Findings

We used our 2D full momentum balance model to present a comparison of flow behavior of different types of ice streams: the deep and steep Jakobshavn Isbrae that is dominated by very large strain rates on the one side, and the shallow and flat Whillans Ice Stream that has very high rates of basal motion on the other. We consider these two ice streams end members of an entire range of ice streams. These findings were presented at the International Glaciological Society's meeting on Fast Glacier Flow in June 2002 and published in the Annals of Glaciology (Truffer and Echelmeyer, 2003). This work has gained significance, since it is becoming increasingly obvious that the deep channel "Isbræ" are very important players in global cryospheric change, such as that currently witnessed at Jakobshavn (Thomas et al., 2003) and the Amundson Bay area (Thomas et al., 2004).

The very steep velocity gradients observed across one margin of Whillans Ice Stream have been a bit of an enigma. Echelmeyer et al. (1994) concluded that a model of ice stream flow needed significant flow enhancement to account for the observed surface velocities. Whillans and van der Veen (1997) reached similar conclusions. At the 2001 West Antarctic Ice Sheet meeting we presented an updated model using better topography and ice temperature data that had become available in the meantime. This higher resolution model required even larger enhancement factors than previous work. In fact, the necessary enhancement factors were in the high range of what is thought possible from considerations about c-axis re-orientation (e.g. Jacka and Budd, 1989), and exceeded what was observed in the field (Jackson and Kamb, 1997). In an effort to resolve this, we developed an approach using continuum damage mechanics. One of us (M. Lüthi) was involved in developing this method for the modeling of fracture in hanging ice masses (Pralong et al., 2003). The same idea can be applied to ice streams and glaciers. Microscopic damage can weaken the ice, which can then lead to higher strain rates. First tests were successful and encouraging (Fig. 1), but the work has not come to conclusion.

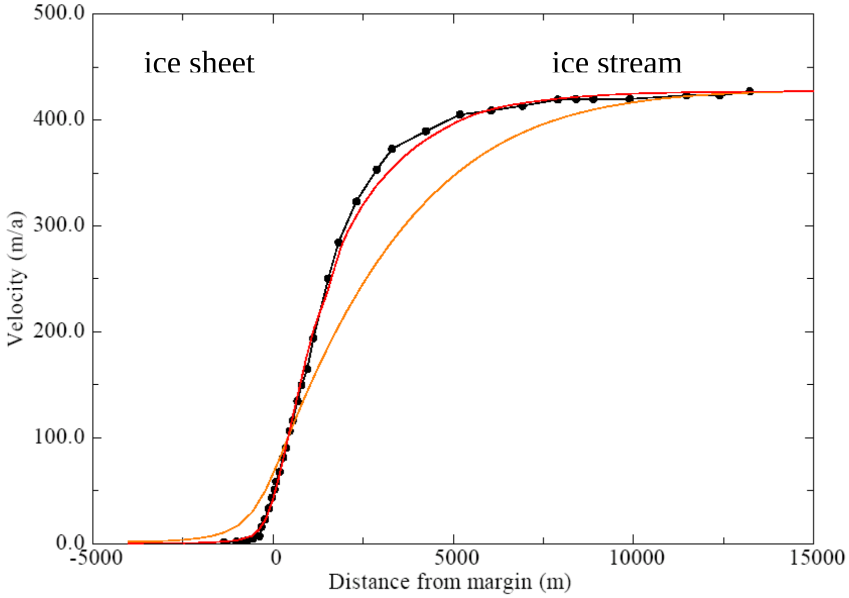

Figure 1: *Comparison of measured (black dots) and modeled velocity at the surface across the ice stream margin. The velocity of the model including damage (red line) follows the measurements much better than without any damage (orange line).Data are from Echelmeyer et al. (1994).*

The main problems at the moment are not well constrained material parameters leading to the results in Fig. 1. The current work also suffers from an ad-hoc healing law for ice damage.

Recently it has become increasingly clear that most current ice flow models are not sufficiently sophisticated to address the complicated flow and stress fields encountered in ice streams. This is particularly true for the outlet glaciers flowing through deep troughs that are grounded substantially below sea level. Any model that is based on the Shallow Ice Approximation (e.g. Hutter, 1983) will not be suitable to describe physical settings where velocities change on length scales of the order of the ice thickness. This is also true of "higher order" models (e.g. Colinge and Blatter, 1998), because they too are based on a smallness assumption of the ratio of typical depth over length scales. With finite element methods it is possible to solve the full 3D mass and momentum balance equations. We have implemented such a model with the publicly available Libmesh library. The result of an idealized ice stream is demonstrated in Figure 2.

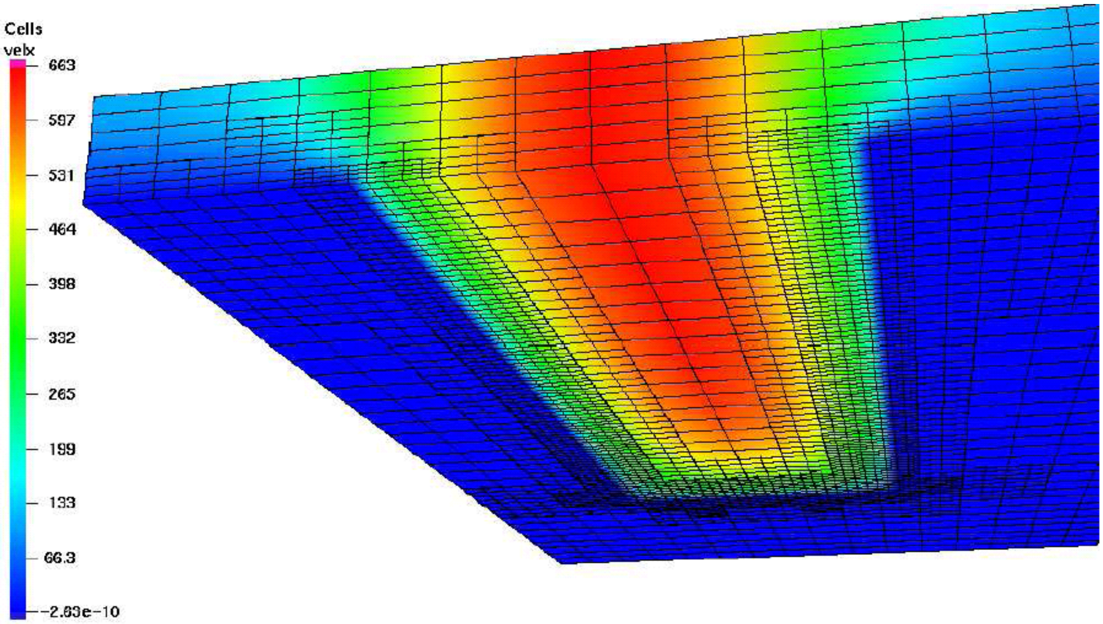

Figure 2: *An idealized ice stream seen from below. The color scale shows speed. The ice sheet surrounding the ice stream is kept frozen. The grid is also shown. Note the result of the adaptive grid refinement that allows better resolution in areas of higher gradients. This is crucial for a successful model.*

A crucial feature of this model is the possibility for adaptive mesh refinement. It creates a denser grid in areas of higher gradients. This is important for keeping computational requirements manageable. A big advantage of this library is that a model can be developed on a local PC and then run in its full complexity on parallel supercomputers, such as the ones at the Arctic Regional Supercomputing Center.

This model was also used as a basis for a proposal recently submitted to NASA's Earth Sciences program. We believe that it will play an important role in the ice sheet modeling community in the coming years.

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