Modified Morland-MacAyeal model for ice-stream flow

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Higher-order models have been a goal of ice sheet modelers as they have attempted to leave behind the limitations of the shallow-ice approximation. SIA is appropriate for the interior slow moving regions of the ice sheet, but due to the fact that all stresses except basal drag are neglected means that SIA fails in the transition zone in streams as the grounding line is approached. Many are approaching this with attempts at so-called "full-momentum" solvers, ie. formulations that neglect no stresses. This approach, however, is computationally very expensive.

The SIA for interior ice, and the Morland Equations for the ice shelf flow [Morland, 1987] both reduce the scale of the problem by integrating out the vertical dimension, taking advantage of the fact that the vertical dimension is very different from the two horizontal dimensions. In the case of SIA, it is the fact that the stress distribution in the vertical can be approximated as varying linearly from zero at the ice surface to the driving stress at the bed, and a mass-conserving velocity profile obtained through the flow law. In the case of the Morland Equations, a uniform velocity with depth and the zero basal drag can be used to remove the vertical coordinate from the formulation. Doing so reduces the scale of the problem for a 100X100 km region modeled with 2 km resolution in x and y and 10 layers in the vertical from 300,000 degrees of freedom to 20,000.

The Morland Equations apply specifically to ice shelf physics, but they have been successfully applied to the transition zone in ice streams with a modification whereby a basal drag of arbitrary magnitude is added to the momentum-source term in the Morland formulation [MacAyeal, 1989; Hulbe, 1998]. While this approach does yield reasonable results, the fact that the addition of this stress after the fact, violates the assumptions that go into the original integration of the vertical dimension, and hence is not self-consistent.

We present a formulation for the diagnostic equation that follows the original Morland derivation closely [MacAyeal, 1997], but include at the outset an explicit term for the basal drag. This self-consistent formulation, coupled with a prognostic equation for mass conservation and solved using the Finite Element Method, is tested for a number of simplified geometries where longitudinal stresses are comparable to the basal drag. The ultimate goal is to include this as an "embedded" higher-order component within an SIA model of the entire ice sheet [Fastook and Sargent, 2004; Fastook, 2007].

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