Implementing and validating a model for basal water

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How water accelerates ice flow

1. Reduced obstacle density

2. Thawing frozen bed

3. Softening subglacial till
Water and fast ice flow correlate

Ice velocity (m/a) (Joughin et al., 2004)

Estimated basal water thickness (mm) (Carter et al., in prep)

Denote regions of net basal accretion

Ice velocity contour
Hydraulic potential explained

- Hydraulic potential \( (h_h) \) = Water pressure \( (P_w) \) + elevation \( (z) \)
- Water pressure \( (P_w) \) = Overburden \( (P_o) \) – effective pressure \( (N) \)
- Surface elevation 11 times more important than bedrock elevation*

\( N \) usually not considered** *(bedrock gradient can be <11 times surface gradient)*

**\( N \) can also vary spatially*
Current Glimmer-cism water model

• Steady state D8
• $Q_{out} = Q_{in} + \text{melt}$
• Cells sorted by $h_h$
  high to low
• $Q_{out}$ distributed
  among all downslope neighbors
• Conservative
• Computationally simple

• Issues:
  • Steady state assumed
  • Water tends to fall into 1 grid cell channels (Le Brocq et al., 2009)

• Needed:
  • Effective pressure
  • A way for water to bypass enclosed basins
Effective pressure

\[ N = \frac{\tau_b^* k_d}{b_{wat}} \]

(Alley 1996)

\[ \tau_b = \text{basal shear stress} \]
\[ k_d = \text{roughness (~1 mm)} \]
\[ b_{wat} = \text{basal water depth} \]

• N treated as function of water thickness
• Water thickness function of hydropotential
• Solving for both requires iterative process
• Enclosed basins complicate this process and become more common each iteration
• Adjusting N also a convenient way to fill holes without editing topography
Routing through enclosed basins

• Calculate $h_{h0}$
• Identify holes
• Raise to level of lowest outlet $h_{h2}$
• Identify $(x,y)$ coordinate of outlet
• Sort by $h_{h2}$ and then distance from outlet
• $N_{\text{fill}} = (z + p_o) - h_{h2}$
Results

$N_{in\_initial}$  $N_{out}$ after five iterations.

Meters of water equivalent
1st iteration

$N_{out} - N_{out\ previous}$

$N_{out} - N_{in}$

Meters of water equivalent
2nd iteration

$N_{out} - N_{out\_previous}$

$N_{out} - N_{in}$

Meters of water equivalent
$N_{out} - N_{out\ previous}$

$N_{out} - N_{in}$

Meters of water equivalent
4th iteration

$N_{out} - N_{out\ previous}$

$N_{out} - N_{in}$

Meters of water equivalent
5th iteration

$N_{out} - N_{out\ previous}$

$N_{out} - N_{in}$

Meters of water equivalent
Average N of last 3 iterations

N

Water layer thickness

Meters of water equivalent

mm
A different distribution of water

- Shallower broader channels in tributary and ice streaming regions
- More water to areas of net basal freeze on
  - Whillans Ice Plain
  - MacAyeal Grouding line
A closer look: Whillans ice plain
A closer look: Downstream MacAyeal IS
Validation

- \( Q_{\text{Sea}} = \sum m \)
- \( B_{\text{trc}} \approx N \)
- Satellite observations of subglacial lake behavior (Carter et al., in prep; See also virtual poster)
Validation

• Radar Sounding can infer presence of water and possible channels.

• Boreholes (Engelhardt et al., 1997) confirm N is on the order of a few m.

• Seismic work Blankenship et al., 1987; Winberry et al., 2009).

• The WISSARD project to send a probe to explore the subglacial water environment in situ providing a raft of new calibration data.
Wish list / Future directions

- A better, but still simple parameterization for N
- Distribution of subglacial sediments
- Grounding Lines
- Higher order 2-D model
- Simulation of outburst events for individual lakes
Conclusions

- Incorporating even the most basic parameterization for effective pressure produces a significantly better correlation between water distribution and sliding velocity
  - Wider shallower streams
  - More water to basal freeze on

- Although N is on the order of a few m water equivalent, in low sloping regions like Whillans Ice Plain, these changes are very significant to water distribution

- The convergence of $h_h$, bwat, and N over most of Siple Coast is a promising result

- Areas in which convergence does not occur may require a higher order routing scheme. Other lines of research have also indicated that these are features of interest (LeBrocq et al., 2009; Creyts et al., personal Communication)
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