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Thermal migration of ice stream shear margins

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Ice stream shear margins can be viewed as boundary layers connecting a Poiseuille-like shear flow in ice ridges with a membrane-like, lateral-shear dominated flow in the ice stream itself. The discharge of the ice stream is then highly sensitive to its width: with a Glen's law rheology, ice velocity scales as the fourth power of ice stream width. A crucial question therefore is how the width of the ice stream evolves over time.

Existing, depth-integrated models of ice stream dynamics typically predict that the bed underlying an ice ridge should freeze over time, while the ice stream bed remains unfrozen, and the transition between the two should occur in the shear margin. Depth-integrated models however cannot describe the details of that transition, which would allow the rate of margin migration to be computed.

We consider this boundary layer problem in detail, focusing on an abrupt transition from no slip to free slip at the point where the bed temperature changes from temperate (i.e., at the melting point) to subtemperate (i.e., below the melting point). This engenders multiple singularities in both, stress field and hence volumetric heating rate, and in heat flux. We show that the strength of these singularities is controlled by the far field, and that one of the singularities in the heat flux must be alleviated in order to allow the ice stream to widen. In the process, we show that at least a small zone of temperate ice must also form above the transition between frozen and unfrozen ice.

We show that the alleviation of the heat flux singularity is possible only for specific combinations of the following quantities : i) the strength of shear heating in the margin dicated by lateral shear stress acting on the ice stream margin ii) the background temperature gradient dictated by surface temperatures and advection in the ice ridge and iii) the margin migration rate. More specifically, in the absence of significant advection from the ice ridge, we are able to show (by using the Wiener-Hopf technique) that margin migration rate is determined uniquely by lateral shear stresses and background temperature gradient.