A Parallel Ice Sheet Model
PISM

Century-scale evolution of the Jakobshavn Isbræ with a high resolution regional model

Correspondence: dellagiu@gi.alaska.edu

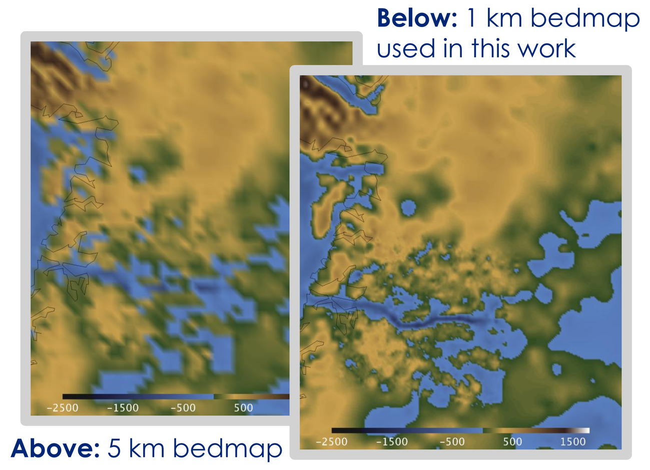
Daniella DellaGiustina[1], A. Aschwanden[1,2], C. Khroulev[1], E. Bueler[1,3], and M. Truffer[1]

1) Geophysical Institute, University of Alaska, Fairbanks. 2) Arctic Region Supercomputing Center, University of Alaska, Fairbanks. 3) Department of Mathematics and Statistics, University of Alaska.

I. Motivation

- "The largest uncertainty in constraining sea level contribution from Greenland lies in the ability of a model to capture changes in the outlet systems"[1]
- Many ice sheet models are only capable of continental scale modeling
- Models of outlet glaciers have been developed, but these are flowline models and provide limited information about the state of a modeled glacier
- The trunk of these glaciers is typically no wider then 5 km, and an outlet glacier model should also be capable of resolving the details of grounding line motion
- Modeling the entire ice sheet (1,800,000 km^2) has resolution limitations (e.g. 2.5 km grid cells), while considering only the area of the outlet catchment (110,000 km^2) can allow much higher resolution modeling (potentially 500 m grid cells)

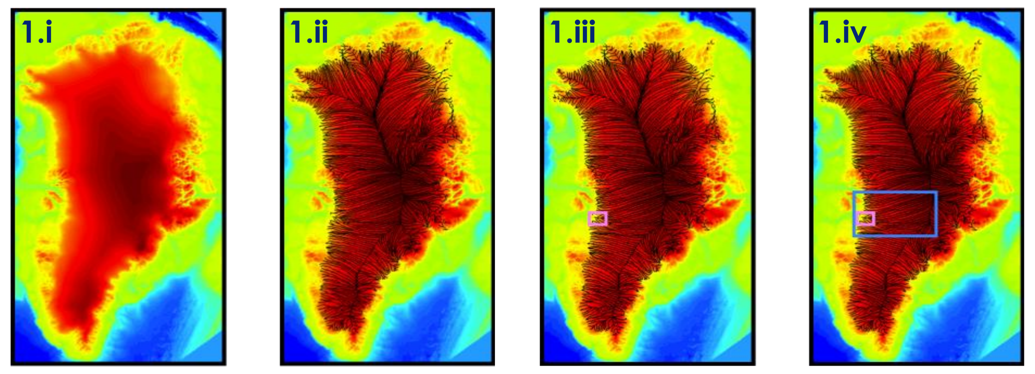
Below: 1 km bedmap used in this work



Above: 5 km bedmap

II. Regional Modeling Tools

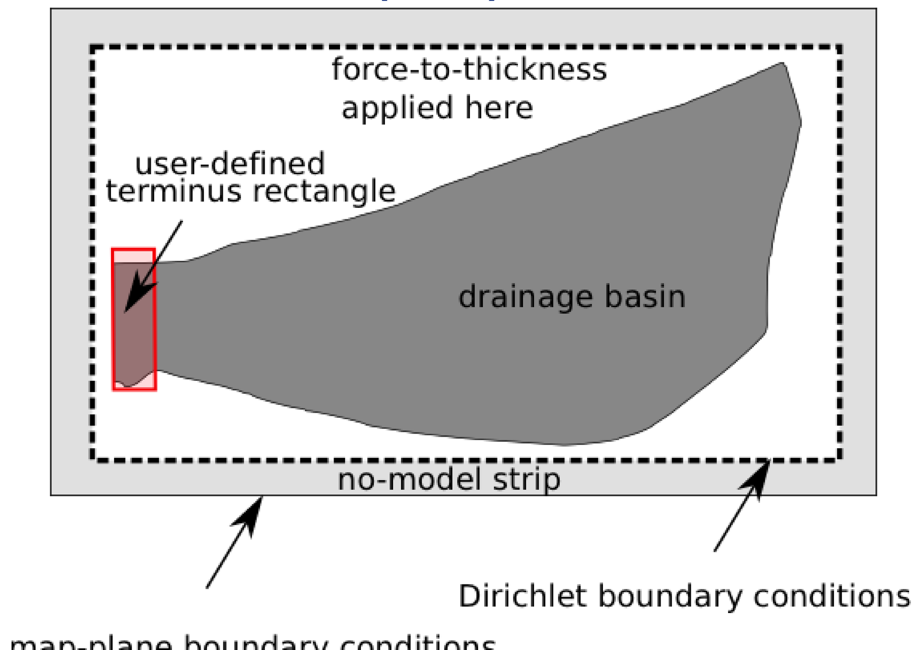
1) Drainage basin (DB) generator, which:
   i. Uses the ice surface elevation to determine the surface gradient flow
   ii. Streamlines are assumed to indicate the horizontal path that a test particle will follow if the ice flows down the surface gradient
   iii. The pink user-defined TERM box that indicates the approximate location of the glacier terminus. The origin of streamlines that end in the TERM after N perturbations are considered part of the DB
   iv. The blue rectangle defines the boundaries of the regional model domain, which contains the DB



2) Domain Boundary Conditions:
   i. Map-plane boundary conditions: Enthalpy, Basal resistance Basal melt water, Ice thickness, and SSA "sliding" velocities
   ii. Dirichlet boundary conditions: Some of these quantities are interpreted as Dirichlet boundary conditions by the key equations in PISM
      a) SIA → ice thickness
      b) SSA → "sliding" velocities
      c) Enthalpy Field Equation → enthalpy
3) Force-to-thickness (FTT) Mechanism:
   i. The area outside the outlet glacier is held near present-day geometry with a "force-to-thickness" mechanism
   ii. This modifies surface mass balance to protect drainage basin from flow to/from unmodeled region:

$$\frac{\partial H}{\partial t} = M + S - \nabla_{x,y} \cdot q$$

Where H is the ice thickness, M and S are the ice equivalent surface and basal mass balances, and q is map-plane ice flux. The FTT mechanism causes M to be modified by a multiple of the difference between the target thickness and the current model thickness: $\Delta M = \beta(H_{tar} - H)$. We add mass ($\Delta M > 0$) where $H_{tar} > H$ and ablate mass ($\Delta M < 0$) where $H_{tar} < H$

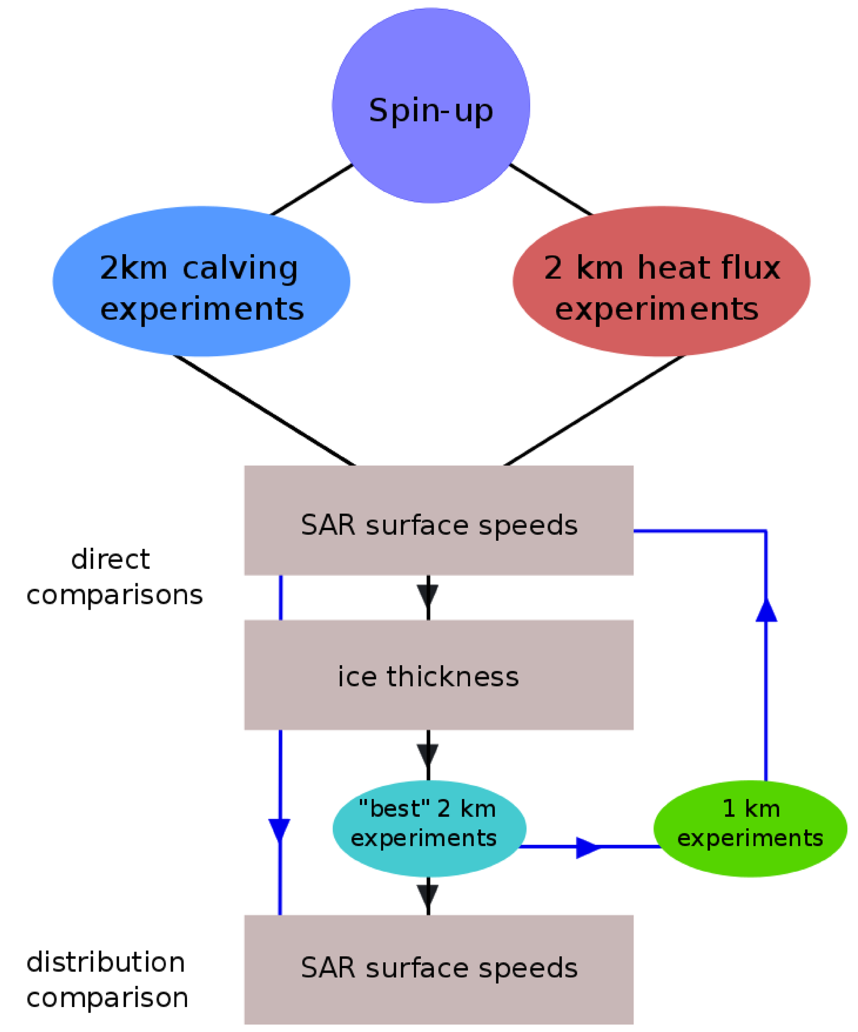


III. Numerical Experiments

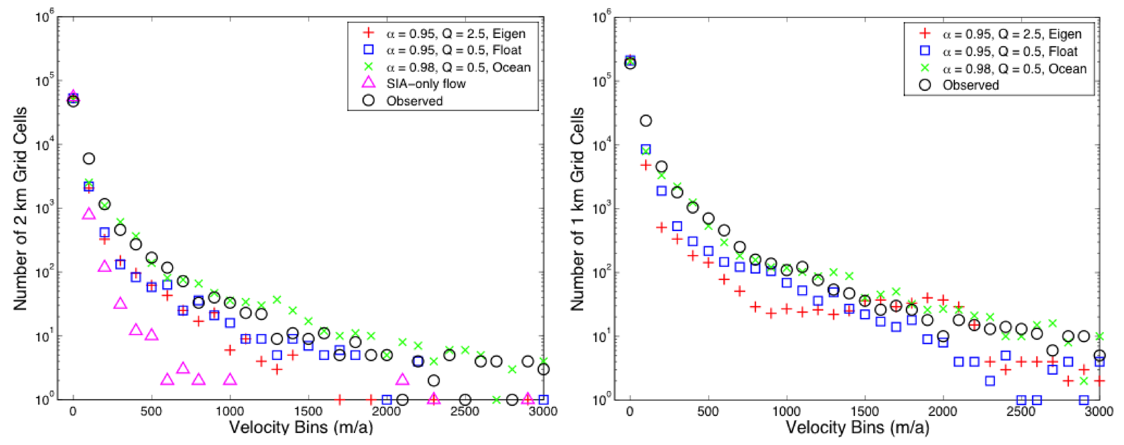
1) Parameter Study: We examine the influence of three key parameters, and their influence of ice dynamics
   i. Basal Resistance:
   ii. Calving Style:
      a) float-kill=all floating ice is immediately calved off
      b) ocean-kill= ice is calved at the present-day calving front
      c) Eigen calving=model builds ice shelf or "floating tongue"
   iii. Ocean heat flux into floating ice
2) Model Inputs and Components:

Grid sizes	2 km → 1 km
Stress balance	SIA+SSA hybrid
Surface mass balance	HIRHAM regional atmospheric climate model [2]
Geothermal flux	Shapiro and Ritzwoller, 2004 [3]
Bedrock topography	Bamber et al., 2001 [4] and CReSIS flightline data for Jakoshavn [5]
Ice thickness	Bamber et al., 2001 [4] and CReSIS flightline data for Jakoshavn [5]
Enthalpy, SSA velocities, basal melt	125,000 a whole-Greenland ice sheet model run with PISM

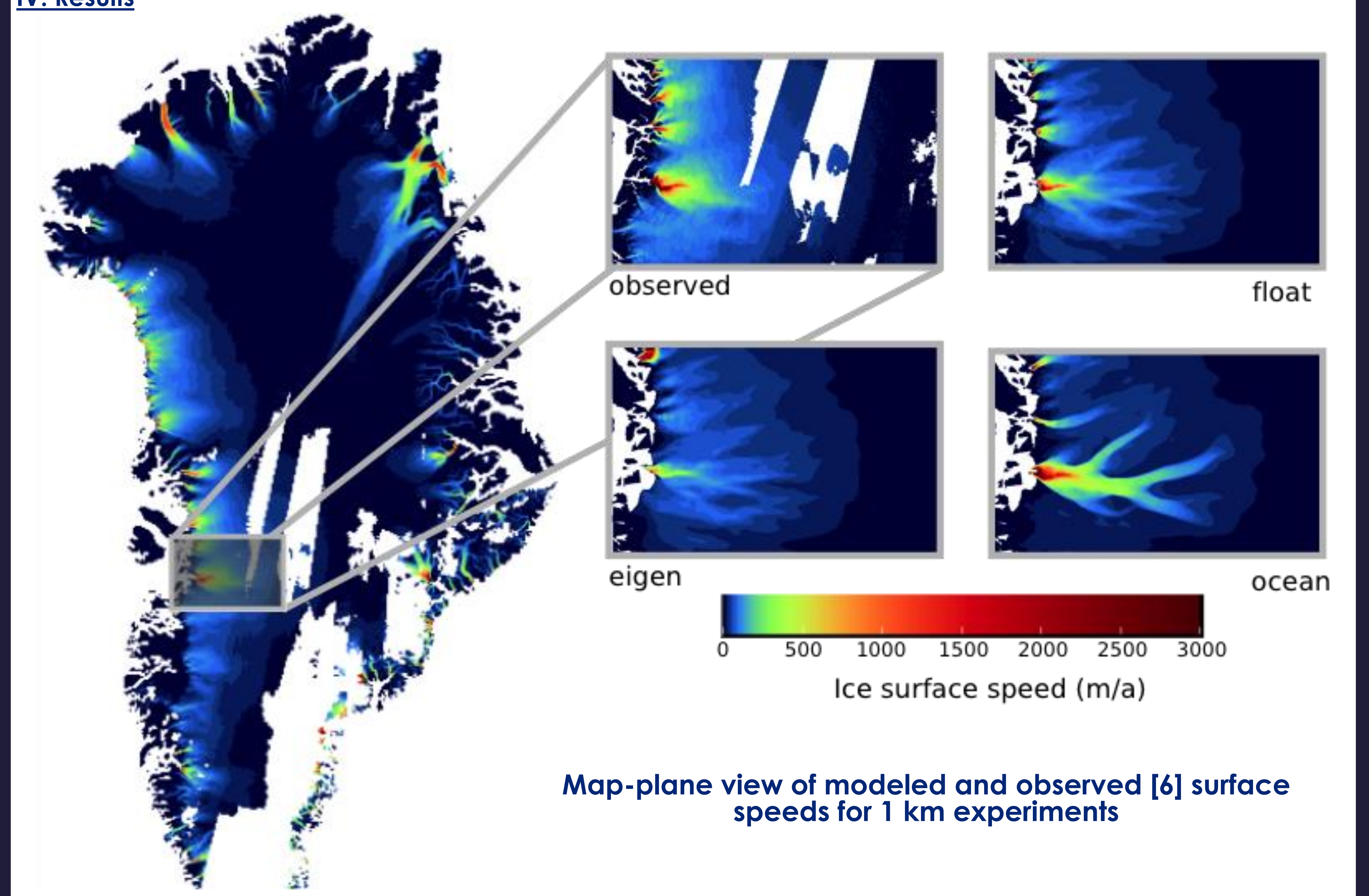
3) A flowchart that depicts the procedure used to generate and validate all of the model results in this parameter study



4) An example of model validation: The distribution comparison between modeled vs. observed surface speeds[6]



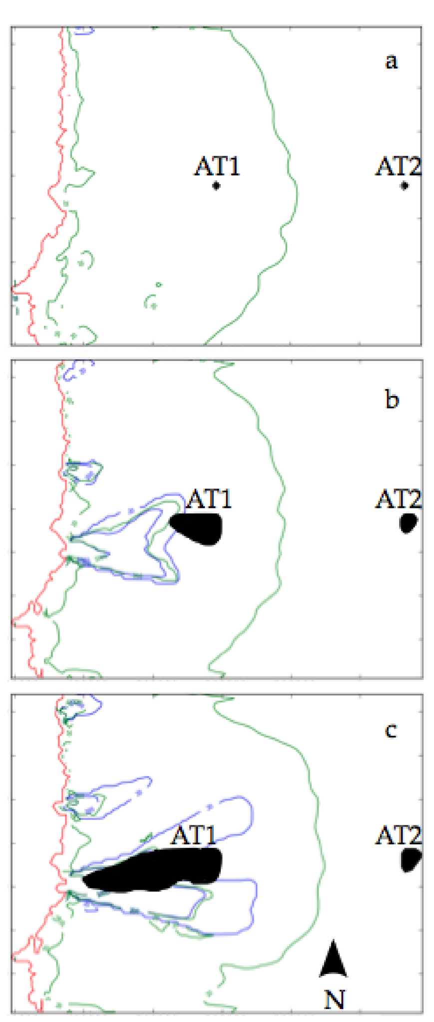
IV. Results



Map-plane view of modeled and observed [6] surface speeds for 1 km experiments

V. Discussion

1) Model capabilities:
   i. The tools are able to perform ice sheet modeling at the regional scale
   ii. The regional model demonstrates a clear improvement over a continental model
   iii. Both fast and slow ice flow are well captured
   iv. We are able to generate and floating ice and make to disappear, using eigen-calving
   v. We are able to produce an increase in ice velocities after the disintegration of a floating tongue
   vi. We are able to generate temperate ice in the trunk of Jakobshavn
2) Observations about this example:
   i. Model is analogous to a one-way nested ice sheet model, so we evaluate the "temporal relevance"
   ii. Ice that is modeled in an unphysical way outside of the drainage basin is not observed to enter the DB on the order of a 1000 a
   iii. Perturbations that occur within the drainage basin appear to be confined to the DB and do not affect the domain boundaries where we have prescribed boundary conditions from a whole-ice sheet model



Snapshots of the age-tracer experiment at (a) 0 a, (b) 500 a, & (c) 1000 a. Here red indicates the position of the coastline, blue and green represent the surface speeds & basal speeds, respectively (m a^{-1}), & black indicate areas of old ice. Courtesy of Constantine Khroulev.

VI. Conclusions

1) The purpose of this study was not to produce a model that closely matches the observations, but rather to identify sets of parameters that cause a given behavior within the model.
2) Future Work:
   i. Provide better estimates of SMB directly to the model
   ii. Improve the way we determine basal resistance using an iterative inverse method
   iii. Use improved bedrock topography
   iv. Run the model at higher resolutions (< 1 km)
3) Summary:
   i. This model is best suited for simulation of a region of an ice sheet at high spatial resolutions (≤1 km) and on short timescales (≤1000 a)
   ii. The model provides improved performance over a continental ice-sheet model
   iii. Both slow and fast ice flow are well captured by the model

References: **[1]**Truffer M. & M. Fahnestock (2007) Rethinking ice sheet time scales, Science, 315, 1508–1510. **[2]**O.B. Christensen, M. Drews, J.H. Christensen, et al. (2008). The HIRHAM regional climate model version 5 (β). Danish Climate Center Report, 06–17. **[3]**N.M. Shapiro and M.H. Ritzwoller. (2004) Inferring surface heat flux distributions guided by a global seismic model: particular application to Antarctica. Earth and Planetary Science Letters, 223, 213–224. **[4]**J. Bamber, R. Layberry and S. Gogineni. (2001) A new ice thickness and bed data set for the Greenland ice sheet. I-measurement, data reduction, and errors. Journal of Geophysical Research, 106:33, 2001. **[5]**J.C. Plummer and C.J. van der Veen. A high-resolution bed elevation map for Jakobshavn Isbræ, West Greenland. In preparation. **[6]**Joughin I., Smith B., Howat I. Scambos T., & T. Moon, (2010) Greenland flow variability from ice-sheet-wide velocity mapping. J. Glaciol., 56, 415-430.