How to improve predictions of future WAIS behavior

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Modeling ice sheets has proceeded from

1. the very simplest parabolic profiles of the perfectly plastic approximation, a 1-D, steady-state solution where the driving stress is exactly balanced by a uniform basal yield stress;

2. on to the elliptical profiles, where a uniform accumulation rate is assumed, again a 1-D steady-state solution, but now the basal stress varies along the flowline;

3. to the shallow-ice approximation, a 1-D flowline or 2-D map-plane, time-dependent models, where only the basal stress is included and is assumed to equal the driving stress;

4. to the "shelfy-flow" models which are ad hoc adaptations of Morland's ice shelf equations, a 1-D or 2-D time-dependent solutions with only longitudinal stresses and an added basal resistance term;

5. to the current full-momentum solvers, true 3-D, time-dependent solutions where all stresses are presumably accounted for.

All of these treatments have in common the requirement that the modeler must specify some parameter that characterizes the coupling of the ice sheet with the bed. For the parabolic profiles it is the yield stress. For elliptical profiles and the shallow-ice approximation it is the ice hardness in the Flow Law and the lubrication factor in the Sliding Law. For shelfy flow it is again the ice hardness and also the basal resistance term For full-momentum it is the explicit basal boundary condition, either a Dirichlet-style specified velocity (zero for no sliding, non-zero for sliding) or a Neumann-style applied stress (the basal resistance, analogous to the term in the shelfy flow).

In modeling the interior of an ice sheet where sliding does not occur, parabolic, elliptical, and shallow-ice do a reasonable job of reproducing ice sheet behavior. Only shallow-ice is time-dependent, and since we are concerned with "predictions," this is a necessary capability. In all three of these, however, a "fitting" process is required to "tune" the model. Early shallow-ice models specified the ice hardness in the Flow Law, but thermo-mechanical coupled models eliminated the need to specify ice hardness, as it could be calculated from the temperature field within the ice sheet. A new parameter, the flow-enhancement parameter, emerged to allow us to still "tune" the model. This new parameter, while an improvement over the old " specification" of ice hardness, is necessary to have the model adequately describe the present configuration. As with other parameters in the model, the flow enhancement factor accounts for something we don't understand (impurity content, etc.). We have mentioned the lubrication factor, a parameter within the Sliding Law that basically serves to turn on and off sliding and to determine its magnitude. We have a clear picture that this depends in some way on the presence and amount of water at the bed, but sliding's actual coupling with the water field is uncertain (as well as being complicated by different kinds of sliding, hard-bed vs. deformable sediment, etc.)

An additional factor to consider in our search for improved predictions, is that we need a good starting point from which to project into the future. We are not starting from a simple steady-state ice sheet, but instead from one that has undergone significant changes in the not too distant past. Most geological reconstructions of the ice sheet have the Ross Sea beneath the current ice shelf fully grounded, possibly out to the continental shelf, with the major retreat occurring relatively late. With such a recent major change in the ice sheet configuration, major features such as the internal temperature field and the distribution of water at the bed will have preserved in them transient features reflective of the retreat history. Both internal temperature and basal water have a strong impact on the ice sheet's dynamic behavior, and hence must be well characterized in order to have a good starting point for a predictive model. The easiest way to accommodate this is to run the model for a glacial cycle capturing the endpoint as initial conditions for the predictive run. One problem with this approach is that the known history of the ice sheet is relatively short, and not unambiguously understood. The expanded extent of the ice sheet, the timing at which it stood at that larger configuration, the increase in the volume, as well as the important timing of the recent collapse are all controversial questions. Another problem of course involves which climate "proxy" to use to drive the ice sheet through it cycle, and how to couple that proxy to the controlling mechanisms.

The point here is that expecting higher-order models to solve all our problems is naive. We need a clearer understanding of the physical processes involved, or at least an adequate and versatile parameterization of said process that can be tuned to match the current configuration. Included in this of course is the recognition that we are dealing with a time-dependent creature, one whose current configuration (the starting point for our predictions) contains transients reflecting recent past behavior, which must be well characterized.