# Springing Forward: The Need for Viscoelastic Ice-Flow Modeling

*R.B. Alley, S. Anandakrishnan, R.T. Walker, B.R. Parizek, T.K. Dupont and D. Pollard*

We argue that viscoelastic ice-flow modeling is essential to allow inversion for the basal “flow law” required for accurate prediction of large and rapid ice-sheet changes.

Despite the importance of deformation within ice, rapid ice-flow changes appear to occur primarily at the bed. And despite a great amount of empirical, theoretical, and modeling effort, we are not especially close to a “flow law” (or more properly, a collection of flow laws) relating basal velocity to basal shear stress, a prerequisite for successful predictive ice-flow modeling. Such a flow law must include the nature of the bed (bumpy bedrock versus soft till, for example) and the responses of the various bed types to changing stress. Comparison of ice-flow velocities at different places with similar basal shear stresses suggests that the nature of the bed can have order(s)-of-magnitude effects on flow speed, and comparison of flow velocities at a place over time similarly suggests that plausible changes in stress can cause order(s)-of-magnitude changes in velocity.

Inversions from the surface-velocity field following MacAyeal, Joughin and others can produce maps of basal drag and basal velocity, but cannot be used to learn a flow law without high-spatial-resolution data on the bed character (frozen/thawed, hard bedrock/till/lake, etc.) to allow comparison of flow over similar beds with different stresses. Appropriate geophysical techniques allow bed characterization, and are essential in moving forward, but realistically cannot be applied across widespread regions quickly.

The best hope for learning the basal flow law may be to relate variations in stress and velocity over time at a range of sites, with sufficient geophysical investigation to demonstrate that the velocity changes arise from the stress changes and not from changes in the basal character; treating this as a perturbation from the surface-velocity inversions would be especially productive. However, stress variations averaged over multi-year intervals are almost always too slow to be useful; the ice sheet would have to do potentially scary things to create a large enough range of stresses for a successful calculation. Far better is to use the natural stress variations provided by tides, iceberg-calving events, glacial earthquakes, meltwater-drainage events, and other nonsteadiness in the glacial system. These can be monitored using continuous GPS, or in other ways. The main difficulty in applying this technique is that the forcings are generally fast enough that the responses include elastic as well as “viscous” elements, and existing flow models generally do not incorporate elastic flow. We are investigating viscoelastic ice-flow modeling; a real advance in this field seems necessary to enable predictive ice-flow modeling.