Potential Vorticity Constraints on Buoyancy-Forced Circulation in Ice Shelf Cavities

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Idealized model studies indicate that sub-shelf melting rates are highest in the southeast corner of ice shelf cavities [e.g. Holland and Jenkins, 2001]. As oceanic heat transport to the ice interface governs the location and rate of basal melting, this finding implies that "warm", dense water is constrained to flow into these regions. We use theory and numerical models to clarify the dynamic controls underlying favored melt locations under different bathymetric scenarios (Figure 1).

An idealized set of numerical experiments employs spatially and temporally fixed buoyancy fluxes in a two-layer isopycnal model to examine the structure of inflow generated under different topographic scenarios. In addition to an overturning circulation, freshwater fluxes force smaller-scale horizontal circulations resulting from vigorous vertical motion in the presence of potential vorticity (PV) gradients [Hallberg and Rhines, 1996]. Flow in the interior is governed by large-scale topographic gradients, yet the deepest regions of the cavity (near grounding lines) are controlled by recirculation around "melting" regions. These experiments suggest there is a self-reinforcing dynamic explanation for eastern-intensified melting, as the melt-induced circulation near the grounding line controls the heat transport to the ice interface.

Thermodynamically "decoupled" numerical experiments are then compared to those that include heat transfer and freshwater fluxes to and from the ice shelf. Near the southern boundary, "coupled" experiments (figure 2) reinforce the conclusion that channeling of inflow to the southeast is favored under a wide range of topographic conditions, and suggest that the location of melt is stabilized by the coupling of the local circulation to the heat source. However, the influence of bathymetry in the cavity interior is muted by realistic stratification, the slope of the ice shelf, and friction. Near the grounding line any large-scale topographic control of flow is dominated by the ice shelf draft.

Heat transport under ice shelves is also forced by time-varying open ocean dynamics, notably tides, potentially decoupling the heat source and the response of flow at depth. Additionally, small-scale topographic conditions under ice shelves may modify the scale and strength at which these phenomena are manifested. The insensitivity to bathymetry demonstrated in these initial experiments suggests extension of this work along two distinct lines - an investigation into the scale (both horizontal and vertical) of bathymetric influence, and further studies into the control exerted by the ice shelf draft. These latter studies may be especially important in strongly forced ice shelf cavities, where ocean dynamics near the ice interface strongly influence heat transport associated ice shelf melting rates [Holland and Jenkins, 1999; Holland and Feltham, 2006].

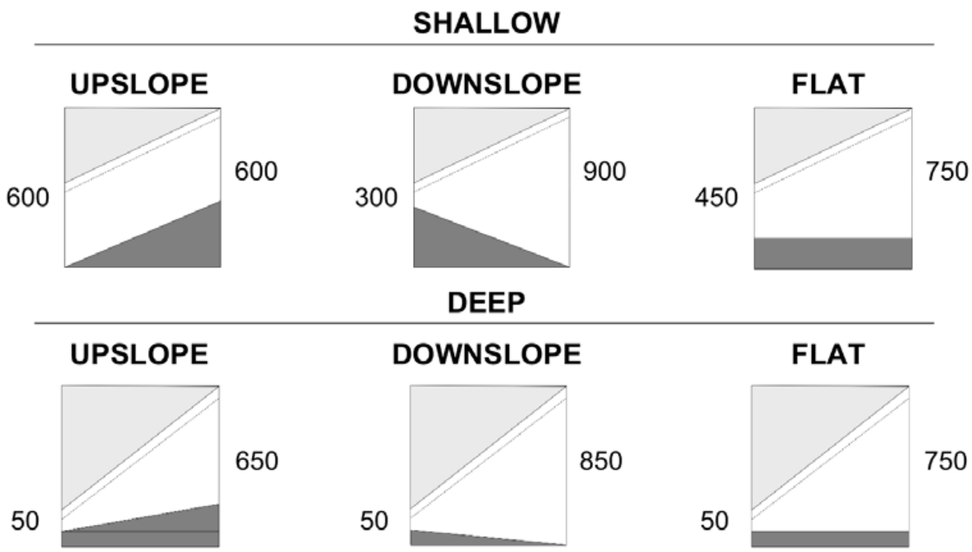

Figure 1. Meridional cross-sections of the (zonally uniform) topographic configurations employed in the experiments. All scenarios have dimensions of 500 km meridionally by 400 km zonally; water column heights at the meridional boundaries are shown (north is to the right). In "decoupled" experiments, a diapycnal mass flux of 0.05 Sv (corresponding to a melt rate of approximately 10-3 Sv) is distributed uniformly over the northernmost and southernmost 7.5% of the domain.

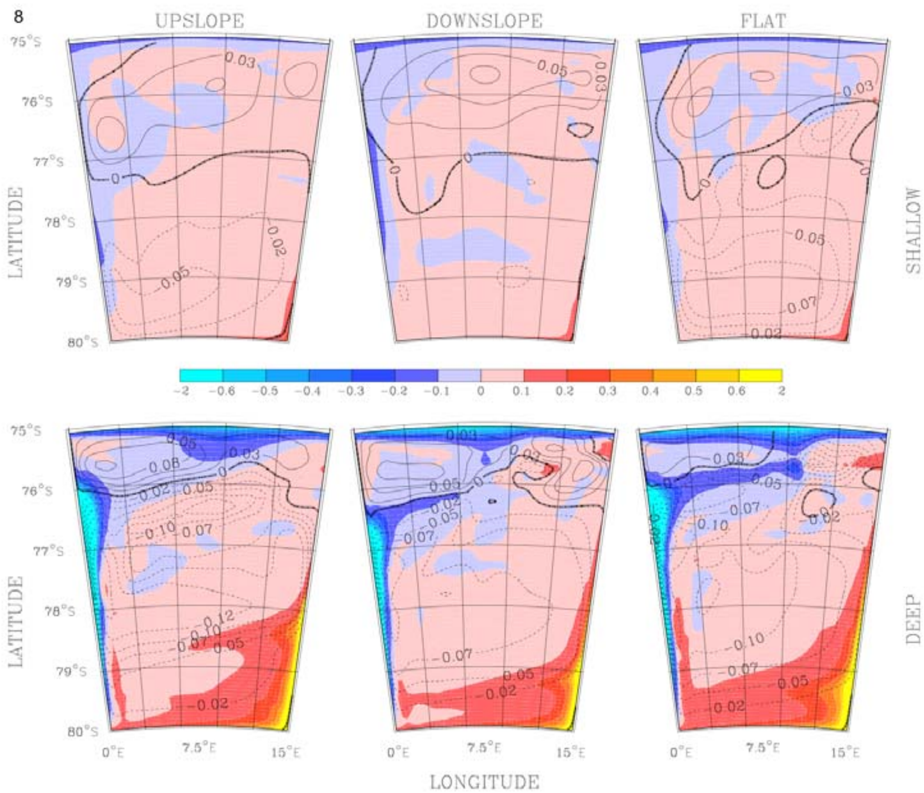

Figure 2. Barotropic volume transport streamfunction (contours, in Sv) and melt rate (shading, in myr-1) in year 30 of the "coupled" experiments. SHALLOW (DEEP) experiments are shown in the top (bottom) row. Although the strength of the horizontal circulation varies, melt locations (and overall rates) are fairly consistent across the topographic scenarios.

References

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