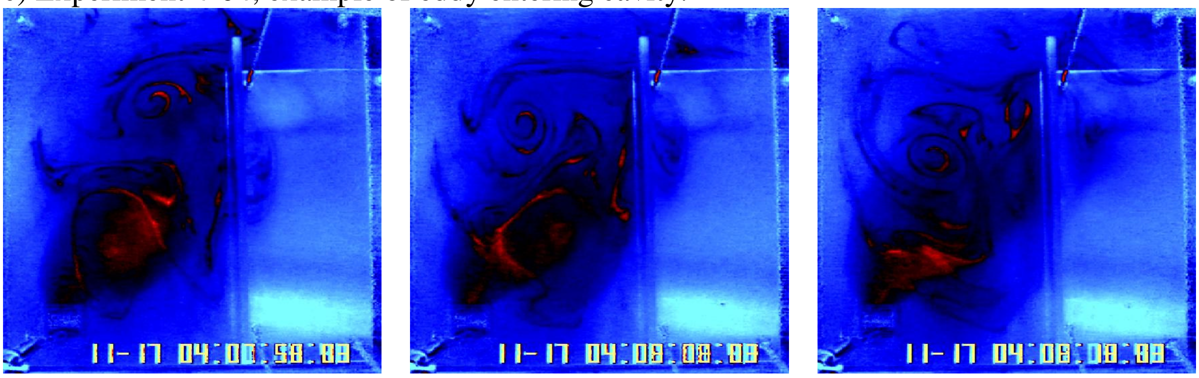
a) Experiment 6-01, example of eddy propagating upslope.



b) Experiment 6-06, example of eddy propagating downslope.



c) Experiment 4-04, example of eddy entering cavity.



d) Experiment 6-08, example of eddy breaking up at the shelf face.

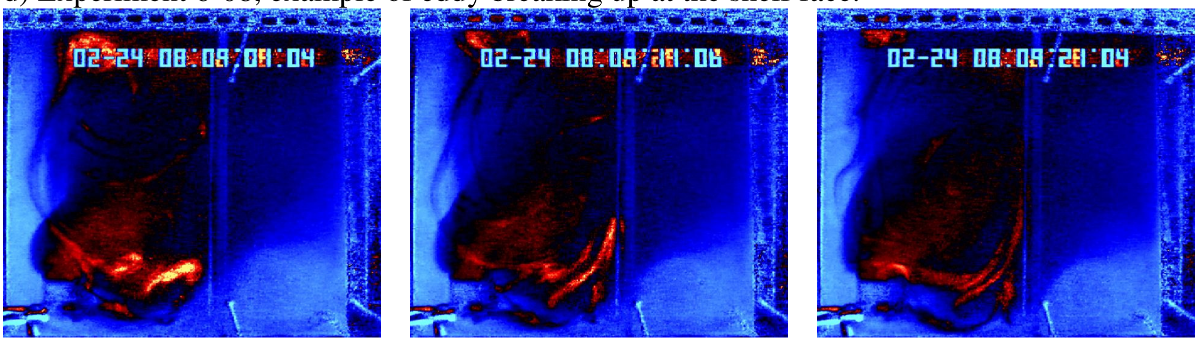


Figure 3: Short image sequences taken from the top mounted video camera showing different eddy behaviour at the shelf face in the perpendicular configuration. Image interval is 10 seconds. Dye has been added to the upper layer to aid in identification of eddies. This is visible as light or dark red streaks. The camera view is as shown by Figure 2b.

References

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