A viscoelastic flowline model applied to tidal forcing of Bindschadler Ice Stream, West Antarctica

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Our objective is to find the basal flow law for Bindschadler Ice Stream

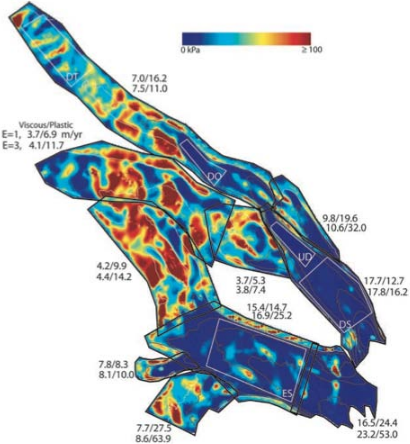
- That is, we want to find the exponent m in the power-law relationship

$$\tau_b(u) = \beta^2 u^{\frac{1}{m}}$$

- Higher exponents lead to greater acceleration and interior drawdown when buttressing is lost*

* Price et al., *J. Glaciol.*, 2008; Joughin et al., *J. Glaciol.*, 2009

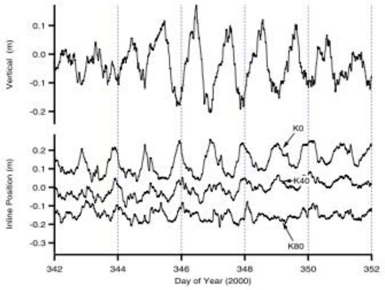
Inversions of time-averaged surface velocity to find basal flow laws can be ambiguous



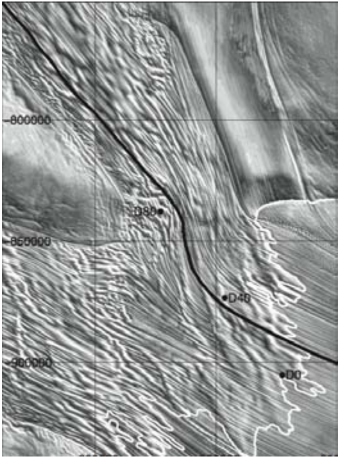
[85] Our inversions are based on a single map of velocity that, for the most part, was collected over a 30-day period. The inversions yield estimates of the basal shear stress that balance forces to match these observations. Either a plastic or viscous till rheology appears to be consistent with the inferred basal-shear-stress distribution. This implies that a determination of the appropriate till rheology (e.g., plastic or viscous) from these experiments is not possible. Any perturbation of this balance of forces (e.g., driving stress or basal shear stress) will yield a new velocity distribution and a resulting new force balance, depending on the rheological properties of the till. Thus a measured time series of velocity change, such as those recently acquired on Ice Streams B and D [*Anandakrishnan et al.*, 2003; *Bindschadler et al.*, 2003], may be what is ultimately needed to determine whether the till beneath the Ross ice streams acts viscously or plastically at all spatial scales [*Hindmarsh*, 1997].

Joughin et al., *JGR*, 2004

The motion of Bindschadler Ice Stream is affected by tides under Ross Ice Shelf



Anandakrishnan et al., *GRL*, 2003



A model that considers elastic perturbations can distinguish between basal flow laws

Maxwell viscoelastic material

- *Stress* is the same across both elements
- *Strain* is the sum of strains on each element

$$\partial_t \sigma = E \partial_t \epsilon - \frac{E}{2\nu}\sigma = E \partial_x u - \frac{E}{2\nu}\sigma$$

Using Maxwell rheology in a 1D flowline model lets us calculate perturbation velocity and stress

- Velocity ends up being determined by a diffusion equation:

$$\partial_x \left(2hE\left\{\partial_x \tilde{u} - \frac{\tilde{\sigma}}{2\nu}\right\}\right) = \frac{\beta^2}{m}\left(u + \tilde{u}\right)^{\frac{1}{m}-1} \partial_t \tilde{u}$$

- We're assuming that ice thickness doesn't change, and that viscosity and basal drag can be found by fitting the original flowline model to InSAR velocity data (for each m).
- We run the time series of velocity perturbations at the grounding line through a harmonic analysis program* to find tidal components, and use this to force the model.

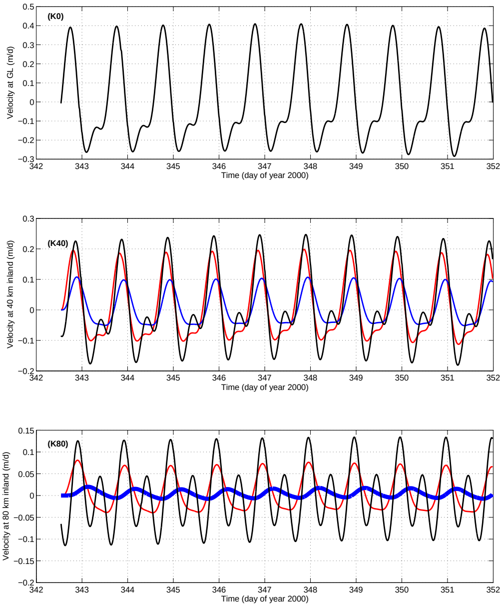
* T_TIDE, Pawlowicz et al., 2002

An "effectively plastic" bed ($8 \leq m < \infty$) best matches the observations

0 km

40 km

80 km



data

m = 3

m = 15

This suggests that Bindschadler Ice Stream would respond rapidly and significantly to any future loss of buttressing from the Ross Ice Shelf

- Previous studies* of Rutford Ice Stream found lower exponents ($m \approx 3$) more consistent with deformation over a hard or frozen bed
- Our results are more consistent with sliding over weakly velocity-strengthening till
- We need more coordinated observation and modeling studies on other ice streams

* Gudmundsson, *The Cryosphere*, 2011