How ice shelf morphology controls the longitudinal distribution of basal melting

Introduction

Satellite observations indicate that basal melting rates are strongly enhanced near grounding lines (e.g. Joughin and Padman 2006). Ice-ocean modeling studies retain this pattern even with highly idealized topography and forcing (Holland, Jenkins et al 2008), suggesting that large-scale ice shelf morphology may underlie longitudinal gradients in melting rate. Walker et al. (2008) have recently demonstrated the dynamic implications of heightened basal melting near the grounding line. Adding a morphologically-dependent distribution of basal melt will improve the ability of glaciological models to assess the “basal slope feedback”, and the more general role of basal melting in ice shelf stability.

Here, we demonstrate how local slope drives oceanic temperature and velocity near “small”, “warm” ice shelves. Melting rates are driven by the product of thermal forcing and flow speed; steep basal slope increases the spatial correlation of these properties near the ice surface. When constrained by the grounding line ocean temperature, a very simple model provides basal melting distributions similar to those generated by idealized numerical simulations. A deeper understanding of mixed layer turbulence under ice shelves, with contribution from both models and observations, is required to validate the simplifications employed in both of these models.

Numerical results

A uniform slope drives an inverse correlation of velocity and temperature

Melt rate (myr⁻¹, shading); thermal driving (°C, contours); velocity (ms⁻¹)

A steep “trunk” drives higher temperature near grounding lines

Melt rate (myr⁻¹, shading); thermal driving (°C, contours); velocity (ms⁻¹)

Can a 1-D local heat balance predict the melting distribution?

Schematic representation of reduced-gravity “mixed” layer heat and mass fluxes along the longitudinal axis of an ice shelf

What does the 1-D model imply for slope-dependent melting?

<table>
<thead>
<tr>
<th>Local</th>
<th>3-D</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta T$</td>
<td>$\Delta T_x$</td>
</tr>
<tr>
<td>$m_e^l$</td>
<td>$m_e^f$</td>
</tr>
</tbody>
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The longitudinal melting distribution is sensitive to slope (no oceanic melt-off to the basal slope feedback) and the magnitude of heat flux coefficients

Local model melt rate-slope and entrainment velocity sensitivity: eastern 25 km

$D$ = $10$ km, $c_B$ = $0.75 \, ^\circ$C, $\Delta T = 0.05 \, ^\circ$C

$D$ = $5$ km, $c_B$ = $0.75 \, ^\circ$C

$D$ = $25$ km, $c_B$ = $0.75 \, ^\circ$C

$D$ = $10$ km, $c_B = 3.8 \, ^\circ$C

$D$ = $10$ km, $c_B = 0.187 \, ^\circ$C

What works?

$\Delta T$ in temperature in “thin” regions

What doesn’t work?

$\Delta T$ in temperature in “thin” regions

Frictional effects (boundary currents)

$\Delta T_x$ - $\Delta T_f$ (small change in slope)

The distribution of basal melting is driven by the spatial correlation of flow speed and temperature

In a local heat balance, mixed layer temperature and flow speed increase with basal slope

A scaling of melt rate with slope depends on ratio of poorly constrained turbulent heat transfer functions

Because basal slope varies strongly, even a weak scaling results in strong basal melting gradients

A local model works best in strongly forced ice shelves with thin boundary layers

More questions...

Is a simplified basal melt model useful? How can we determine the boundary layer dynamics (and thus input parameters) under ice shelves? Oceanographic measurements – ice front and under ice Ocean modeling – intercomparisons, shear parameterizations, sensitivity to tales Glaciologic observations – localized maps of melting, ice topography Role of channels and/or crevassing? Stratification? When and how quickly does ice advection stabilize the basal slope feedback?