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The thermomechanics of ice-stream margins

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The mass balance of the West Antarctic ice sheet depends primarily on the location and flow speed of arterial drainage routes called ice streams, which represent localized zones of rapid ice flow separated by ridges of comparatively stagnant ice. Our understanding of ice-stream dynamics and our ability to predict the flow velocity and configuration of ice streams in light of changing environmental conditions, however, is incomplete. One main challenge in current models of ice streams is the treatment of the shear margin, which plays an important role in the force balance of an active ice stream.

The lack of a clear correlation between topography and ice-stream location on the Ross ice shelf in combination with observations of migrating ice-stream margins suggest that a physical mechanism must exist that determines the location of the margin and the flow speed of the stream self-consistently. Three possible mechanisms are the transition from a frozen to a temperate bed in the shear margin, the formation of a subglacial drainage channel or the existence of sticky spots. The goal of this study is to test whether and how these three mechanisms contribute to ice-stream dynamics.

We propose a 2D thermo-mechanical model representing a cross-section through the ice-stream margin perpendicular to the downstream flow direction. We assume that the ice flows over a bed consisting of Coulomb-plastic till. The position and extent of the ice stream is determined by where the shear stress at the bed attains the local and spatially variable yield stress. If the basal stress falls below the yield stress, the ice is assumed to lock to the bed. While a simplified variation of this model setup can be solved analytically, we adopt a numerical treatment to be able to incorporate a realistic ice rheology. We validate our numerical approach both against previous analytical solutions and against observations.

We find that the rapid velocity increase across the shear margins of the active ice streams is indicative of a temperate zone at depth, where the heat production from lateral shear is most intense. A transition from a temperate to a frozen bed or the existence of drainage channels may both play an important role in the dynamics of active ice streams, but are probably less important close to the initiation region. All three mechanisms, however, are prone to instability suggesting that the ice streams on the Ross ice shelf might be in a precarious balance.