Laboratory Experiments Investigating the Influence of Fjord Circulation on Outlet Glacier Melting

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Beginning in 1996, Greenland's outlet glaciers rapidly retreated and accelerated, increasing their discharge to the ocean and contributing more noticeably than in the past to sea-level rise. A similar trend has also been observed around the Antarctic ice sheets. The magnitude of the acceleration of these glaciers was unexpected to many glaciologists, whose numerical models of large ice sheets have variations in ice mass on millennial–timescales. Clearly, this highlights our lack of thorough understanding of the dynamics regulating the motion of glaciers. In particular, the conditions regulating the interaction of glaciers with surrounding sediments, rock and water are poorly understood. As highlighted by the Intergovernmental Panel on Climate Change (IPCC) in 2007, today the largest uncertainty in predicting sea-level rise comes from the lack of a correct representation in climate models of the rapid changes observed in outlet glaciers. More than a decade later, the leading hypothesis is that the acceleration was triggered by increased submarine melting at the glaciers' edge, driven by warming ocean waters. However, our understanding of the submarine melting process is very limited.

In this project, with support from The James M. and Ruth P. Clark Arctic Research Initiative, I proposed to conduct idealized laboratory experiments to investigate the ice-ocean interaction near a vertical 'glacier' (i.e. no floating ice tongue) in a two-layer stratified fluid, similar to Sermilik Fjord where Helheim Glacier terminates. In particular, I focused on the investigation of the efficiency of various fjord circulations in transporting heat to the outlet glaciers, the effect of bottom water temperature on submarine melting, and the influence of upstream surface meltwater coming out at the base of the glacier on the melting of the ice-ocean interface and the fjord circulation.

Two fjord circulations are compared to a control experiment with no forced flow. The estuarine circulation is generated by introducing fresh water at melting temperatures from a source at the water free surface near the ice block representing the glacier. The wind driven circulation is generated by vertically displacing a solid block at the end of the tank opposite the ice block, mimicking the observed fjord circulation driven by wind events. The magnitude of both circulations can be systematically varied. The circulation pattern observed in the control and estuarine experiments is similar to those observed in previous studies. A thin light plume of cold melt water mixes with ambient waters and rises until it finds either the interface between the two layers, if in the bottom layer, or the free surface, if in the top layer. The results suggest that the melt water mainly deposits within the interior of the water column and not entirely at the free surface, as confirmed by field observations. In the wind driven experiments, the submarine melting of the glacier is only slightly enhanced. However, the submarine melting is strongly dependent on the bottom layer temperature and it increases with increasing temperature, as expected.

In summer, the discharge of surface runoff at the base of the glacier (subglacial discharge) causes the circulation near the glacier to be much more vigorous and is associated with a larger melt rate than in winter. In the laboratory the effect of a subglacial discharge is simulated by introducing fresh water at melting temperatures from a source at the base of the ice block representing the glacier (Figure 1). The influence of both a line and a point source of subglacial discharge on submarine melting are investigated. The submarine melting increases substantially with subglacial discharge.

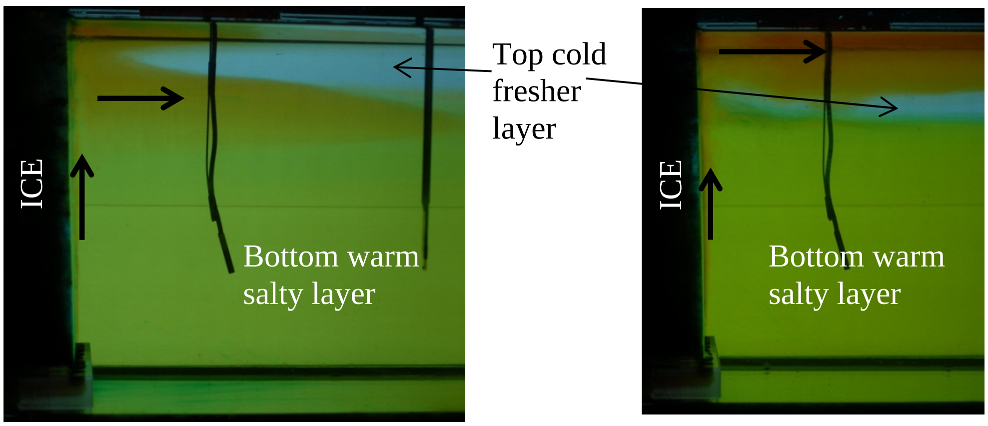

Figure 1. Side view of two experiments in which an ice block is inserted in a tank containing warm salty water at the bottom (yellow) and cold fresher water at the top (white). A light plume (red) containing meltwater and subglacial discharge rises vertically near the glacier (ice block in the laboratory). Left: the light plume intrudes at depth at the interface between the bottom warm salty layer and the top cold fresher layer. Right: the light plume reaches the free surface and intrudes above the top cold fresher layer. The difference between the two experiments is the subglacial discharge, larger in the experiment on the right.

In summary, the fact that submarine melting is influenced dramatically by the subglacial discharge means that the discharge details, e.g. the numbers of ‘holes’ though which the subglacial discharge water enters the fjord and the water flow rate in each hole, are extremely important and can considerably influence the submarine melting. Furthermore, on the ocean side, the fjord stratification has also a fundamental role for the submarine melting and for the melt water dispersal as it determines the strength and fate of the light plume of meltwater and subglacial discharge rising vertically near the glacier. This, in turn, indicates that the ocean, in part, controls the shape of these glaciers and, thus, their stability. By identifying the relevant processes and mechanisms, this work is strongly contributing to the improvement of climate computer models and, therefore, our ability to interpret past and to predict future sea level change.

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