Greenaland Outlet Glaciers: What ice-sheet modelers would like from observationalist

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8 May, 2014

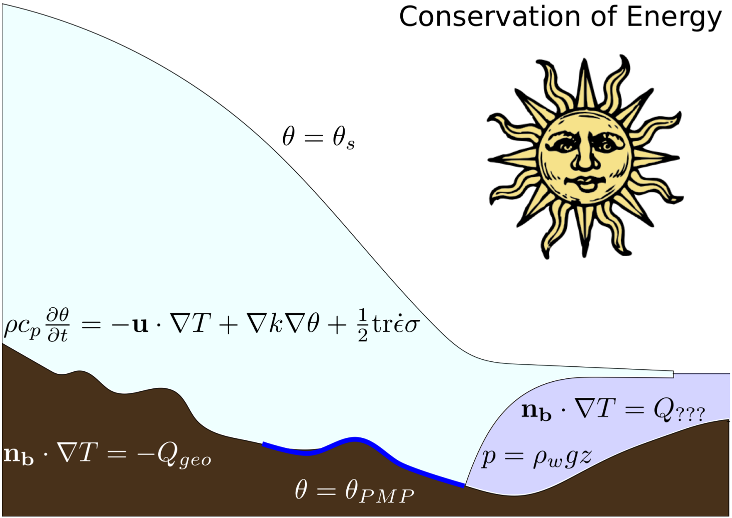
Introduction

What is a model?

Before answering what a model needs, we should discss what a model is, and what models do.

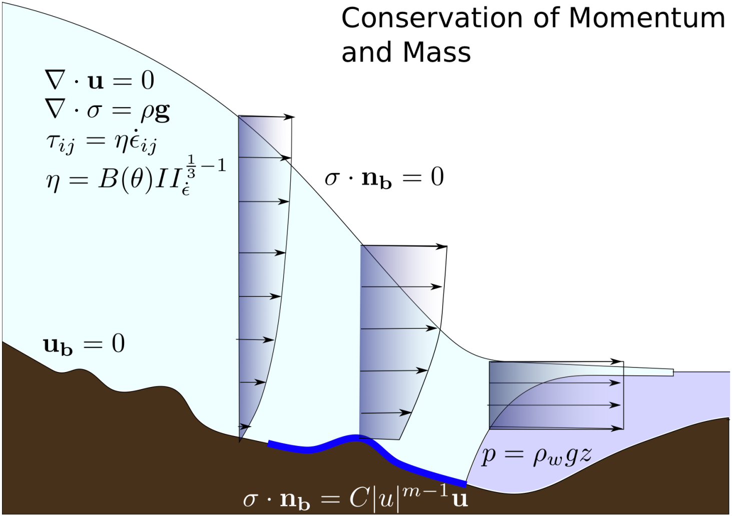
Model Component I

Conservation of energy



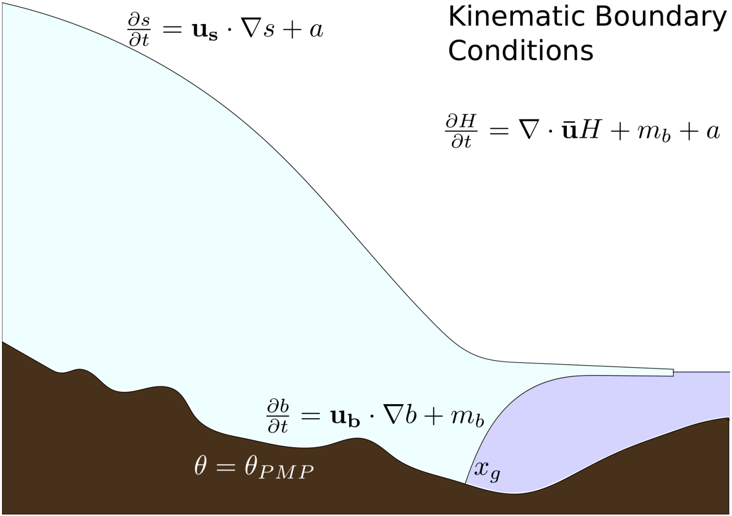
Model Component II

Conservation of mass and momentum



Model Component III

Kinematic boundary conditions



Model Component IV: Adjoint based methods for data assimilation

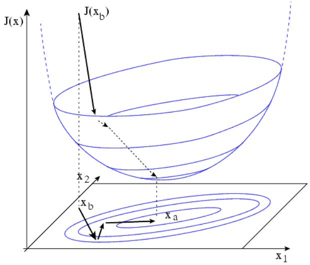
Fast parameter estimation and sensitivity studies

Forward model: $Ax = b$
Adjoint model: $A_p\lambda = b_p$
Solving the adjoint system for λ, the gradient is written

$$\frac{dg}{d\mathbf{p}} = g_{\mathbf{p}} - \lambda^T(A_{\mathbf{p}}\mathbf{x} - \mathbf{b}_{\mathbf{p}})$$

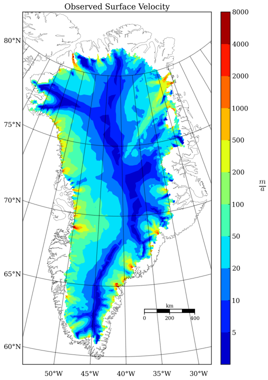
noting that;

- **x** is the result of solving the forward model,
- Computing $A_{\mathbf{p}}$ and $\mathbf{b}_{\mathbf{p}}$ are assumed to be analytic expressions, and can be treated *"automatically"*.
- Automatic differentiation is performed using the `PySym` package for symbolic manipulation of expressions.

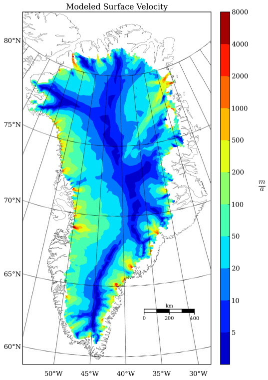


Assimilation Example

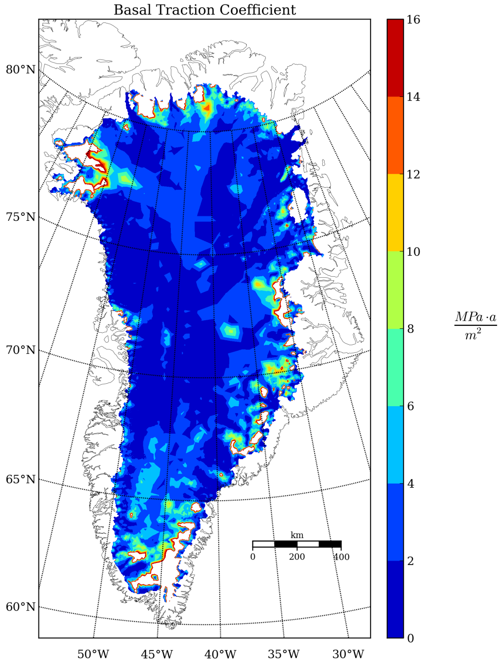
Match surface velocity to observation

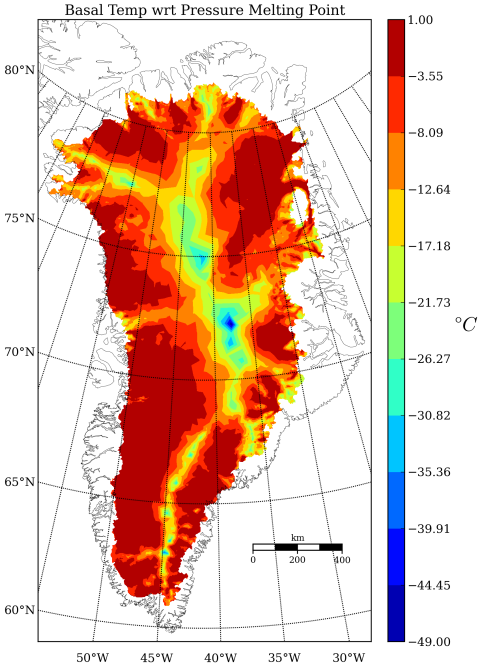


Observed velocity 2007-2008

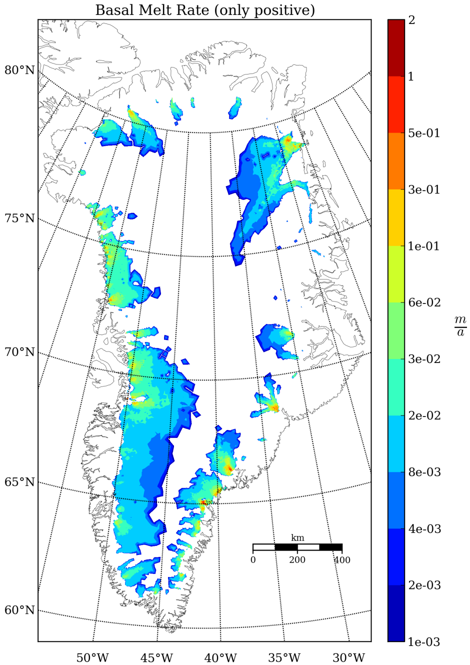


Modeled velocity


Basal Traction Coefficient
80°N
75°N
70°N
65°N
60°N
50°W
45°W
40°W
35°W
30°W
km
0
200
400
16
14
12
10
8
6
4
2
0
$\frac{MPa \cdot a}{m^2}$

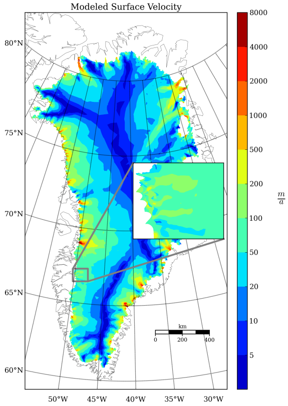


Basal Temp wrt Pressure Melting Point
80°N
75°N
70°N
65°N
60°N
50°W
45°W
40°W
35°W
30°W
km
0
200
400
1.00
−3.55
−8.09
−12.64
−17.18
−21.73
−26.27
−30.82
−35.36
−39.91
−44.45
−49.00
°C


Basal Melt Rate (only positive)
80°N
75°N
70°N
65°N
60°N
50°W
45°W
40°W
35°W
30°W
km
0
200
400
2
1
5e-01
3e-01
1e-01
6e-02
3e-02
2e-02
8e-03
4e-03
2e-03
1e-03
$\frac{m}{a}$

Model Nesting

Get boundary conditions from lower resolution runs.



Problem Statement

What could go wrong with such a terrific model?

In spite of the relative sophistication of the approach, and (superficially) compelling results, process level investigation and predictive runs with models of this type remains elusive for several reasons having to do with the data. We illustrate one here.

Model/Data incompatibility

Conservation of mass

The continuity equation

$$\frac{\partial H}{\partial t} = -\nabla \cdot (\overline{\mathbf{u}}H) + \dot{a}$$

Data can constrain equation:

Model/Data incompatibility

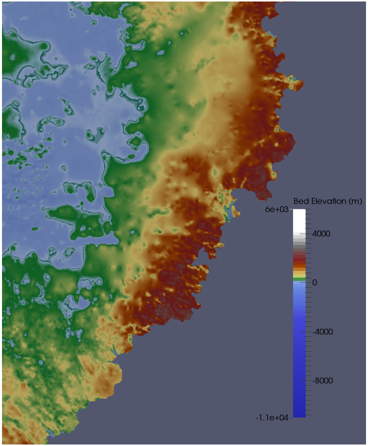
Conservation of mass

The continuity equation

$$\frac{\partial H}{\partial t} = -\nabla \cdot (\bar{\mathbf{u}} H) + \dot{a}$$

Data can constrain equation:

- Thickness, H along flight tracks,



Model/Data incompatibility

Conservation of mass

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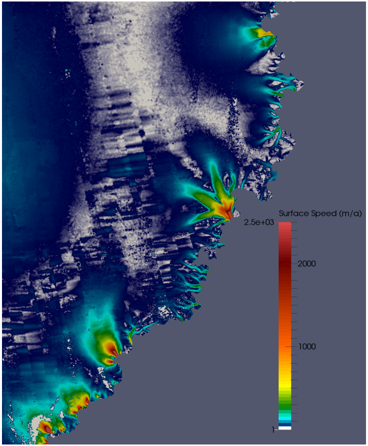
$$\frac{\partial H}{\partial t} = -\nabla \cdot (\overline{\mathbf{u}} H) + \dot{a}$$

Data can constrain equation:

- Thickness, H along flight tracks,
- Velocity, $\overline{\mathbf{u}}$, if $\mathbf{u_s} \sim \overline{\mathbf{u}}$



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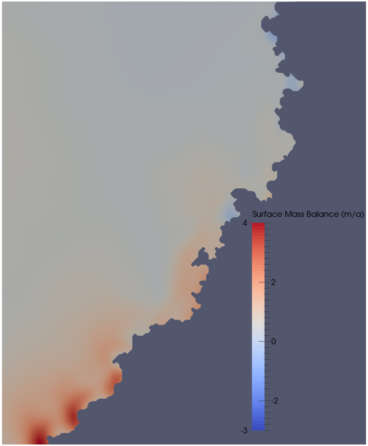
Data can constrain equation:

- Thickness, H along flight tracks,
- Velocity, $\overline{\mathbf{u}}$, if $\mathbf{u_s} \sim \overline{\mathbf{u}}$
- $\dot{a}$ estimated from regional climate models



Model/Data incompatibility

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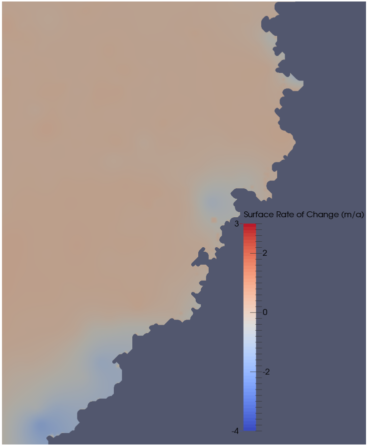
Data can constrain equation:

- Thickness, H along flight tracks,
- Velocity, $\bar{\mathbf{u}}$, if $\mathbf{u_s} \sim \bar{\mathbf{u}}$
- $\dot{a}$ estimated from regional climate models
- $\frac{\partial H}{\partial t}$ from satellite.



Model/Data incompatibility

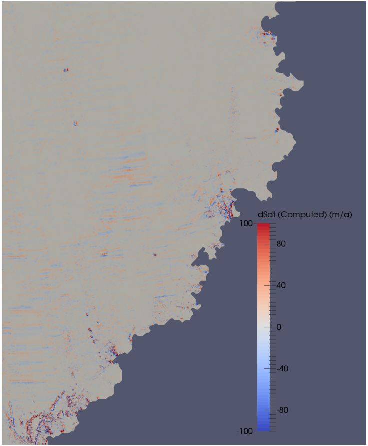
Conservation of mass

The continuity equation

$$\frac{\partial H}{\partial t} = -\nabla \cdot (\overline{\mathbf{u}} H) + \dot{a}$$

Data can constrain equation:

- Thickness, H along flight tracks,
- Velocity, $\overline{\mathbf{u}}$, if $\mathbf{u_s} \sim \overline{\mathbf{u}}$
- $\dot{a}$ estimated from regional climate models
- $\frac{\partial H}{\partial t}$ from satellite.
- $\frac{\partial H}{\partial t}$ computed from *data*.



Data Priorities

Given issues with conservation of mass

Near simultaneous *collection of:*

- Surface velocity
- Surface elevation

Along with continued improvement to the:

- Bed elevation

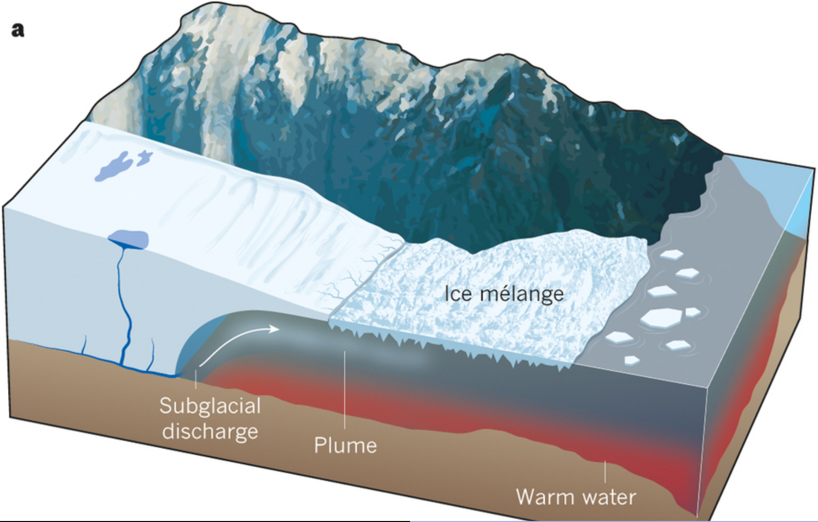
And to complete the equation:

- Surface rates of change
- Surface mass balance (AWS)

All of these data collection efforts should be supported by algorithmic improvements to the ways that data are interpolated.

A second major source of uncertainty

Basal melt rate

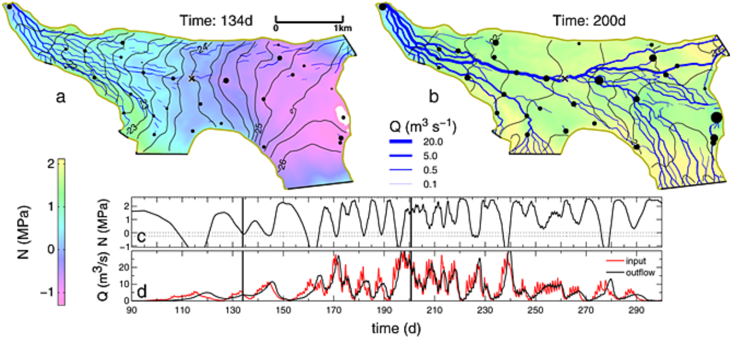


Data Priorities

Related to submarine melt

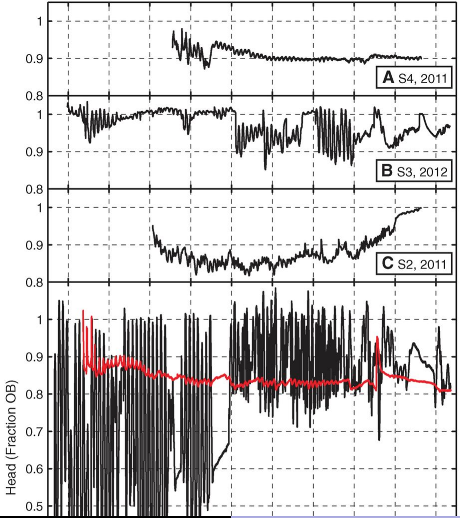
- Bottom topography extending into fjord, and under shelf
- Ocean circulation pattens
- Sub-glacial discharge
    - Total flux
    - Location of channels or sheet of flow
    - Seasonal changes

The need for borehole data



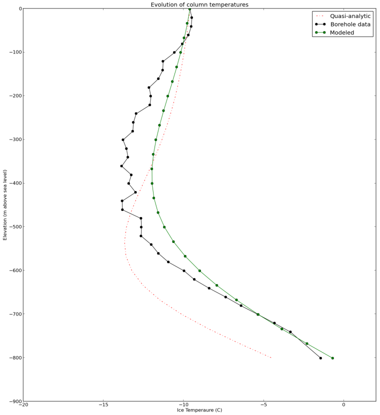
Borehole Data

Pressure constrain basal hydrology and sliding models



Borehole Data

Temperature constrains sliding models/ice fabric



Add to the "glacier node" described in the US CLIVAR report:

To constrain basal hydrology and sliding models

From boreholes collect:

- Basal water pressure (unique signatures in marine terminating glaciers)
- Temperature profiles
- Deformation rates

And in the same location do:

- High precision GPS
- AWS
- Ground penetrating radar surveys

With data collected $\sim$hourly.