Better physics using full momentum solver in 2D vertical slice domain, where does longitudinal stress really matter? Application to the Thwaites Glacier flowline

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The commonly used shallow-ice approximation neglects all stresses except the basal drag, an assumption that is very good for inland ice but may be very poor for fast-flowing, low-surface slope ice streams, where longitudinal stresses may not only be important, but may in fact be the dominant stress [fastook04b]. A higher-order approach is to couple the mass- and momentum-conservation equations (the prognostic and diagnostic equations [macayeal97]) and solve with no neglected stresses. In the process of developing such a full-momentum solver in 3D, for embedded application within the map-plane University of Maine Ice Sheet Model (UMISM) [fastook93c], we are testing a 2D simplification which models a vertical slice through the ice sheet along a flowline. This allows us to do two things: 1) implement and test the complex boundary conditions that must be specified for a full-momentum solver, and 2) evaluate when and where longitudinal stresses are important or even dominant.

Specification of the differential equation describing conservation of momentum (also referred to as the "balance of forces") allows for two types of boundary conditions [thjhughes87]: 1) Dirichlet, where the state variable, in this case the velocity, is specified, and 2) Neumann, where the conserved flux, in this case the force applied on the boundary, is specified. Where the bed is frozen, Dirichlet boundary conditions are the obvious choice, as the velocity is zero and can be specified as such. Where the bed is not frozen, where sliding is occurring (for example, in ice streams, where our shallow-ice approximation breaks down), we cannot specify the velocity, but instead must specify the force exerted on the ice by the bed in resisting its forward motion. We know that this resistive force cannot exceed the driving stress (if it equals the driving stress, we have the shallow-ice solution). A temptation is to use some fraction of the driving stress, and indeed, this approach does produce the concave profile characteristic of an ice stream, but the fraction is hard to define (a model parameter). A better approach, and the one we have taken, is to use a boundary-layer. We can preserve our Dirichlet-type specification of zero velocity on the boundary, but allow greater deformation within the boundary layer to simulate sliding at the bed. This soft layer can be interpreted either as a deformable till or as a layer of water-saturated ice at the melting point (slush). In either case its thickness will be negligible compared with the ice thickness, and while the geometry and mechanical properties (how thick and how soft) are still difficult to define, at least they have a physical meaning, which is a good thing for a model parameter to have.

We apply this to a flowline along the Thwaites Glacier in the Amundsen Sea sector using excellent new data from the Airborne Geophysical survey of the Amundsen Sea Embayment (AGASEA), by University of Texas [holt06] and British Antarctic Survey [vaughan06] teams.

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