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A Simple Diagnostic Model of the Circulation Beneath an Ice Shelf

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The ocean circulation beneath ice shelves supplies the heat required to melt ice and exports the resulting freshwater. It therefore plays a key role in determining the mass balance and geometry of the ice shelves and hence the restraint they impose on the outflow of grounded ice from the interior of the ice sheet. Despite this critical role in regulating the ice sheet's contribution to eustatic sea level, an understanding of some of the most basic features of the circulation is lacking.

The conventional paradigm is one of a buoyancy-forced overturning circulation, with inflow of warm, salty water along the seabed and outflow of cooled and freshened waters along the ice base. However, most sub-ice-shelf cavities are broad relative to the internal Rossby radius, so a horizontal circulation accompanies the overturning. Primitive equation ocean models applied to idealised geometries produce cyclonic gyres of comparable magnitude, but in the absence of a theoretical understanding of what controls the gyre strength, those solutions can only be validated against each other. Furthermore, we have no understanding of how the gyre circulation should change given more complex geometries.

To begin to address this gap in our theoretical understanding we present a simple, linear, steady-state model for the circulation beneath an ice shelf. Our approach in analogous to that of Stommel's classic analysis of the wind-driven gyres, but is complicated by the fact that his most basic assumption of homogeneity is inappropriate. The only forcing on the flow beneath an ice shelf arises because of the horizontal density gradients set up by melting. We thus arrive at a diagnostic model which gives us the depth-dependent horizontal circulation that results from an imposed geometry and density distribution. We describe the development of the model and present some preliminary solutions for the simplest cavity geometries.