Basal boundary conditions for ice sheet models

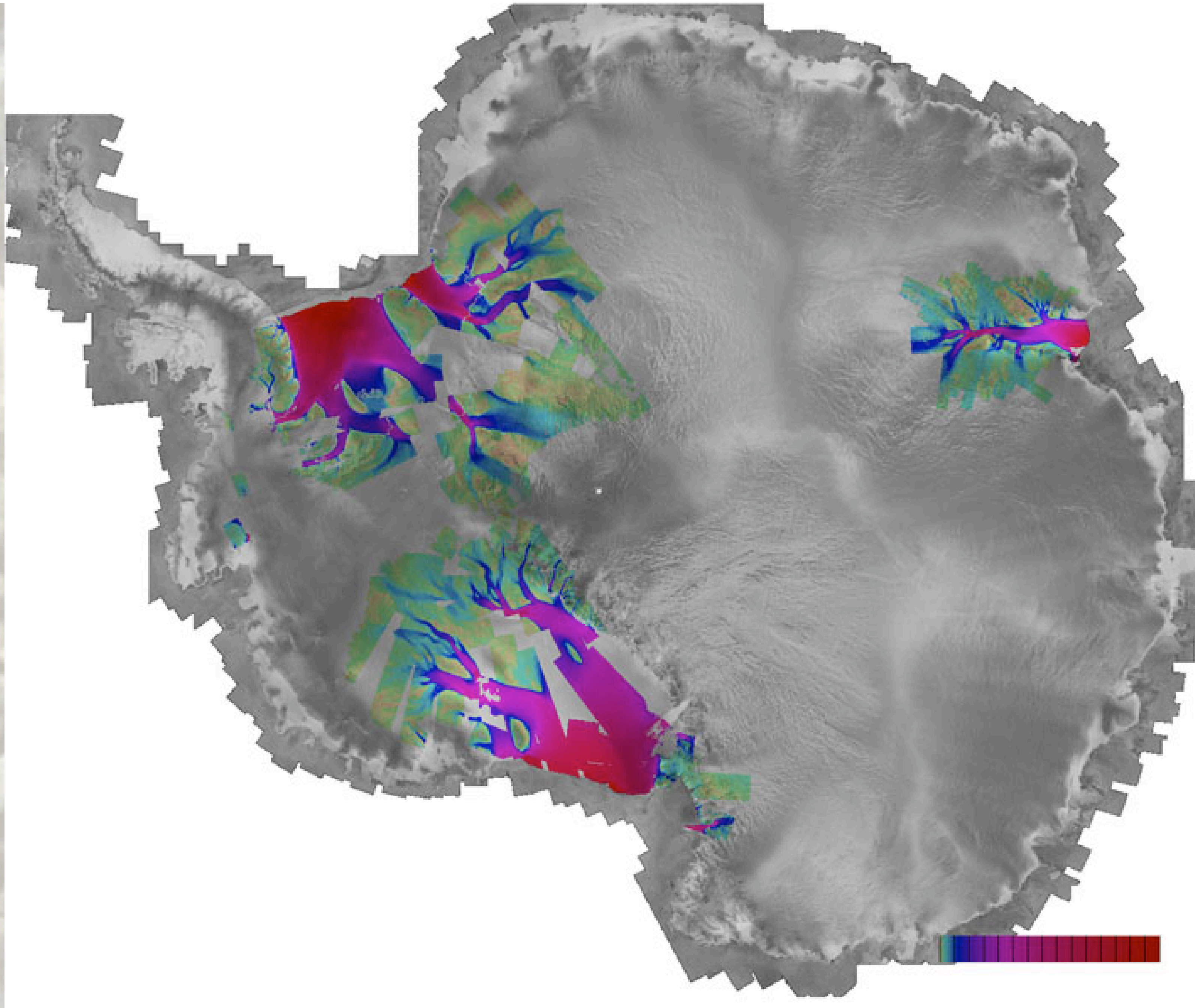
Slawek Tulaczyk
Department of Earth and Planetary Sciences
Universit of California, Santa Cruz, CA

Introduction and Motivation

Observation 1: Basal sliding controls location, mechanics, and dynamics of most or all fast-flowing ice streams and outlet glaciers

Observation 2: These parts of ice streams that are experiencing velocity changes over short timescales are also the ones where basal sliding appears to be the predominant mechanism of motion

Problem: Whereas treatment of internal ice deformation has improved recently (high-order stresses), representation of basal tractions is extremely simple



Ice velocity map from Dr. Ian Joughin, UW (red colors ~1000 of m/yr, blue ~100 m/yr, yellowish-green ~10 m/yr)

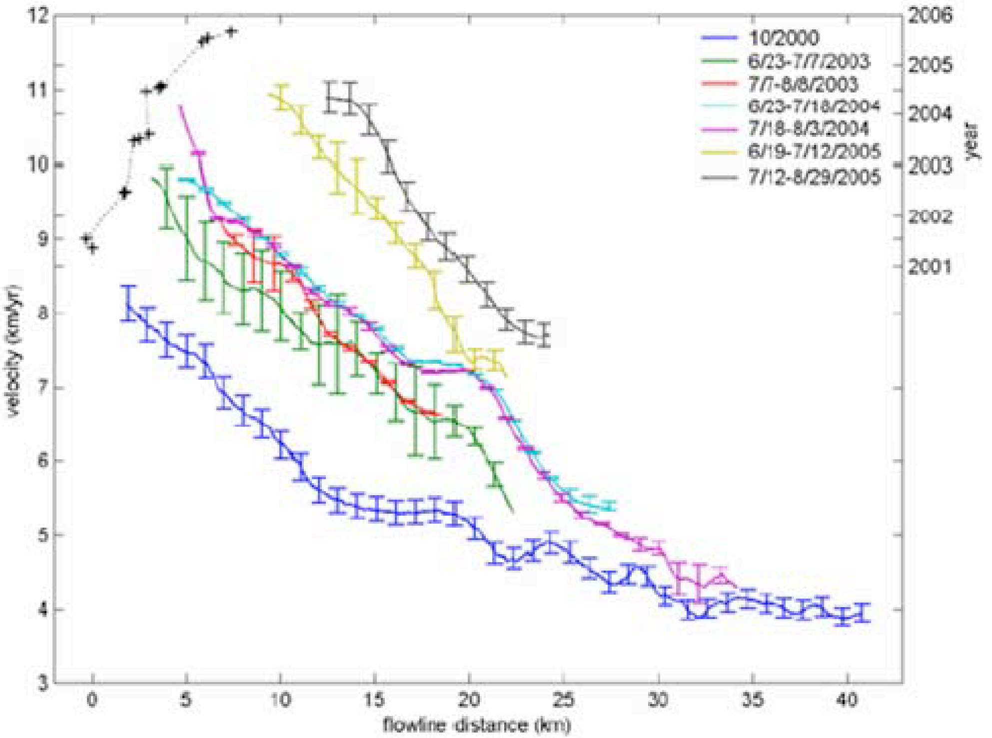
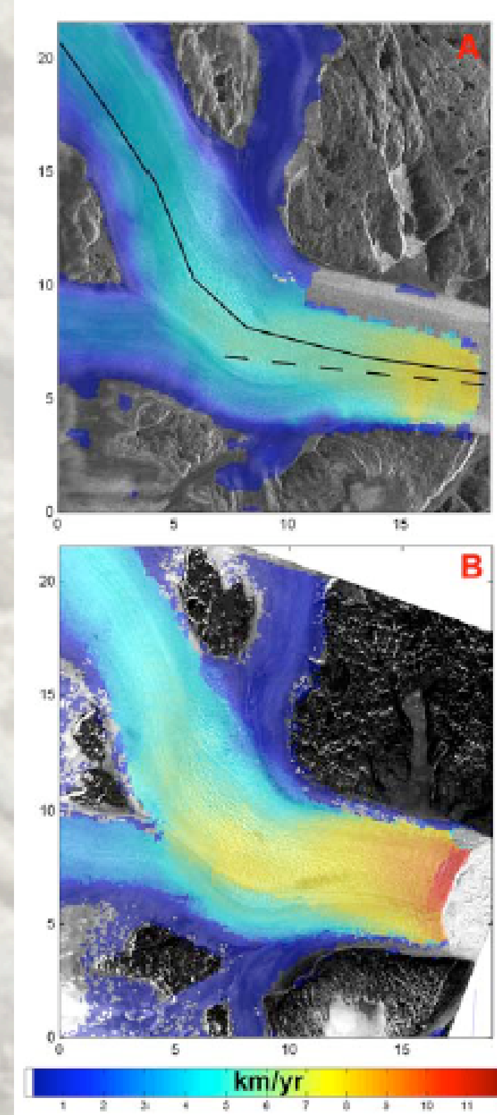
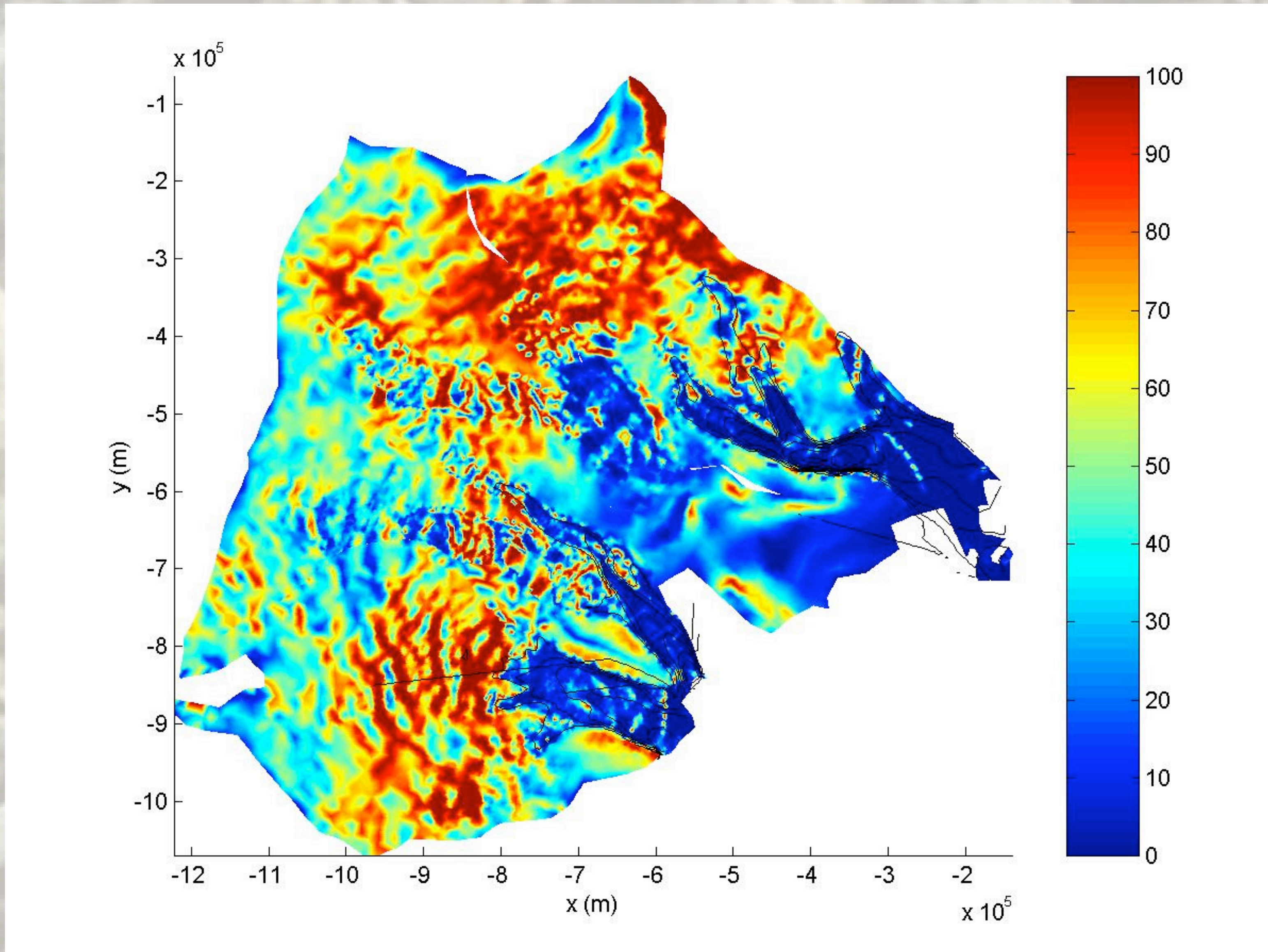


Figure 3. Surface velocity along the flow-line shown in Figure 1a with the origin at the 2000 front position. Crosses mark the observed position of the calving front versus time on the right hand axis. Feature-tracking error varies with time separation and correlation/co-registration uncertainty, which were interpolated from vectors within 100 m of each point on the flow line.



Acceleration of Helheim Glacier, SE Greenland, Howat et al., 2005



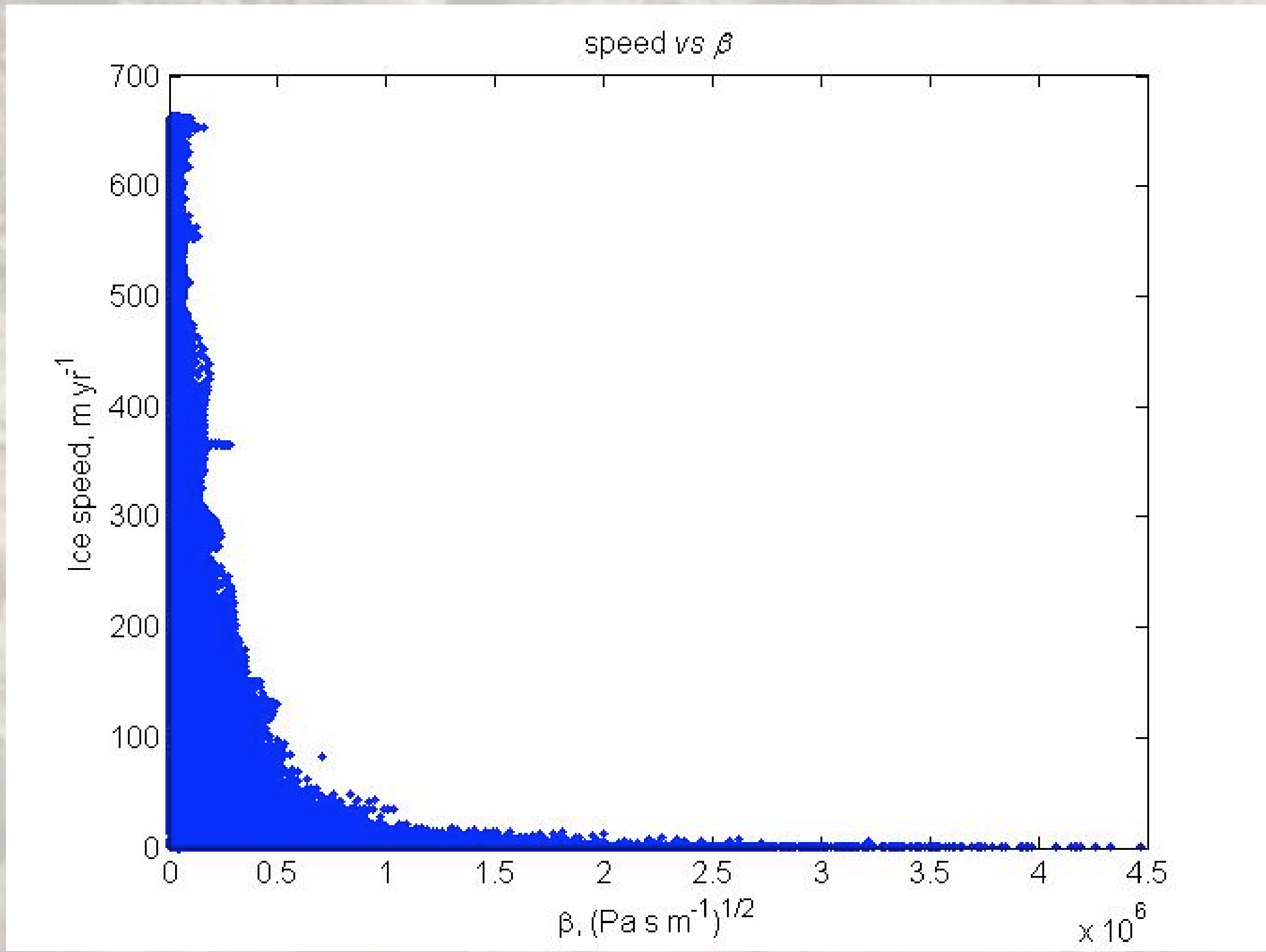
$$\tau_{b,x} = \beta^2 u$$
$$\tau_{b,y} = \beta^2 v,$$

Map of basal traction derived from inversion of velocity data for Siple Coast (Joughin et al., 2004)

Simple 'Sliding Laws'

$$U = \frac{\tau_b}{\beta^2}$$

$$U = C_o \tau_b^n$$



Ice speed as a function(?) of the sliding parameter for one of the Siple Coast ice streams (from Dr. Sergienko)

Observational studies suggest ‘sliding laws’ with varying degree of non-linearity and variable empirical parameters.

Four physical factors appear to control basal resistance to ice sliding:

1. Basal roughness
2. Rheology of basal ice
3. Subglacial water pressure
4. Presence of deformable subglacial sediments

$$U = C\frac{\tau_b^n}{N^m}$$

C = empirical constant accounting for interface and material properties, e.g. roughness

N = subglacial effective stress

n, *m* = empirical exponenets

Future options:

1. Business as usual (linear laws with a single empirical constant)
2. Introduce subglacial hydrology and couple to basal resistance
3. Use data and inversions to map out spatial variability of basal/subglacial properties (distribution of subglacial sediments, bed roughness, basal rheology)

$$U = C\frac{\boldsymbol{\tau}_b^n}{N^m}$$

Introduce subglacial hydrology and couple to basal resistance

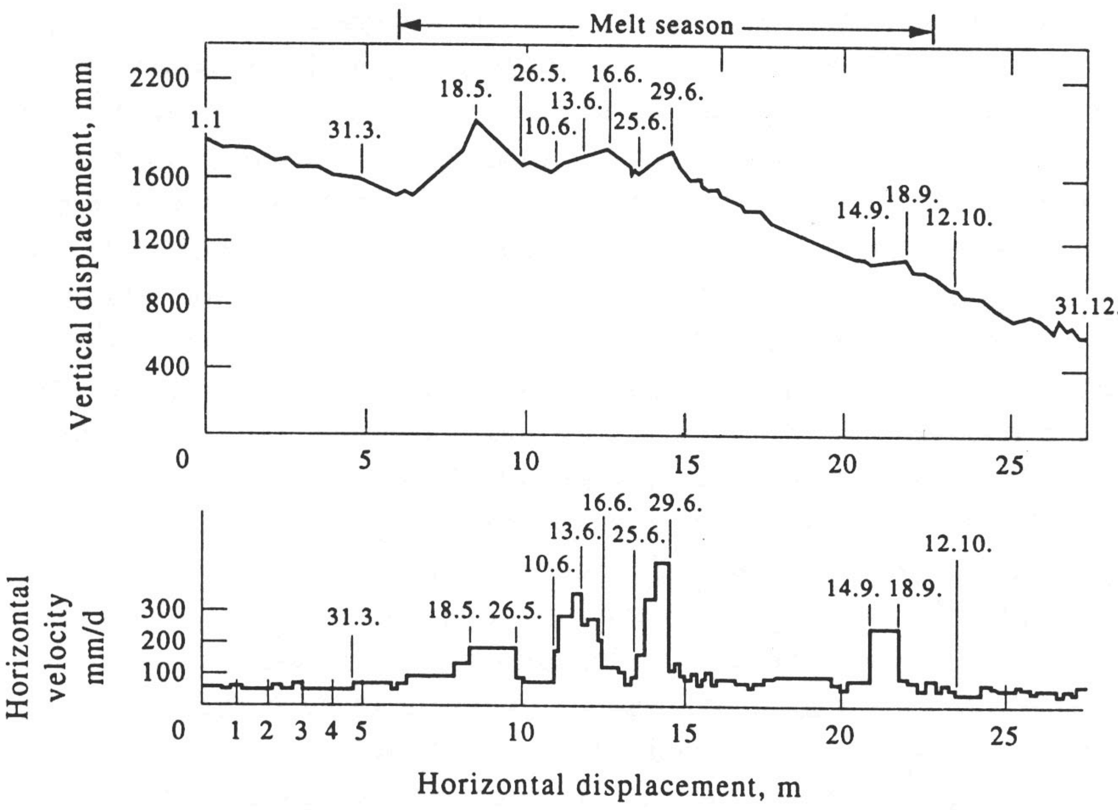
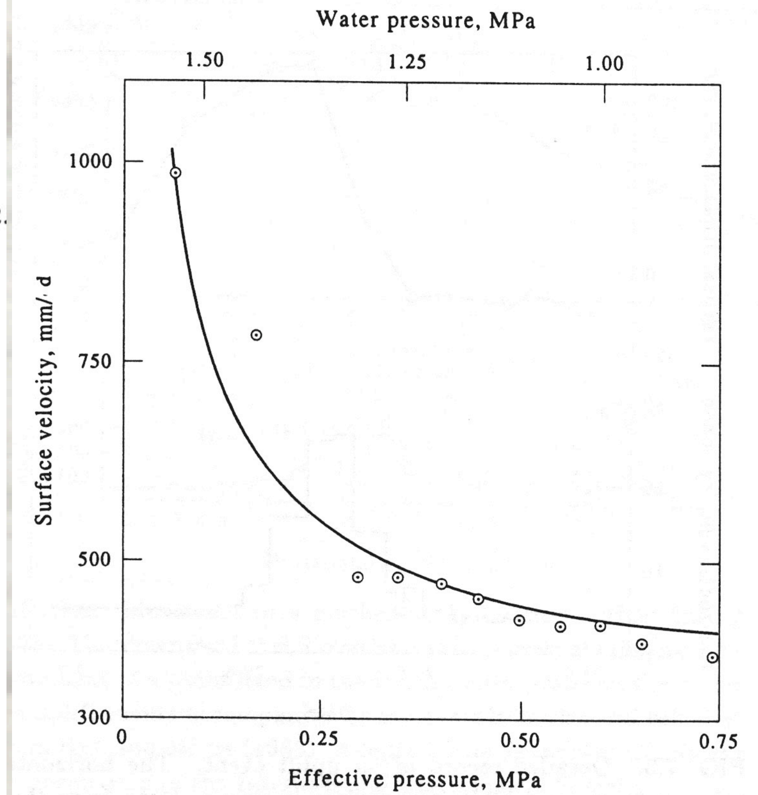


FIG. 7.2. Movement of a marker on Unteraargletscher during 1975. The downward trend over the year represents down-slope movement of a point fixed in the ice. Superimposed on the trend are uplift events accompanied by increases in horizontal velocity. From Iken and others (1983). Adapted from *Journal of Glaciology* by permission of the International Glaciological Society.



Why focus on hydrology as the next step:

1. Doable over near term (Johnson and Fastook, 2002)
2. Evidence of large water volumes moving subglacially over months, years, etc. (Gray et al., 2005; Fricker et al., 2007)
3. Inclusion of subglacial hydrology may increase model veracity to the point that mapping of spatial geologic variability will be less pressing (e.g. areas of abundant water may correspond to areas of sediments and low roughness)

How to do it?

Problem: Effective stress and water pressure are not conserved quantities

Solution: Use subglacial water volume/thickness (Johnson and Fastook, 2002)

Caveat 1: Relationships used should be able to account for observed non-linearities and thresholds (U vs. N)

Caveat 2: Treatment of hydrology should incorporate the duality of drainage modes (tunnel vs. distributed)

Caveat 3: Need for water storage term (subglacial lakes)

Use data and inversions to map out spatial variability of basal/subglacial properties (distribution of subglacial sediments, bed roughness, basal rheology)

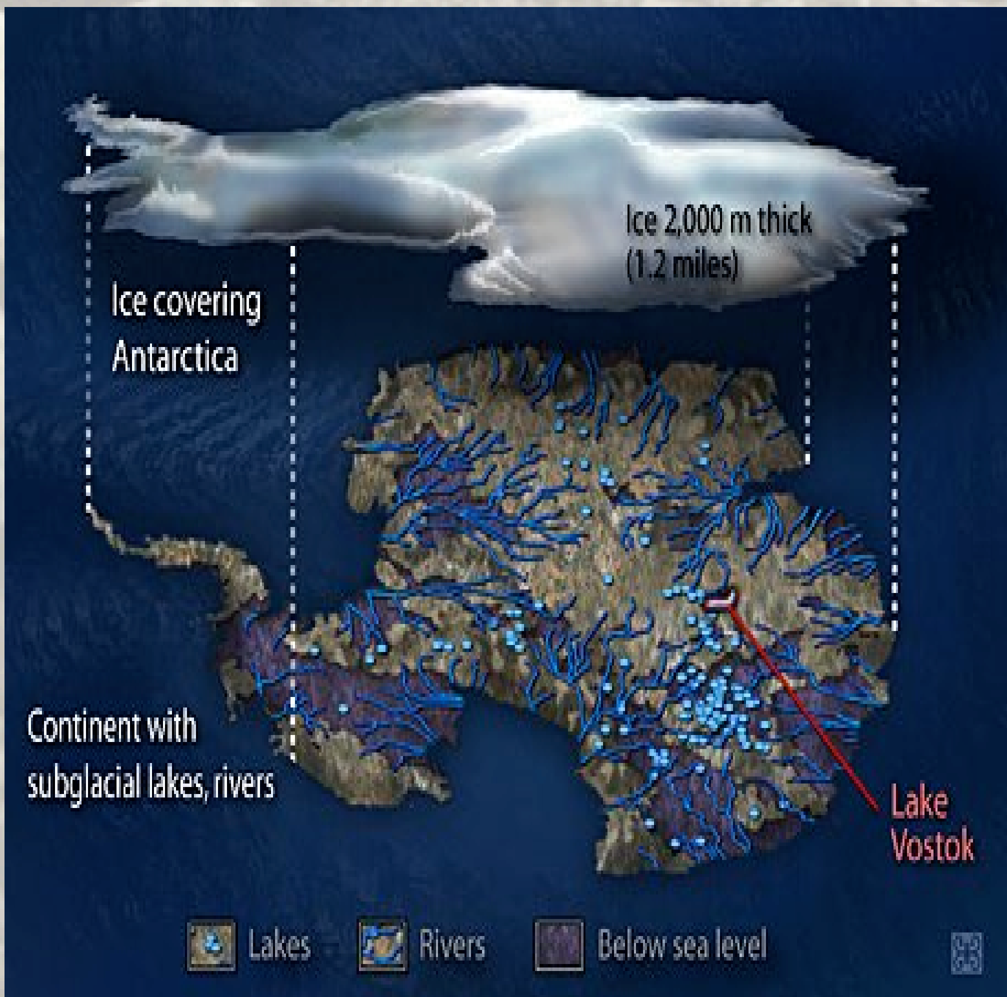
Inversions are doable within a short time horizon, collection of additional geophysical and satellite data is a longer term proposition

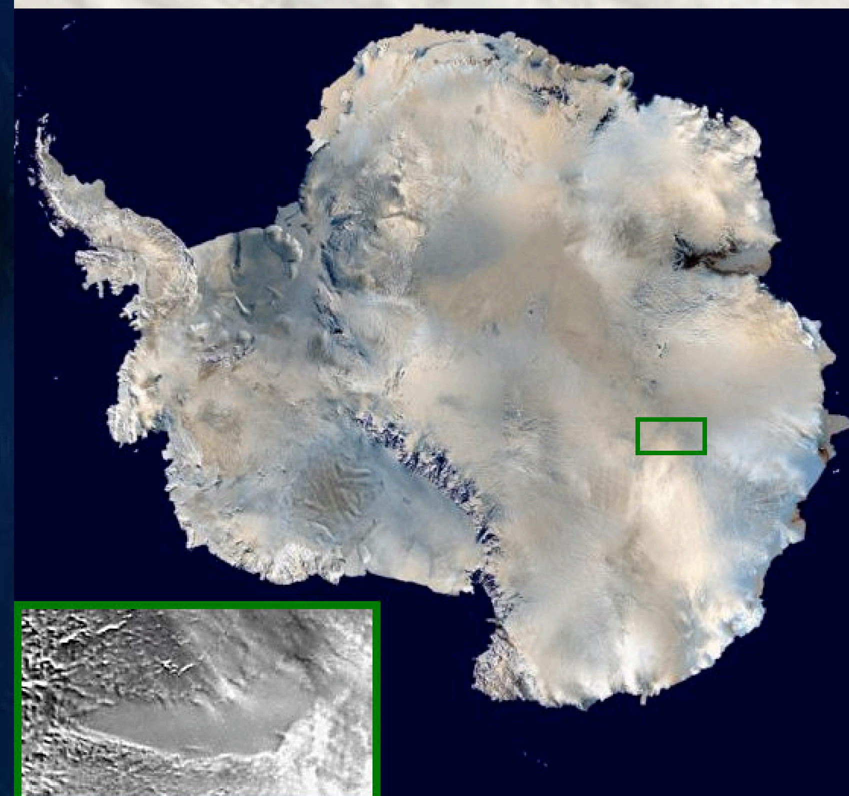
Proposed discussion foci:

How to improve implementation of subglacial hydrology and sliding?

How to best take advantage of existing velocity and geophysical data to constrain spatial variability in sliding parameters?

Future recommendations for collection of relevant data





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