Control of the width of West Antarctic ice streams by internal melting in the ice sheet near the margins

Thibaut Perol[1, 2], James R. Rice[2]

[1]Ecole Normale Supérieure de Paris, Paris, France
[2]EPS and SEAS, Harvard University, Cambridge, MA, USA

Could the 40 to 80 km widths of West Antarctic (Ross Shelf) ice streams be controlled by onset of melting within the ice sheet at the stream margins?

The streams are driven by gravity which is resisted by basal drag, inferred to be small, and by shear stress at the lateral margins, assuming longitudinal stress gradients are unimportant [Whilans & van der Veen, JG'93]. Lateral shear stress in the sheet scales with the difference between gravitational stress and basal drag, and increases linearly with the lateral distance X from the center of a stream. With increasing X, that lateral shear stress times the creep strain rate it induces becomes a significant heat source within the ice sheet (proportional to X^4 using Glenôs law), and must induce internal melting.

We study this possibility using data for a set of 5 ice stream profiles (A, WNar, C, D, E) of Joughin et al. [JGR'02]. They used measured lateral shear strain rates at the margins, and a depth-averaged values of the Glenôs law creep parameter, based on a 1-D conduction-advection heat transfer analysis, without internal heating, to estimate the lateral drag. We find that when we incorporate the product of their drag stress and strain rate as a source in a conductive heat transfer model, the predicted margin temperatures are in excess of melting over some depth range for all five profiles.

Next, we reformulated the 1-D vertical heat flux problem allowing some lower depth range of the of ice sheet to be partially melted ice at the melting temperature, with the rest of the sheet frozen and undergoing conductive heat transfer. The sheet was subjected to a uniform lateral shear rate, allowing the Glen's law parameter and local shear stress to be different for the two zones. The predicted fraction of the thickness that is molten, if any, depends on the lateral shear strain rate. For the profiles (A, WNar, C, D, E), the observed strain rates are respectively (1.2, 2.4, 0.6, 0.9, 1.9) times the levels at which internal melting should begin; with the exception of profile C, the results are compatible with the hypothesis that the margin is undergoing internal melting. Also, the model predicts that a 5% increase in lateral stress, and hence in ice stream width, is enough to go from onset of internal melting to melting half the thickness of the ice sheet.

The liquid production rate in the melting zone is also predicted. Using the permeability model of Nye and Franck [JG'73], melt rains downward via a vein system and reaches a Darcy flux of ~5 m/yr at the bed. We expect that the massive drainage associated with melting causes low fluid pressurized R-channel development; making effective normal stress on the bed adjacent to the channel notably larger than in the central regions of the stream. That is conjectured to lock the ice sheet to the bed outboard of the R-channel and hence create the limit to width of the stream of fast-flowing ice.