The heroic age of ice sheet modeling: Glimmer, CISM and all that

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A heroic age for ice sheet modeling?

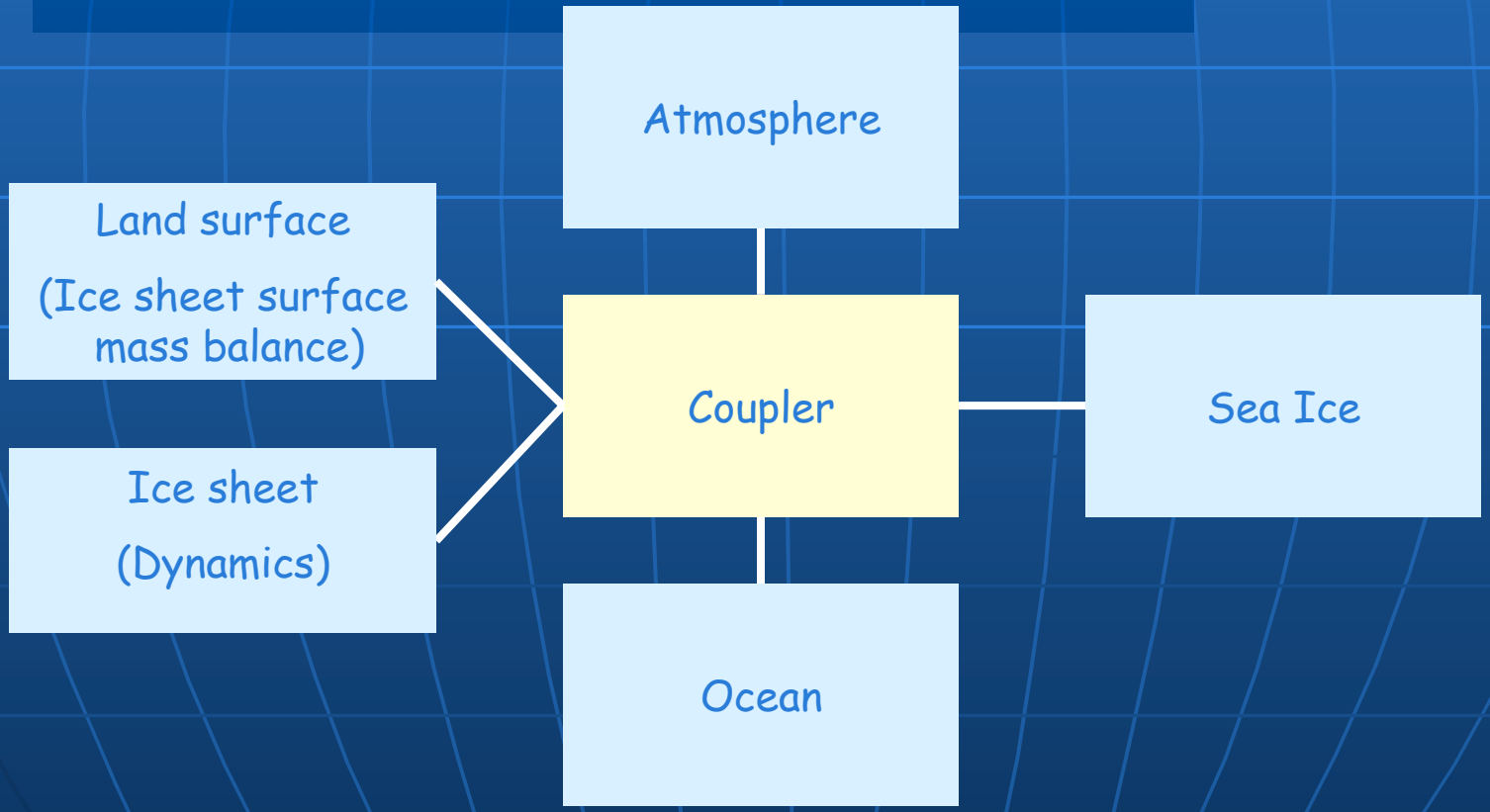
- We are trying to do many hard things at once:
  - Improved dynamical cores (full-Stokes and/or higher-order stress balance)
  - More realistic physics (surface mass balance, basal hydrology, iceberg calving, sub-shelf melting, grounding-line migration, etc.)
  - High grid resolution (~1 km or less)
  - Coupling to global climate models
- And we're expected to produce significantly improved sea-level predictions (with error bars) for IPCC AR5.

Glimmer-CISM

- The **Glimmer** ice sheet model (Rutt et al. 2009) was developed by Tony Payne et al. in the U.K. with the goal of coupling dynamic ice sheets to global climate models.
- NSF has supported development of a Community Ice Sheet Model (**CISM**) based on Glimmer.
  - Jesse Johnson's wiki: http://websrv.cs.umt.edu/isis
- DOE has supported coupling of Glimmer to the Community Climate System Model (**CCSM**).
  - CCSM Land ice working group (meeting Feb. 2010 in Boulder): http://www.ccsm.ucar.edu/working_groups/Land+Ice/
- The U.S. and U.K. groups have recently combined efforts:
  - BerliOS repository: http://developer.berlios.de/projects/glimmer-cism/
  - 6-member steering committee (M. Hagdorn, J. Johnson, W. Lipscomb, T. Payne, S. Price, I. Rutt)

Ice sheets in the Community Climate System Model

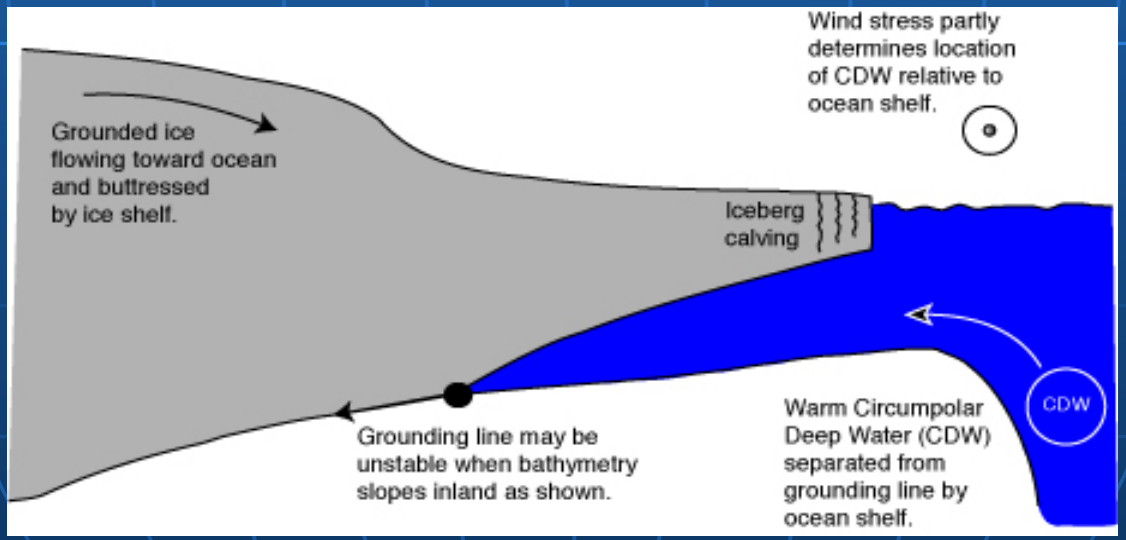
- Glimmer has been coupled to CCSM version 4 and will be used for IPCC runs with a dynamic Greenland ice sheet.
- The surface mass balance of ice sheets is computed by the land surface model on a coarse grid (~100 km) in multiple elevation classes, passed to Glimmer via the coupler, and downscaled to the ice sheet grid (~10 km).



DOE IMPACTS

IMPACTS = Investigation of the Magnitudes and Probabilities of Abrupt Climate Transitions

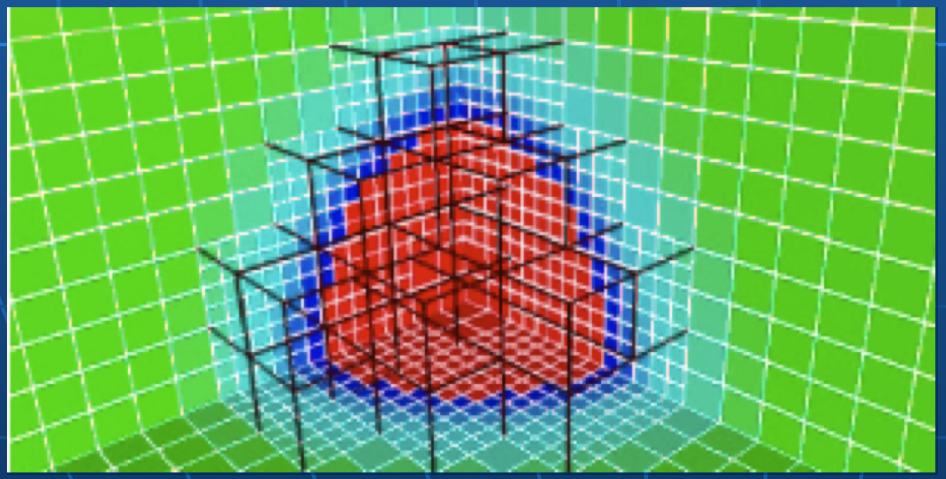
- 5-year program on abrupt climate change
- One project (LANL, NYU) focuses on the potential instability of the West Antarctic ice sheet
  - Couple Glimmer-CISM to the HYPOP ocean model on regional scales
  - Model ocean circulation beneath dynamic ice shelves

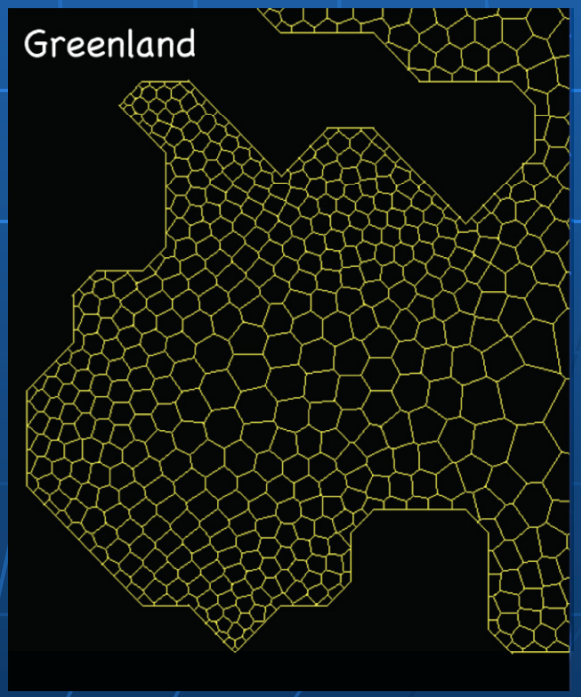


DOE ISICLES

ISICLES = Ice Sheet Initiative for Climate at Extreme Scales

- New 3-year program to develop advanced ice sheet models using efficient, scalable computational methods
- Dynamical cores to be incorporated as options in Glimmer-CISM
- Six projects with similar goals, different tools
  - Matrix solvers and preconditioners (e.g., PETSc, Trilinos)
  - Adaptive mesh refinement (e.g., Chombo)
  - Unstructured grids (e.g., Voronoi meshes)

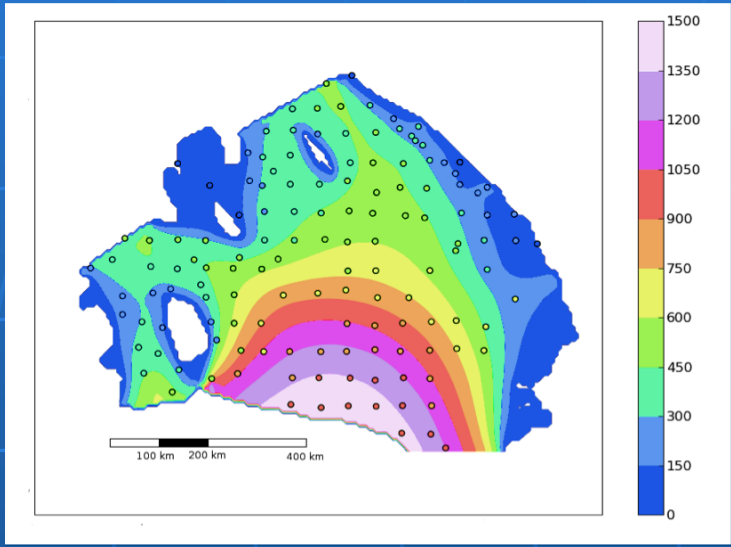


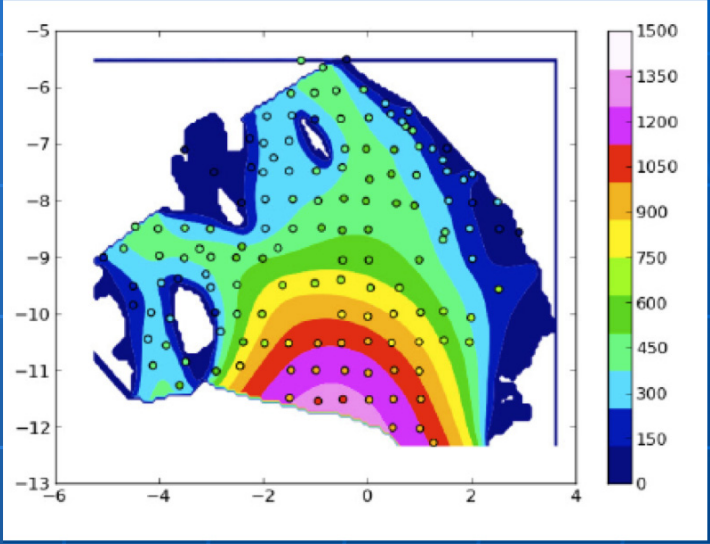


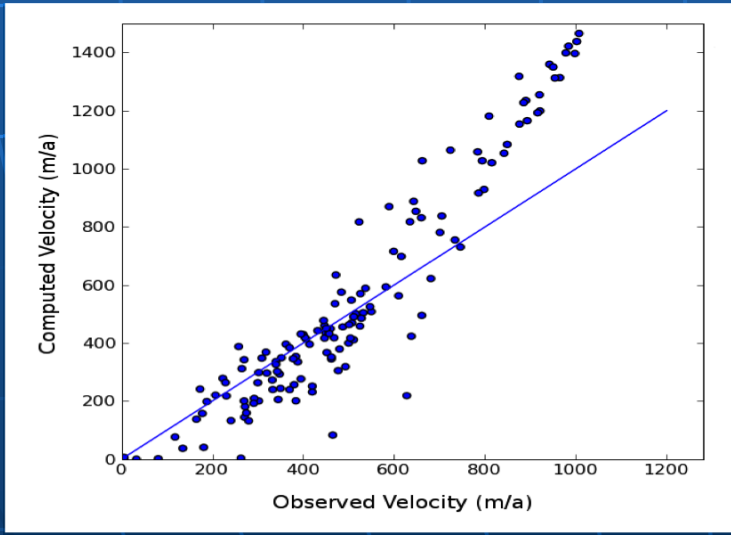
Glimmer-CISM results

- The model now includes two "higher-order" ice-flow schemes (Payne-Price and Pattyn-Bocek-Johnson). All important stresses are included in a unified way (e.g., Blatter 1995, Pattyn 2003).
  - These codes are serial (and slow), but parallelization is under way.
- Both schemes have been tested for idealized cases (e.g., ISMIP-HOM) and are now being used for more realistic simulations.
  - EISMINT Ross Ice Shelf test (MacAyeal et al. 1996)
  - Greenland ice velocities with tuned basal sliding
  - Time-dependent ice stream evolution with plastic till

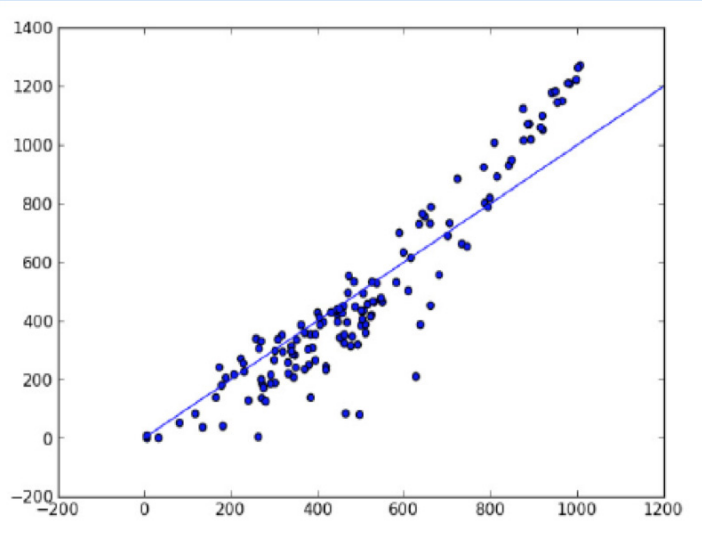
EISMINT Ross Ice Shelf experiment







Pattyn-Bocek-Johnson



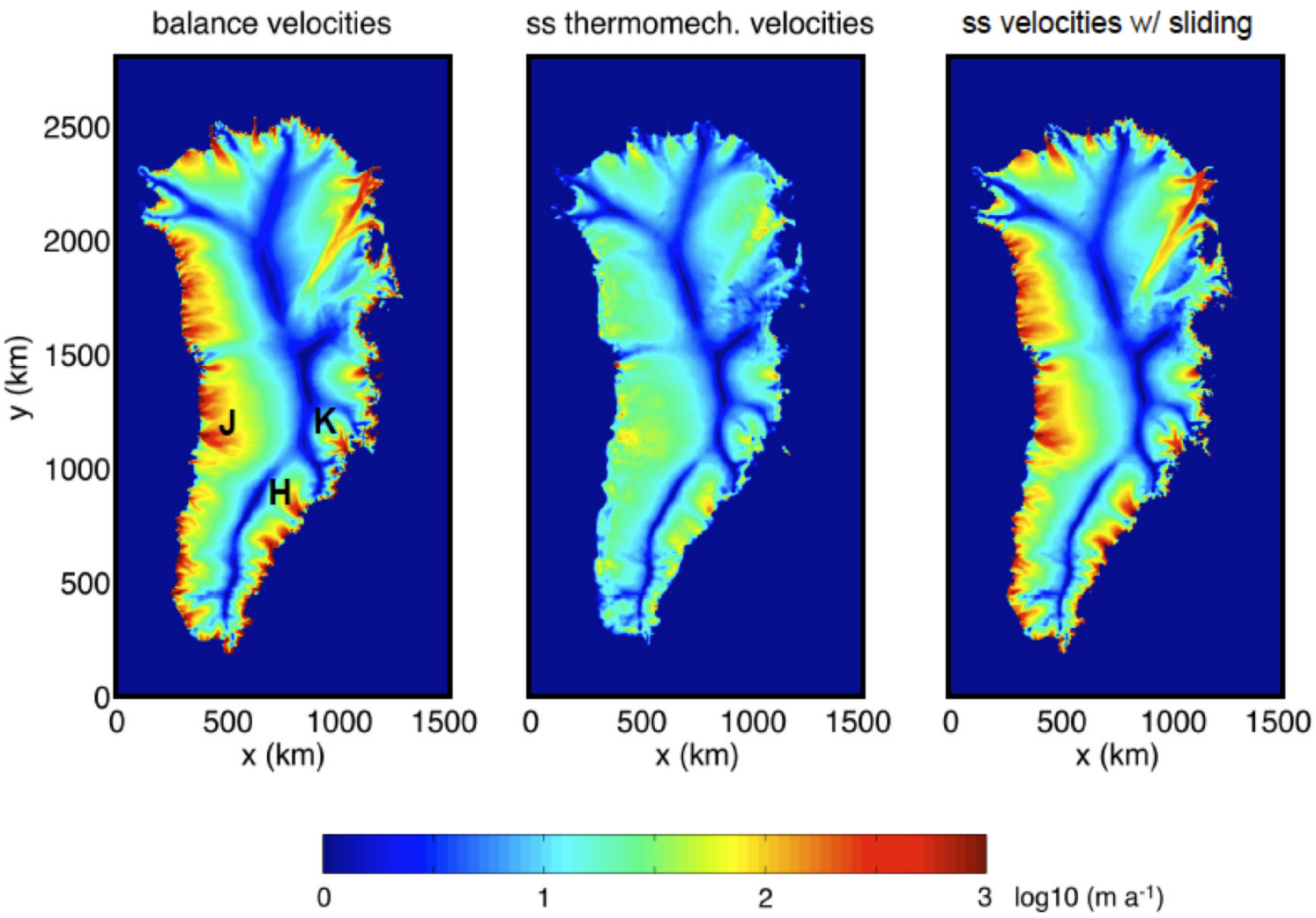
Payne-Price

Comparison to original results

(MacAyeal et al. 1996)

Model	Velocity misfit (X^2)	Max velocity (m/yr)
Bremerhaven1	3605	1379
Bremerhaven2	12518	1663
Chicago1	5114	1497
Chicago2	5125	1497
Grenoble	5237	1508
Pattyn-Bocek-Johnson	**4962**	**1495**
Payne-Price	**2538**	**1307**

Greenland: Model vs. balance velocities (Payne-Price)



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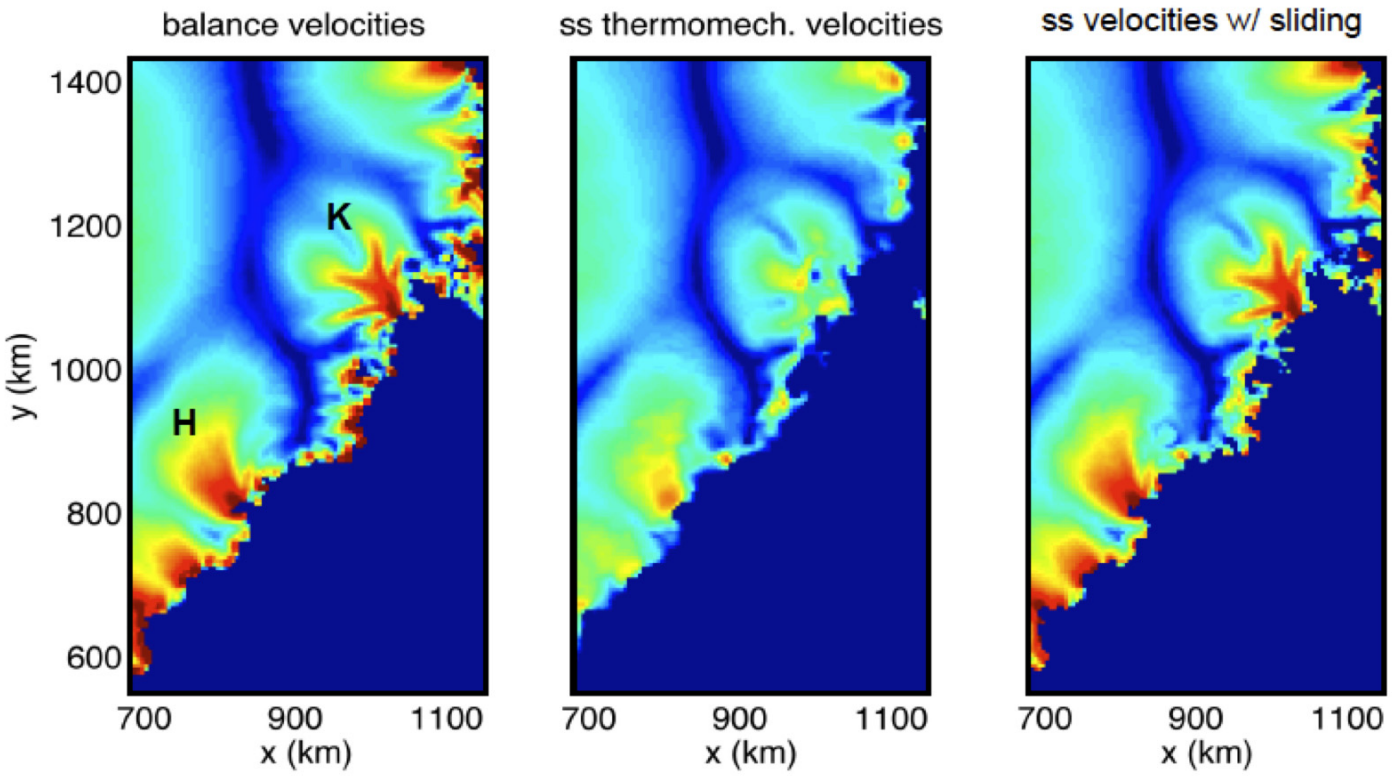
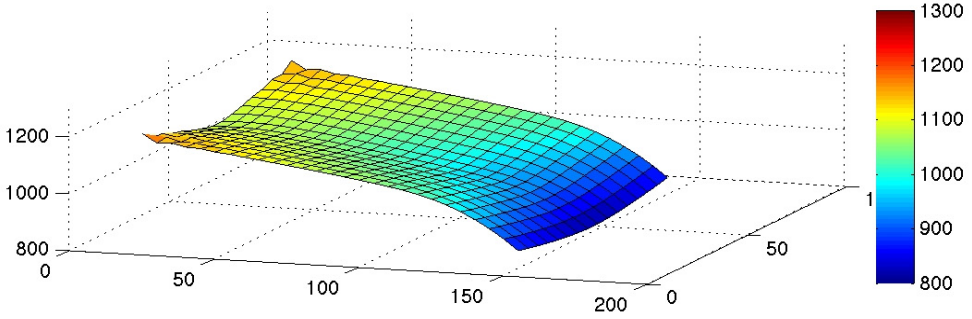


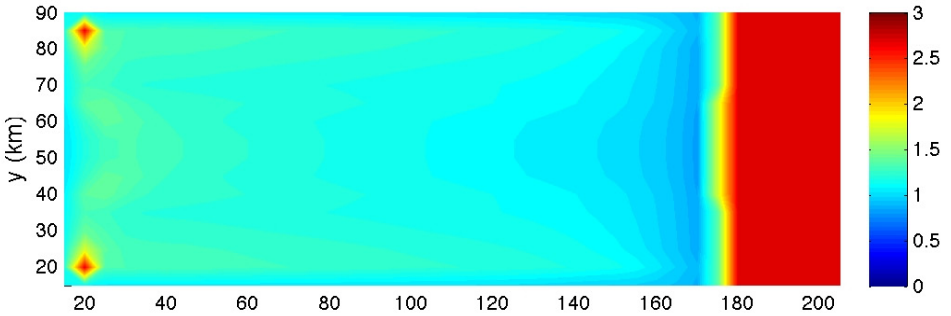
Ice stream binge/purge cycle

- Higher-order ice-flow model coupled to basal processes model based on work of Tulaczyk and Bougamont (meltwater goes into local till)
- Ice thickens => Increased basal melting
  - => Till saturates and yields
  - => Ice flow accelerates
  - => Ice is drawn down
  - => Bed cools, till stiffens, sliding stops
  - => Ice thickens again

elevation (m)



basal water (m



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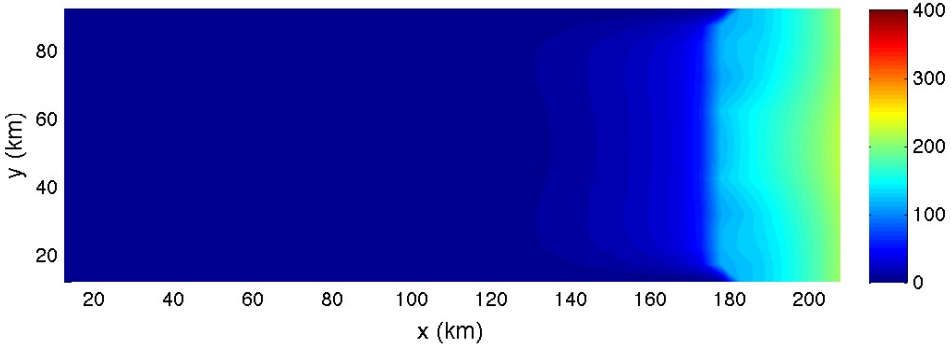
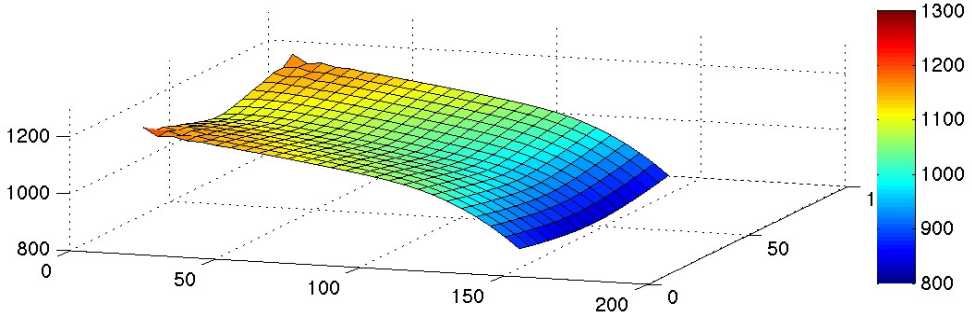
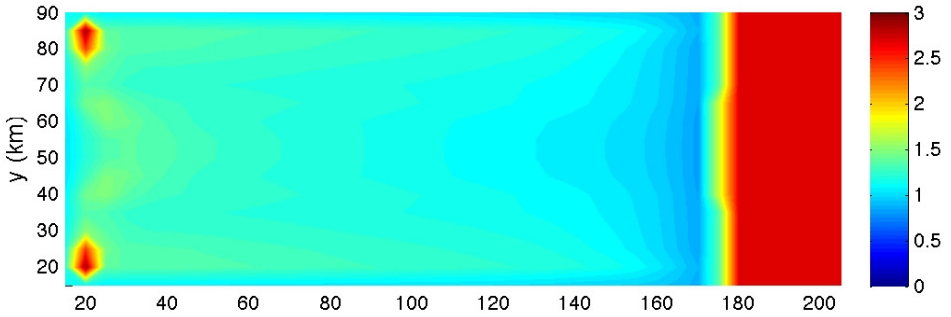
speed (m a^{-1})



elevation (m)



basal water (m



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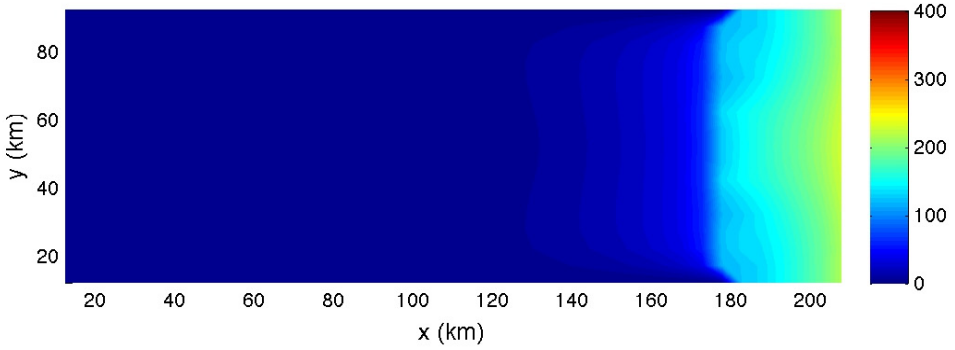
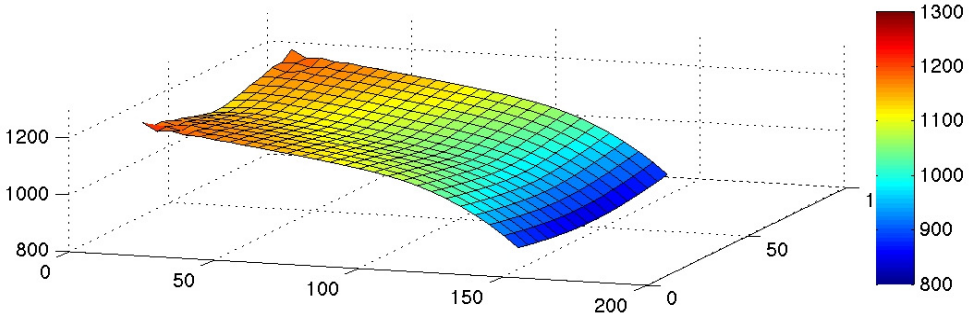
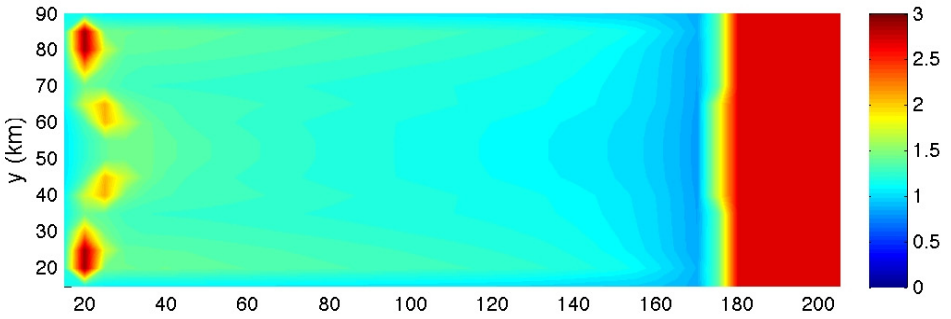


elevation (m)



basal water (m



Time = 100 a

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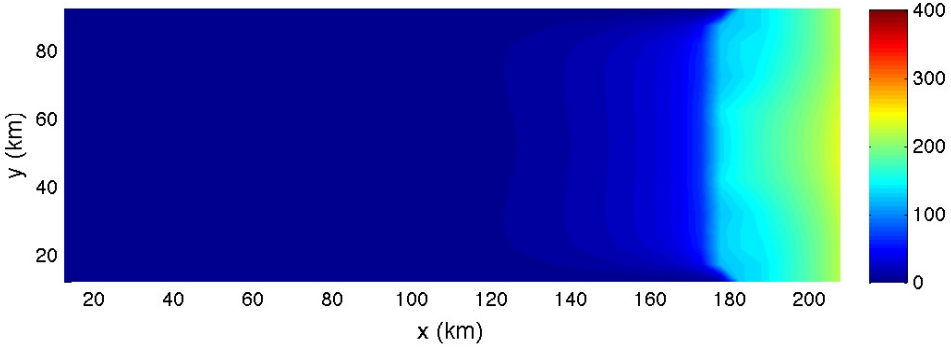
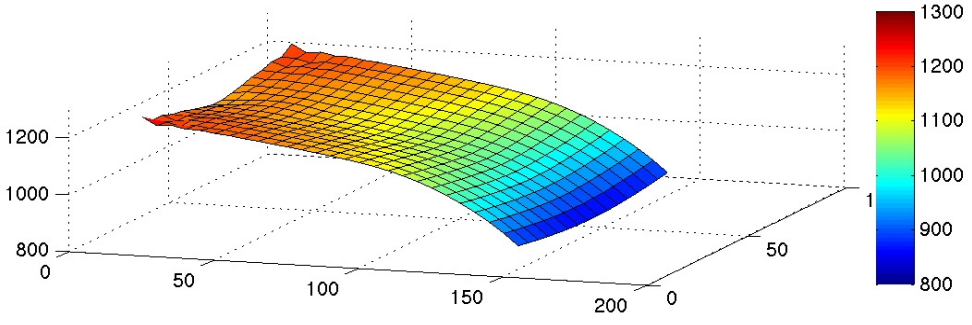
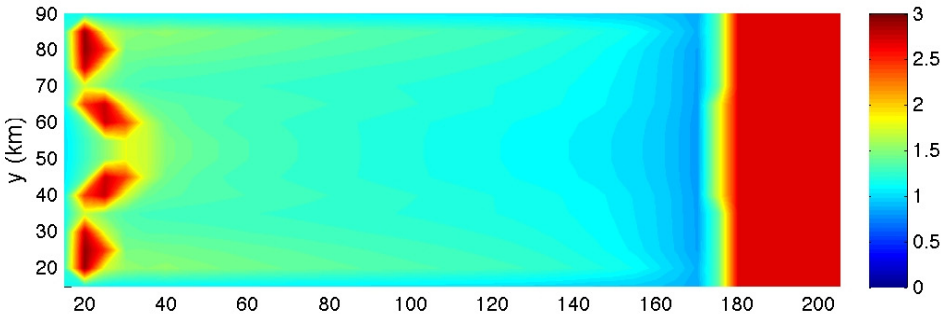


elevation (m)



basal water (m



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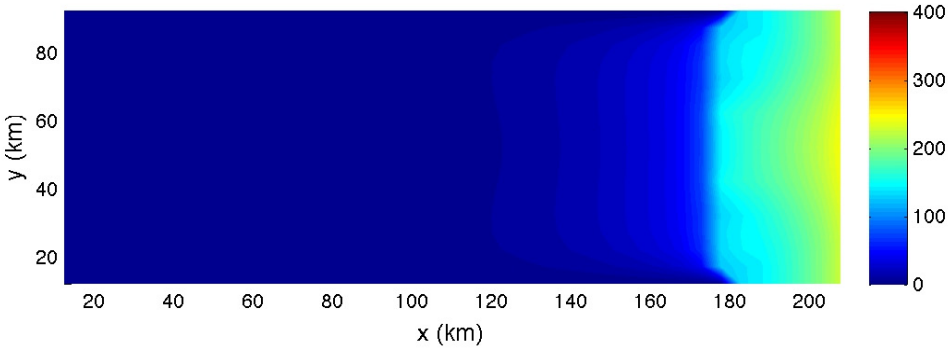
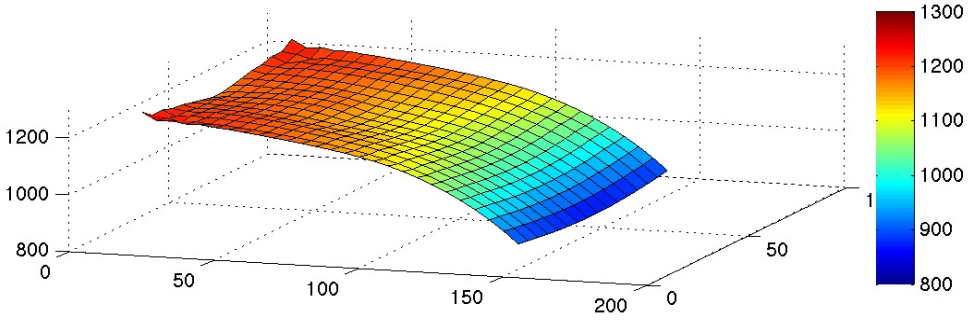
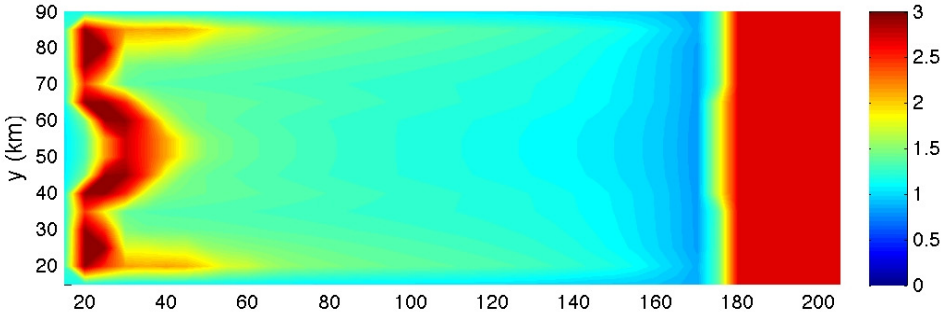


elevation (m)



basal water (m



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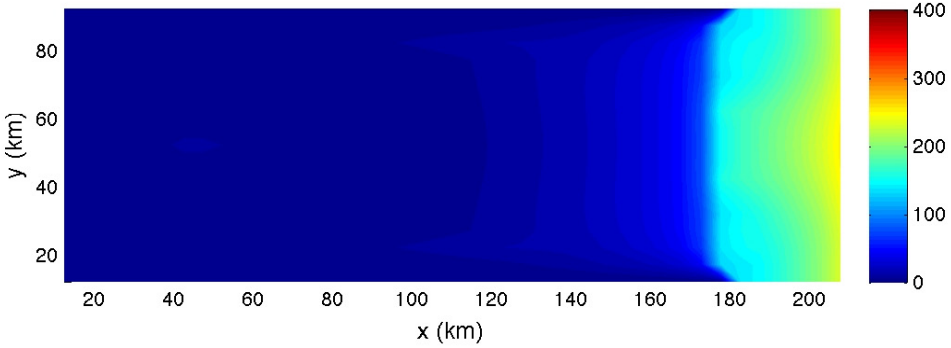
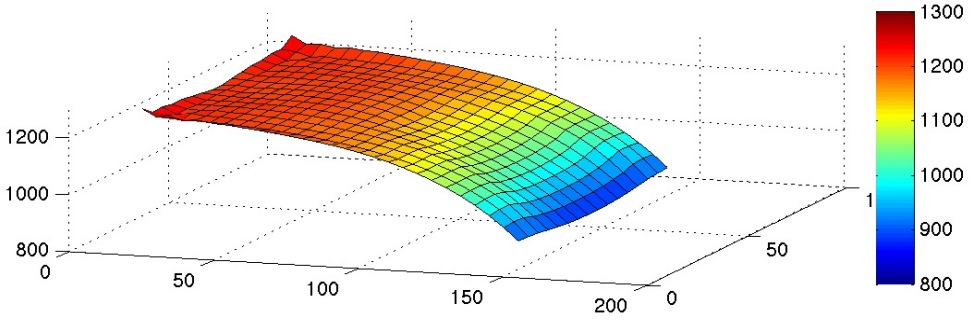
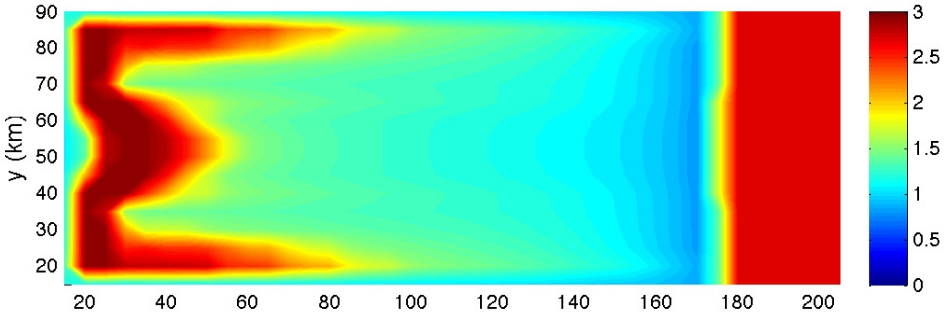


elevation (m)

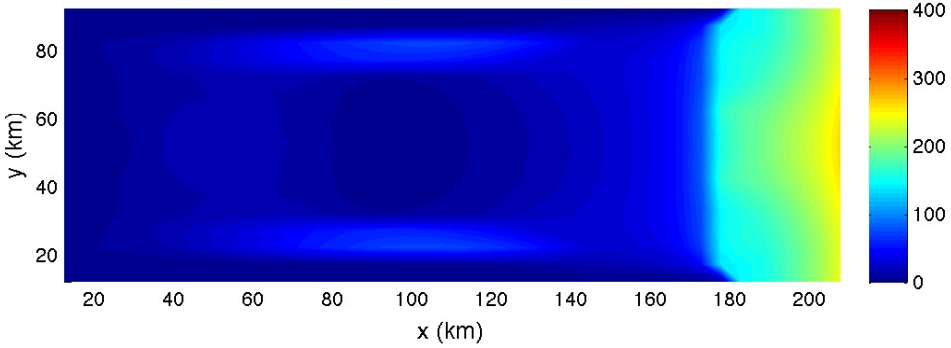


basal water (m

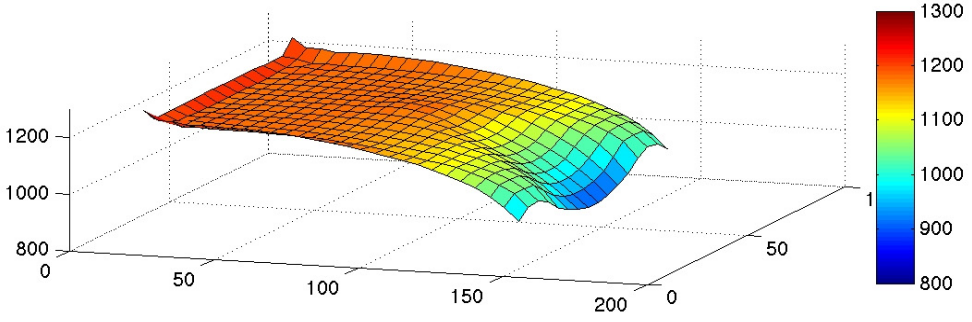


Time = 250 a

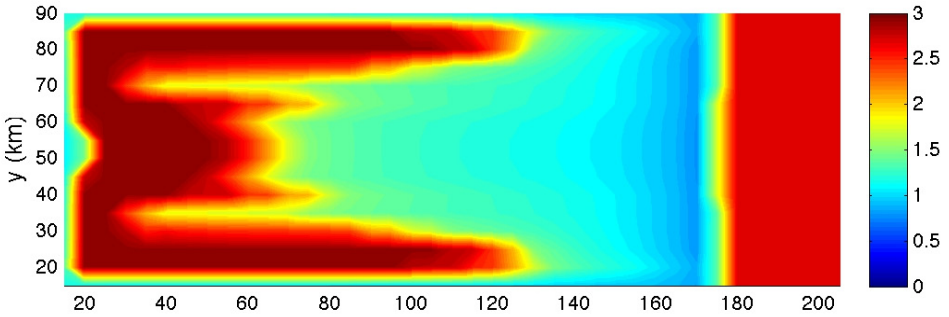
speed (m a^{-1})



elevation (m)

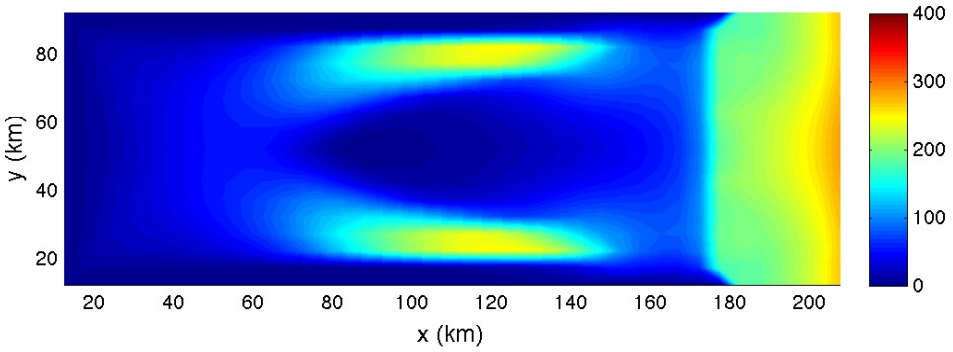


basal water (m

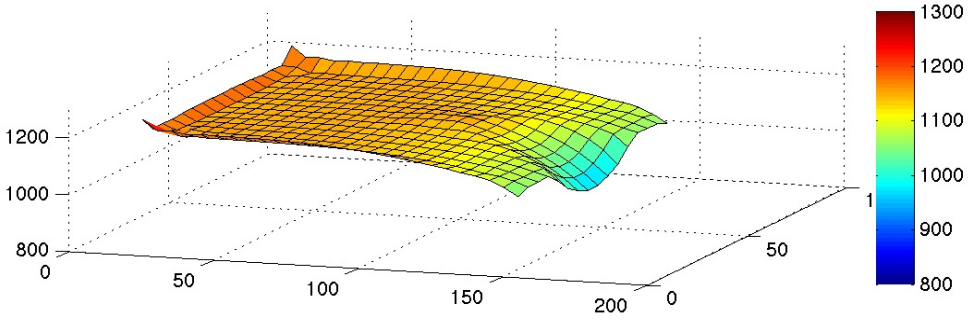


Time = 300 a

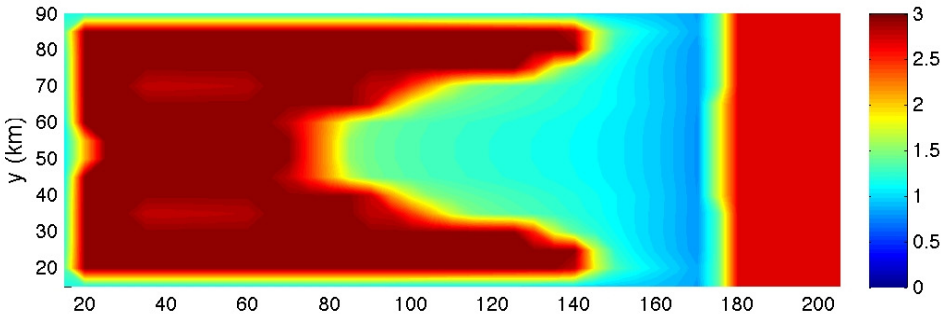
speed (m a^{-1})



elevation (m)



basal water (m



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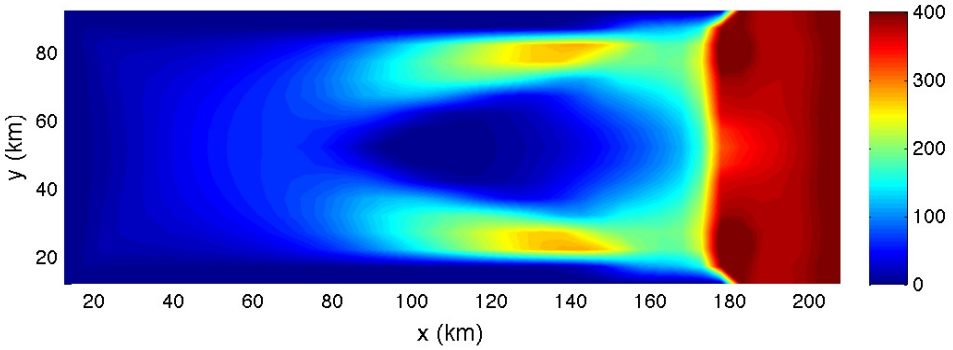
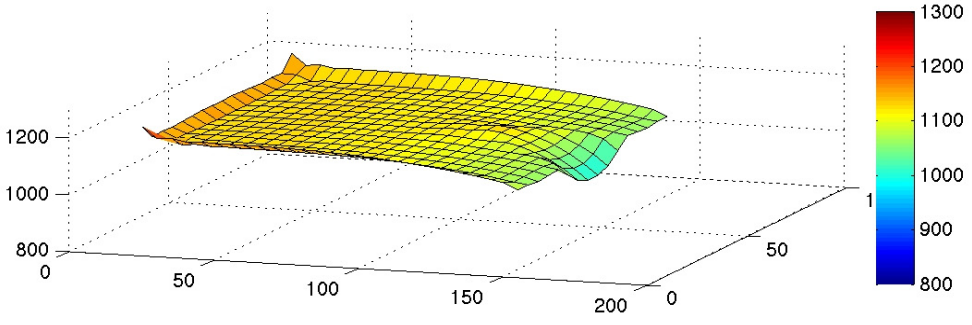
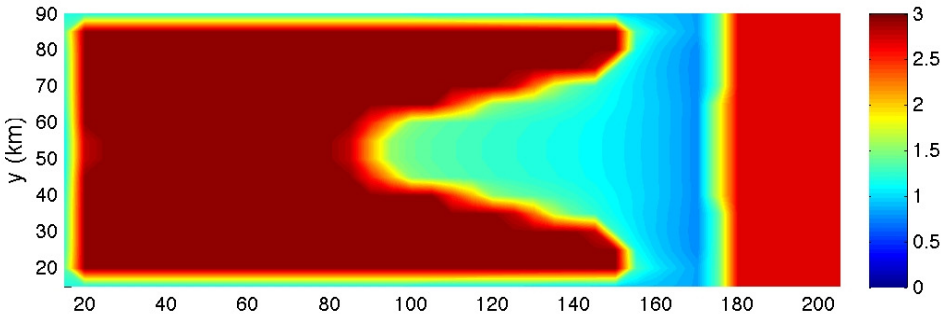


elevation (m)



basal water (m



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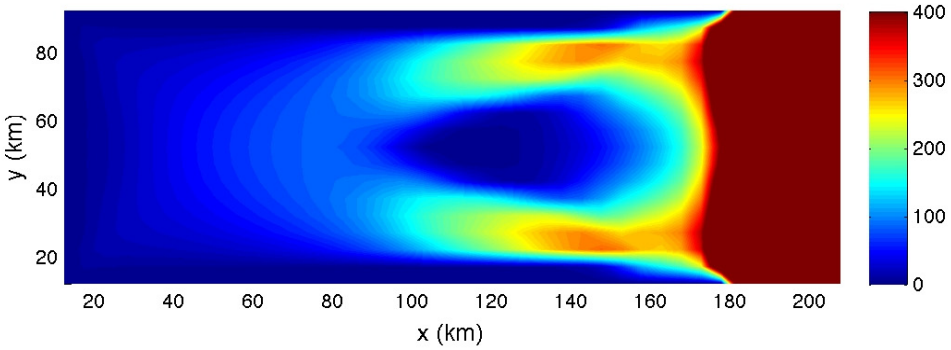
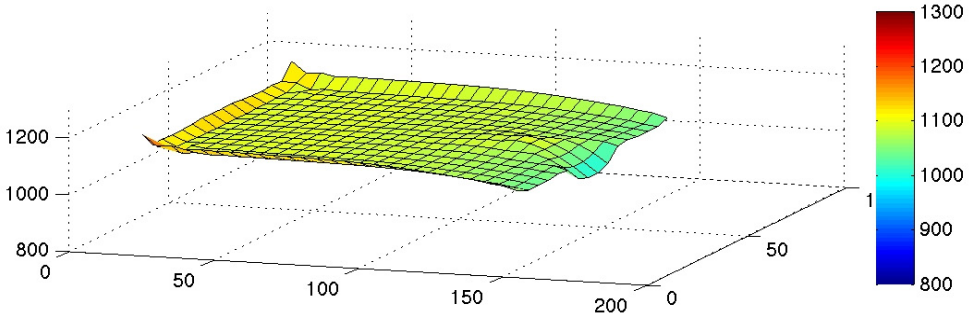
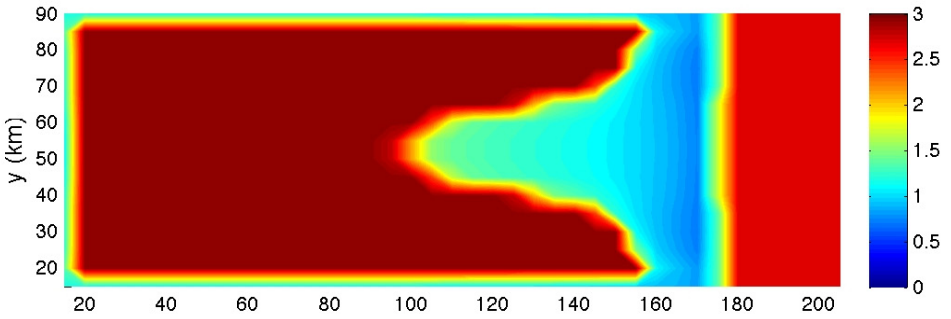


elevation (m)



basal water (m



Time = 450 a

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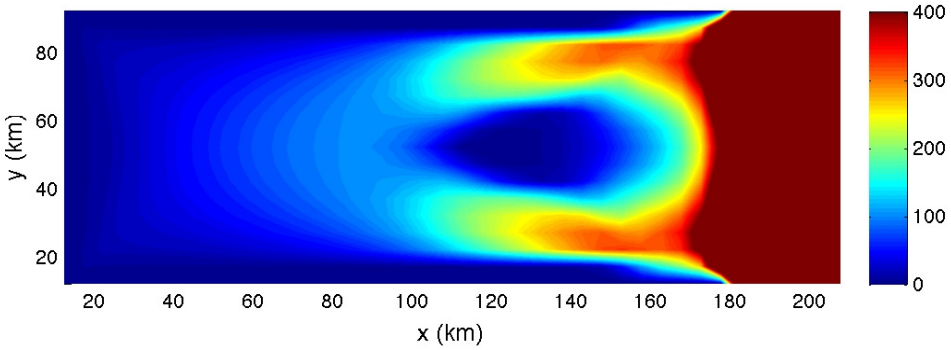
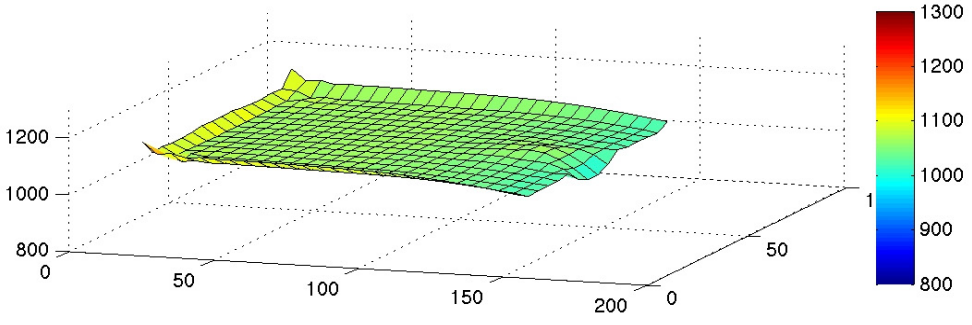
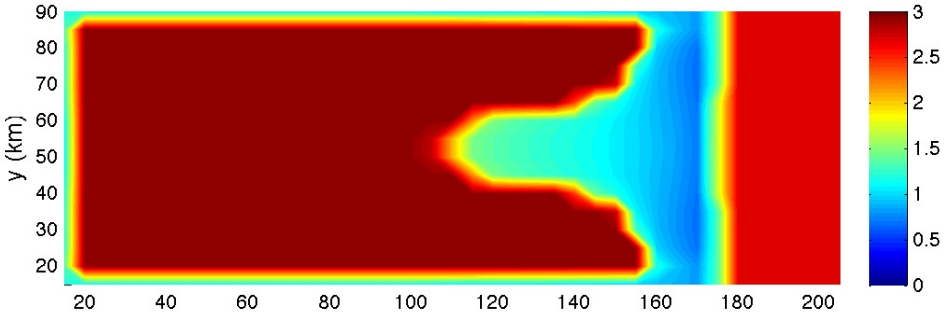


elevation (m)



basal water (m



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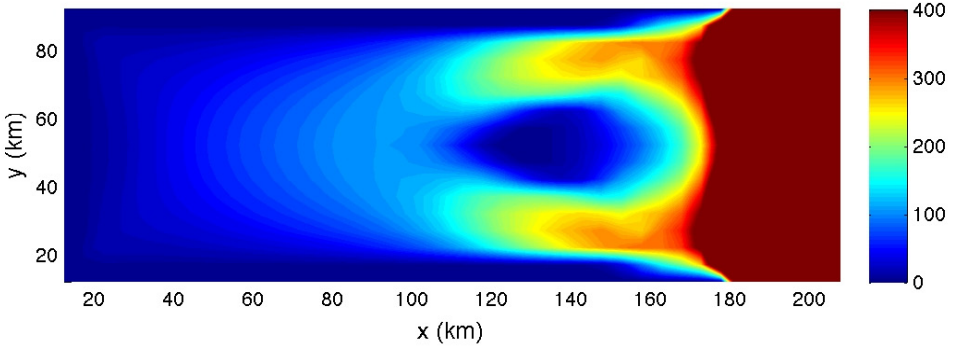
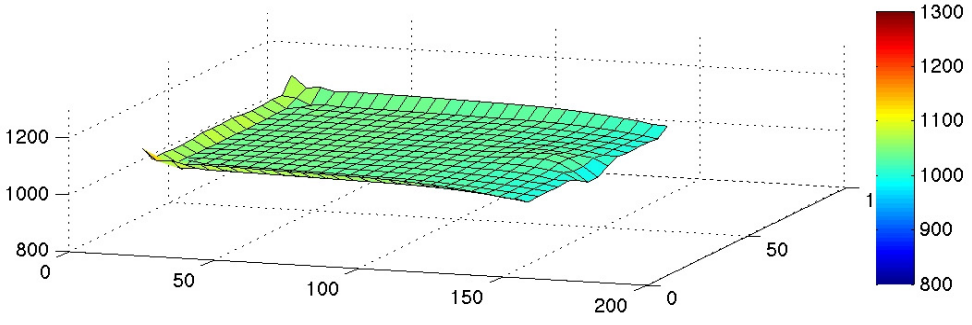
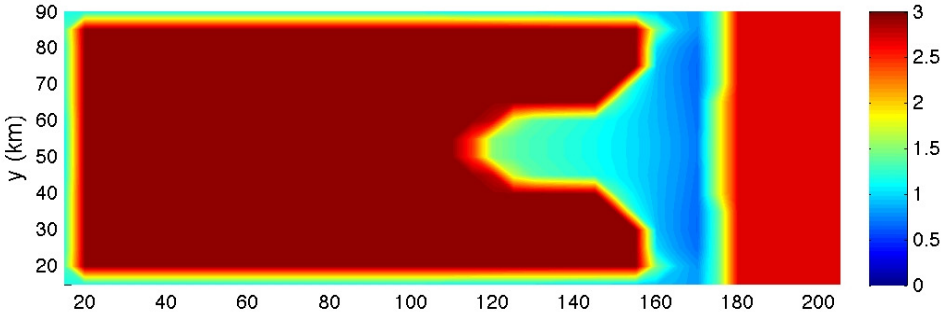


elevation (m)



basal water (m



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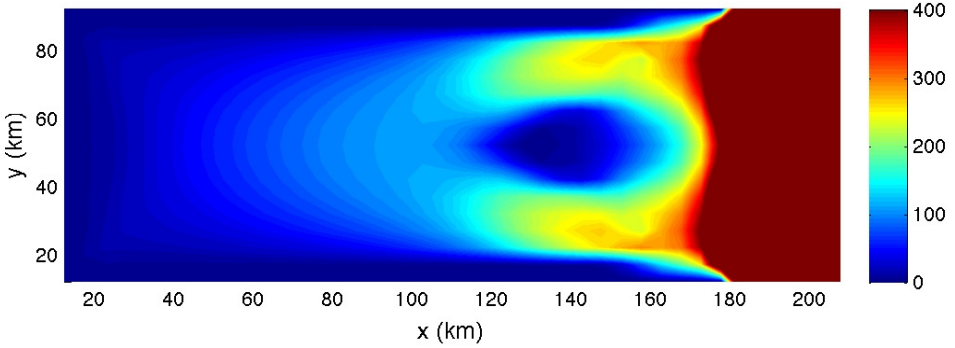
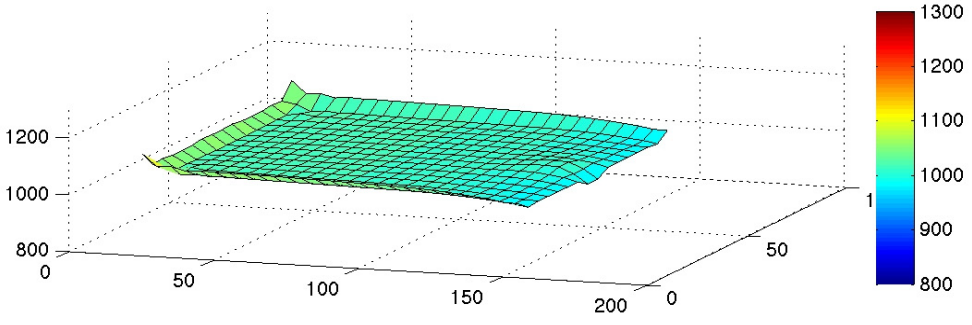
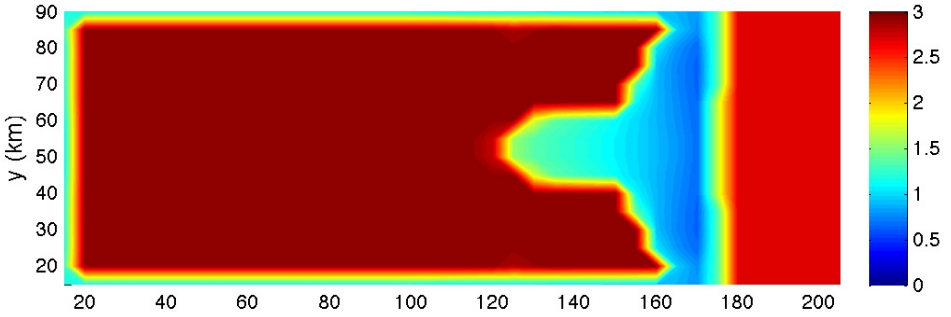


elevation (m)



basal water (m



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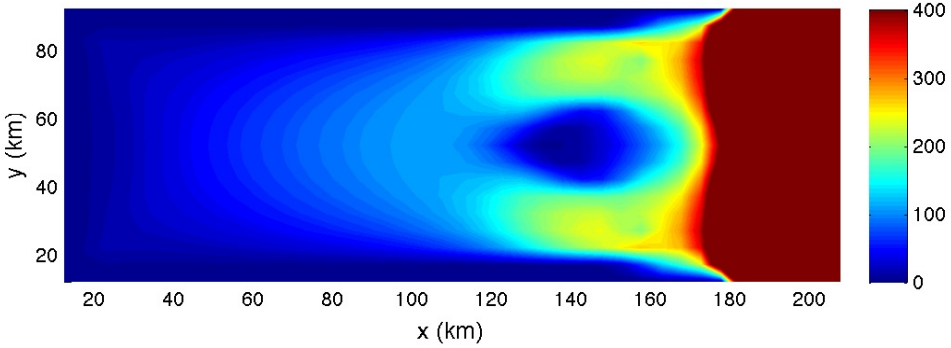
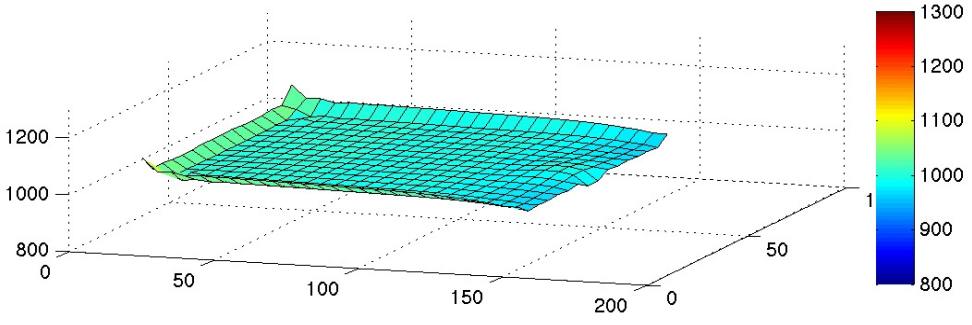
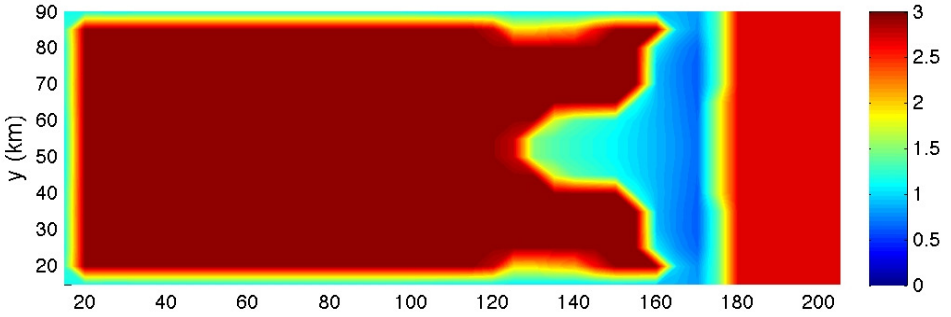
speed (m a^{-1})



elevation (m)

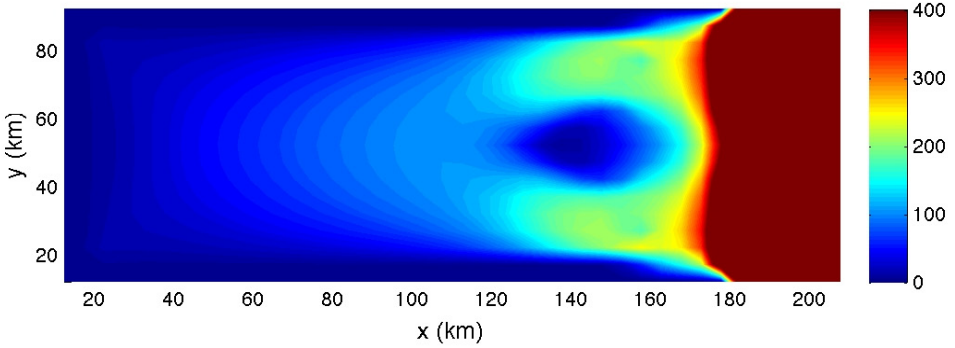


basal water (m

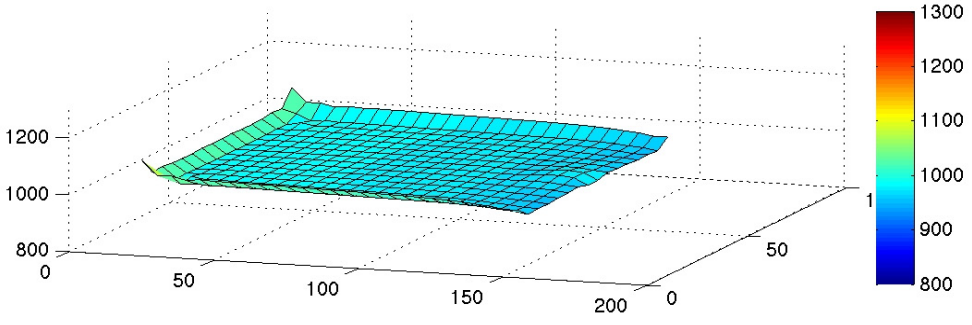


Time = 650 a

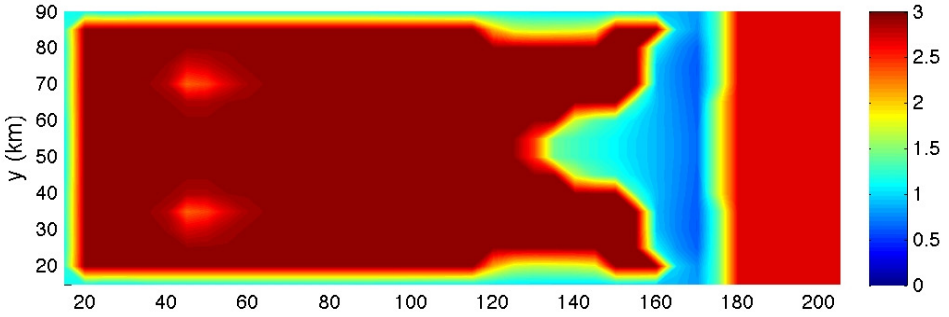
speed (m a^{-1})



elevation (m)

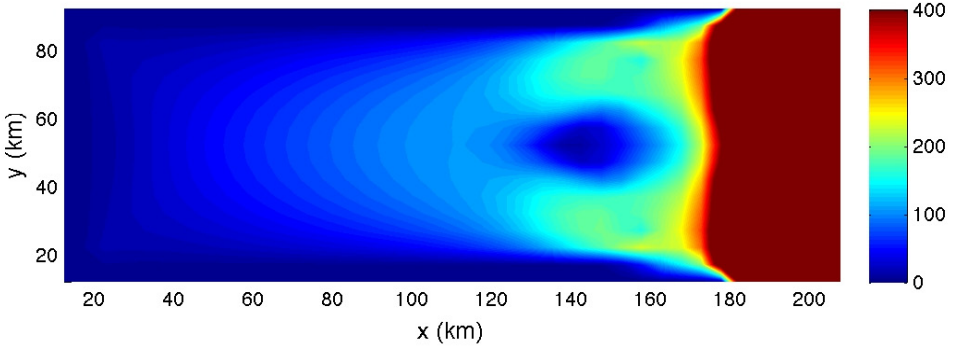


basal water (m

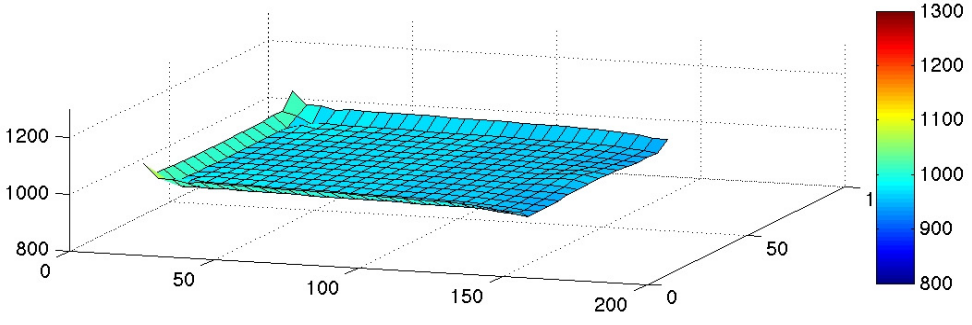


Time = 700 a

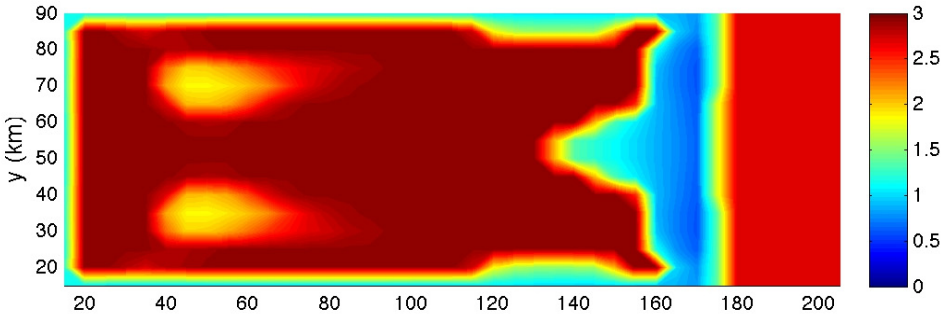
speed (m a^{-1})



elevation (m)

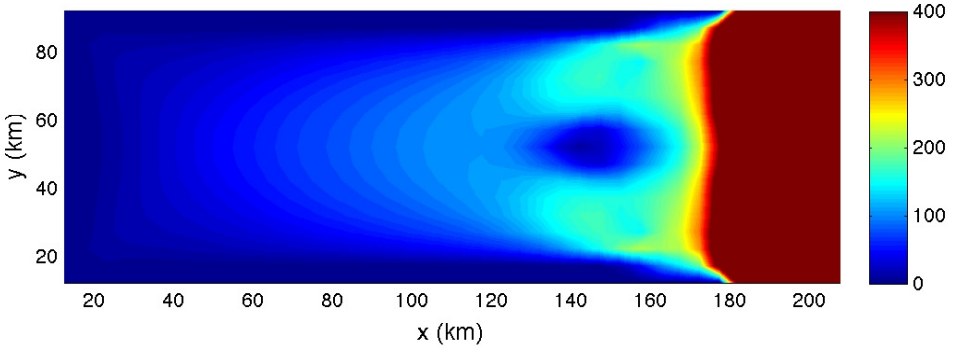


basal water (m

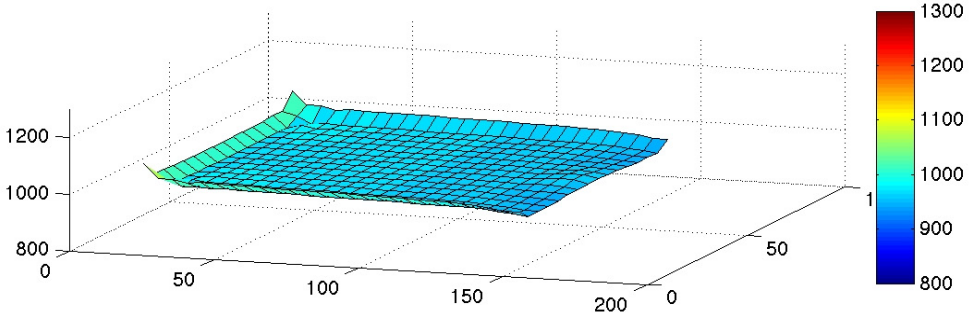


Time = 750 a

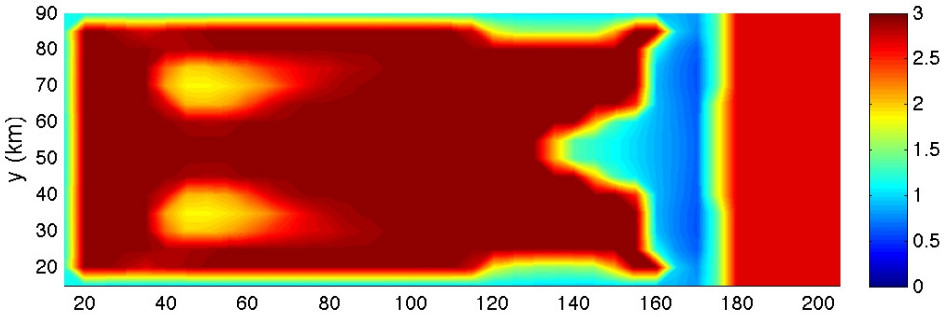
speed (m a^{-1})



elevation (m)

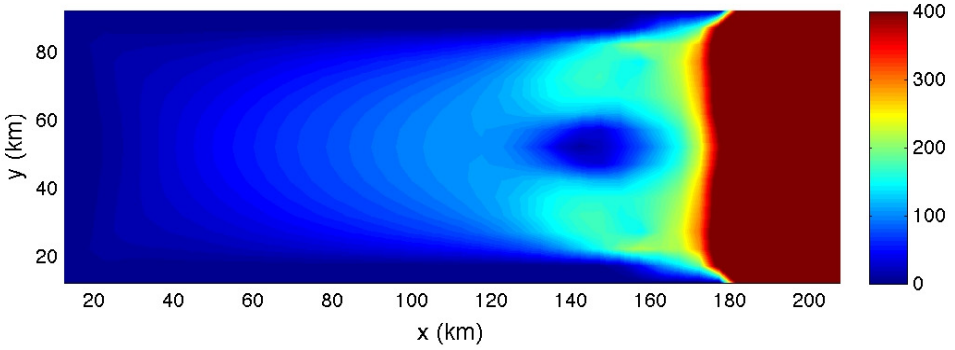


basal water (m

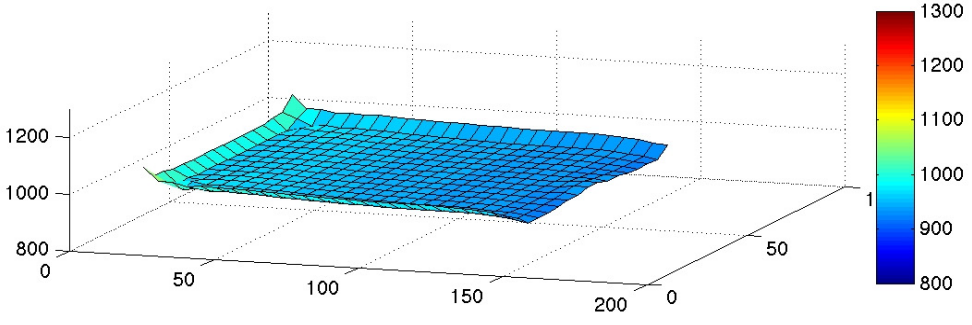


Time = 800 a

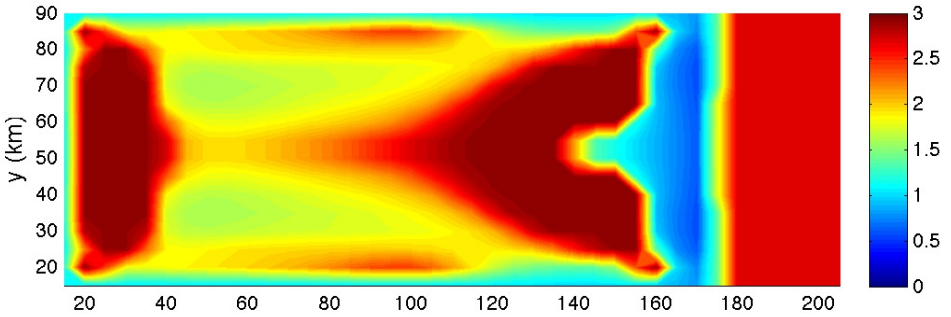
speed (m a^{-1})



elevation (m)

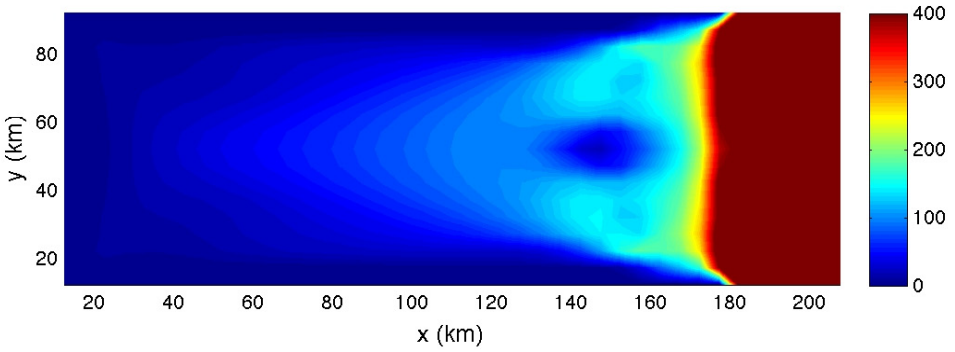


basal water (m

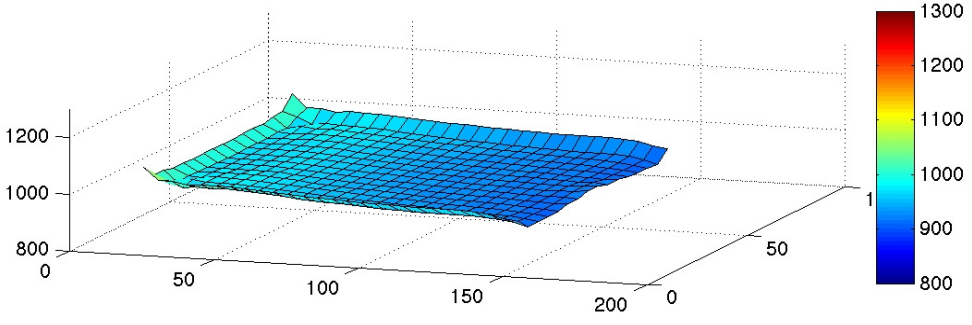


Time = 850 a

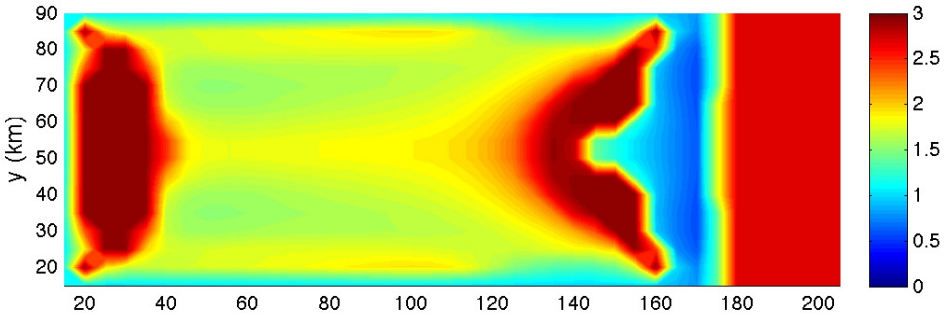
speed (m a^{-1})



elevation (m)

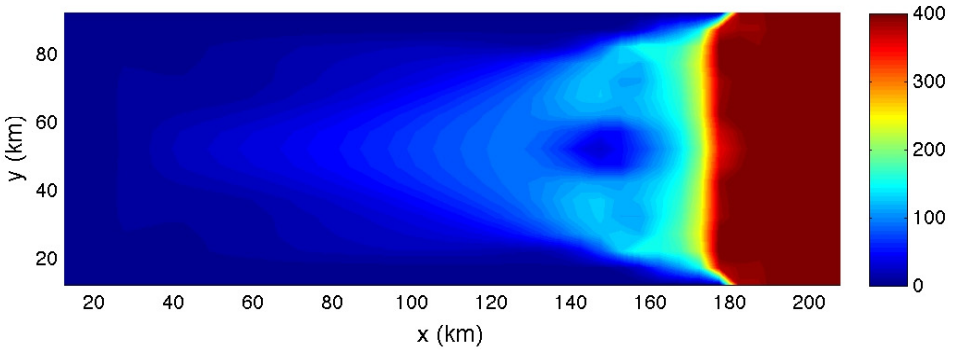


basal water (m

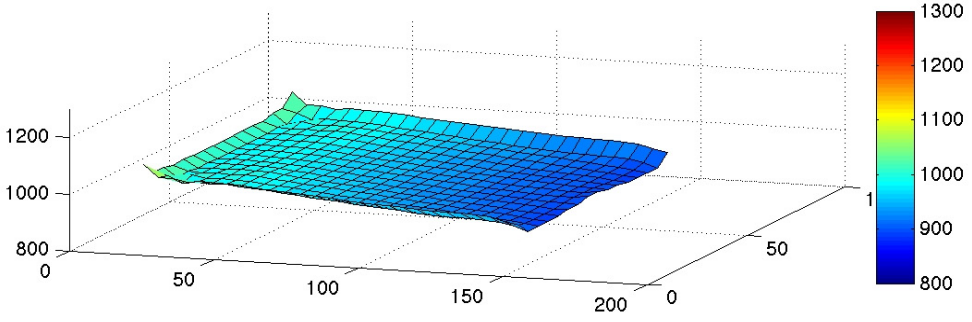


Time = 900 a

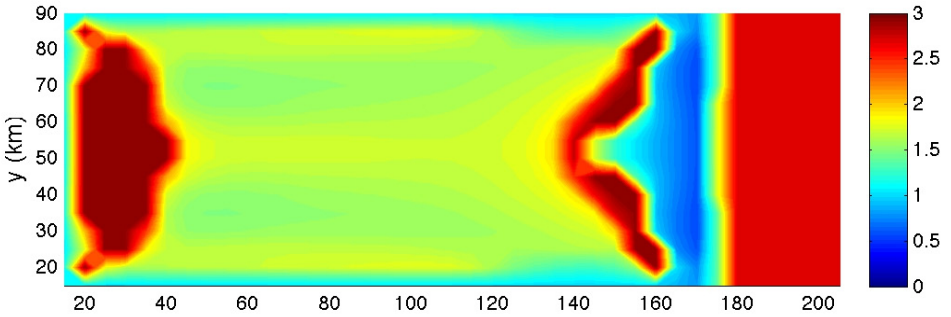
speed (m a^{-1})



elevation (m)

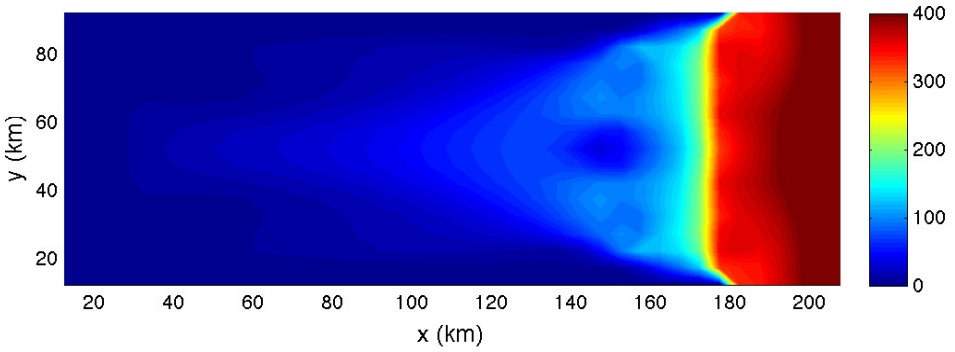


basal water (m

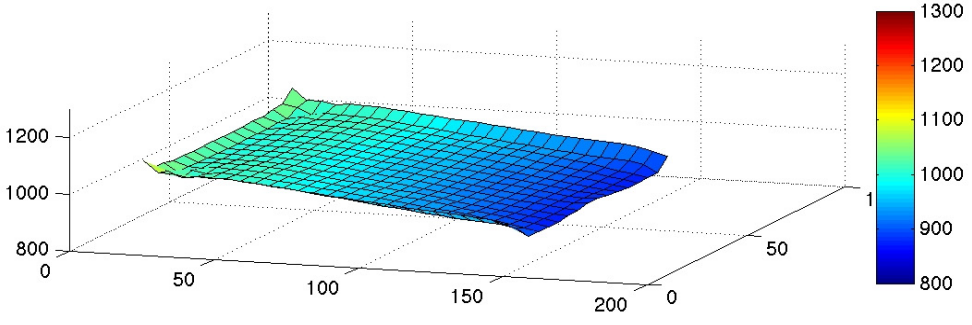


Time = 950 a

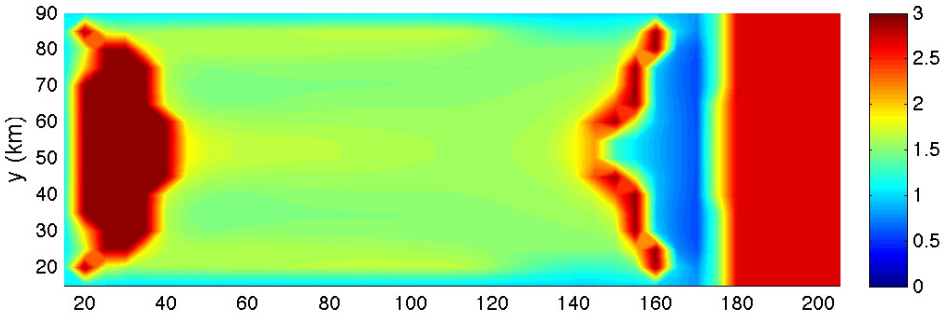
speed (m a^{-1})



elevation (m)

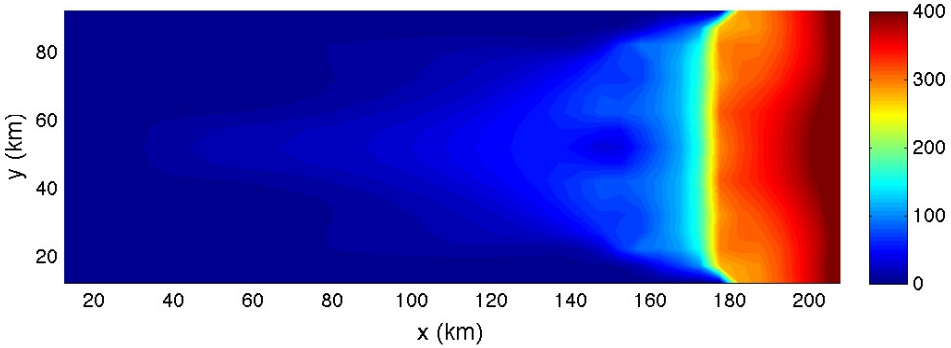


basal water (m



Time = 1000 a

speed (m a^{-1})



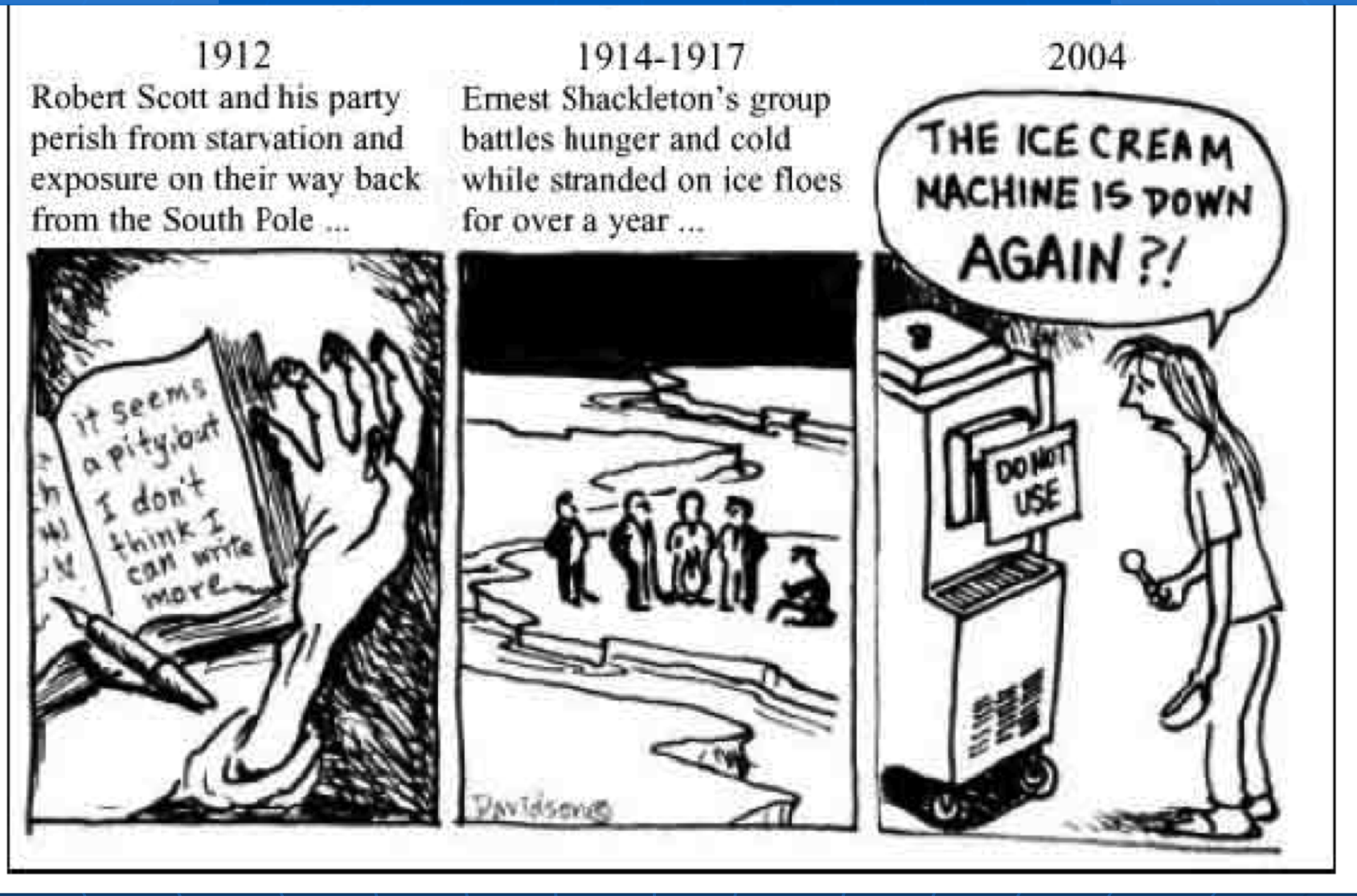
Summary

- We have a 3D ice sheet model (Glimmer-CISM) that can simulate outlet glaciers, ice streams, and ice shelves using either of two higher-order flow schemes.
- The model is nearly ready for coupled climate experiments using CCSM. We plan to do IPCC AR5 experiments with dynamic, higher-order ice sheets (at least Greenland).
- The model is evolving rapidly. Scalable solvers and adaptive grids will make "heroic" (high-resolution, whole-ice-sheet) simulations routine.
- We welcome collaborators, especially for science applications.

Heroic age of Antarctic exploration

Matt Davidson, The Antarctic Sun, 18 Jan. 2004

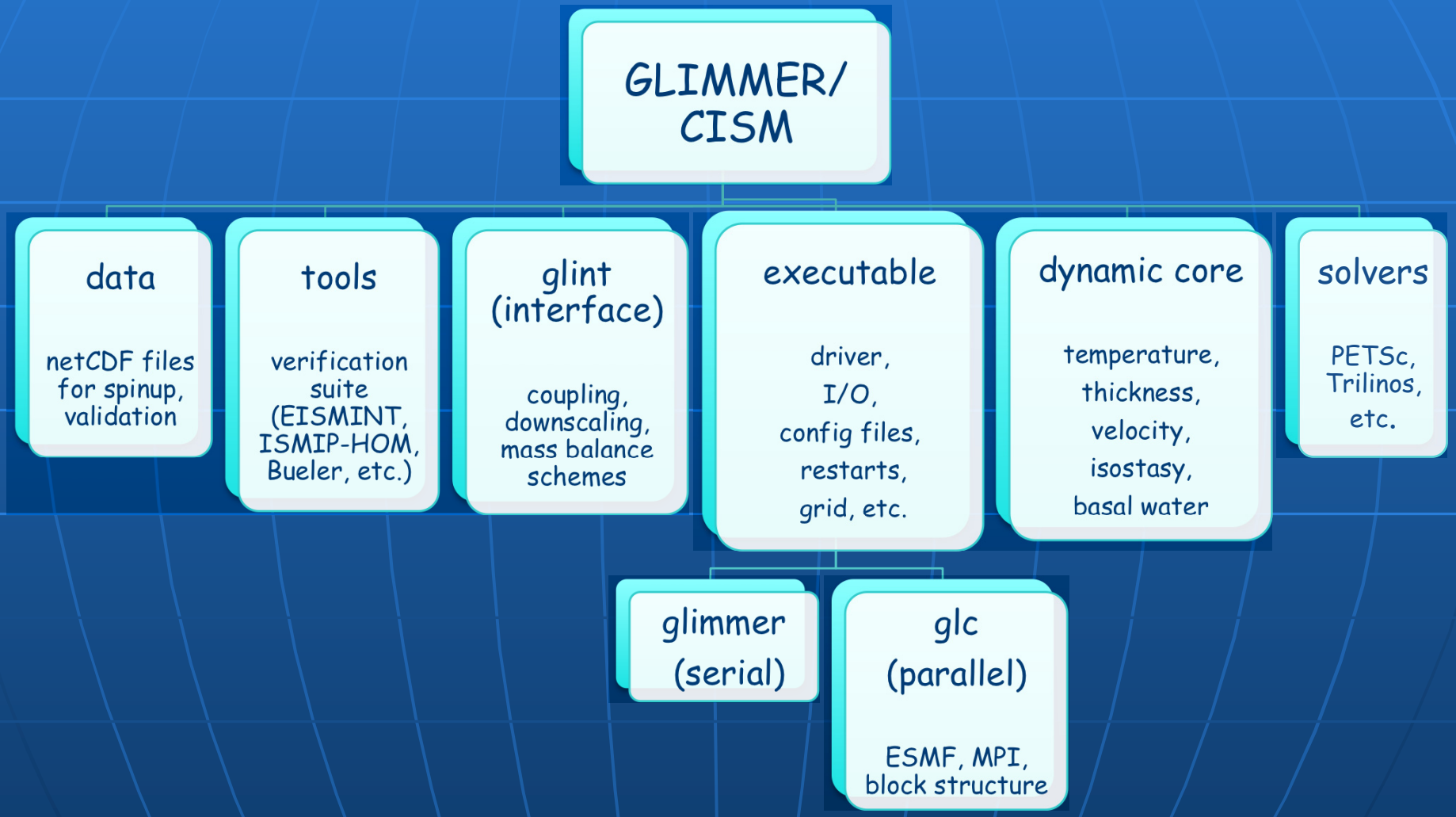
After the heroic age . . .



Matt Davidson, The Antarctic Sun, 18 Jan. 2004

Extra slides

Model framework



Proposed CCSM4 experiments with GLIMMER
(0.9° x 1.25° atm, 1° ocn)

1. Control

- Pre-industrial control, 230+ yrs
- Pre-industrial control, 0.5°, ~100 yrs
- 20th century (1870-2005)

2. IPCC AR5 scenarios

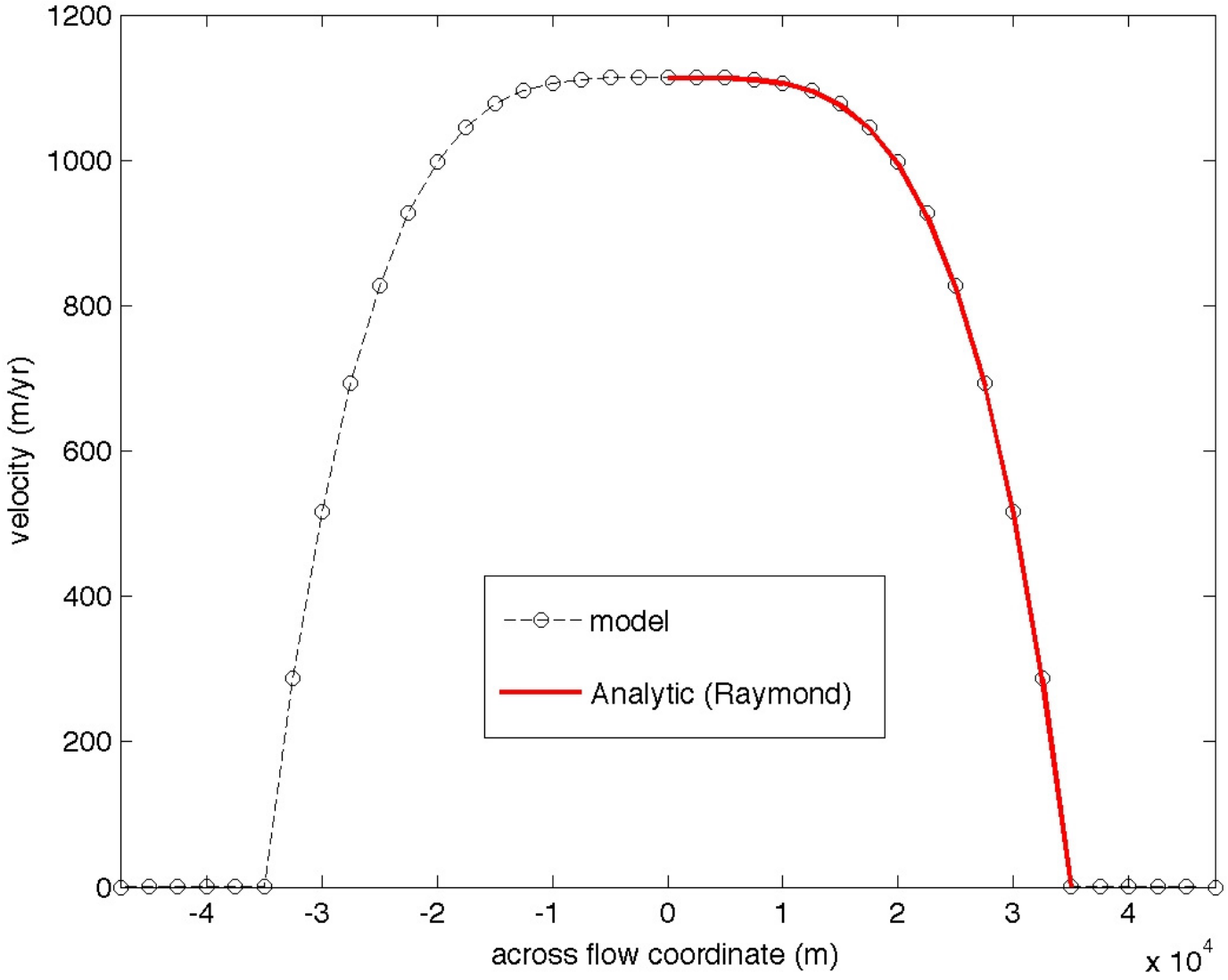
- RCP4.5, 100-300 yrs
- RCP8.5, 100-300 yrs

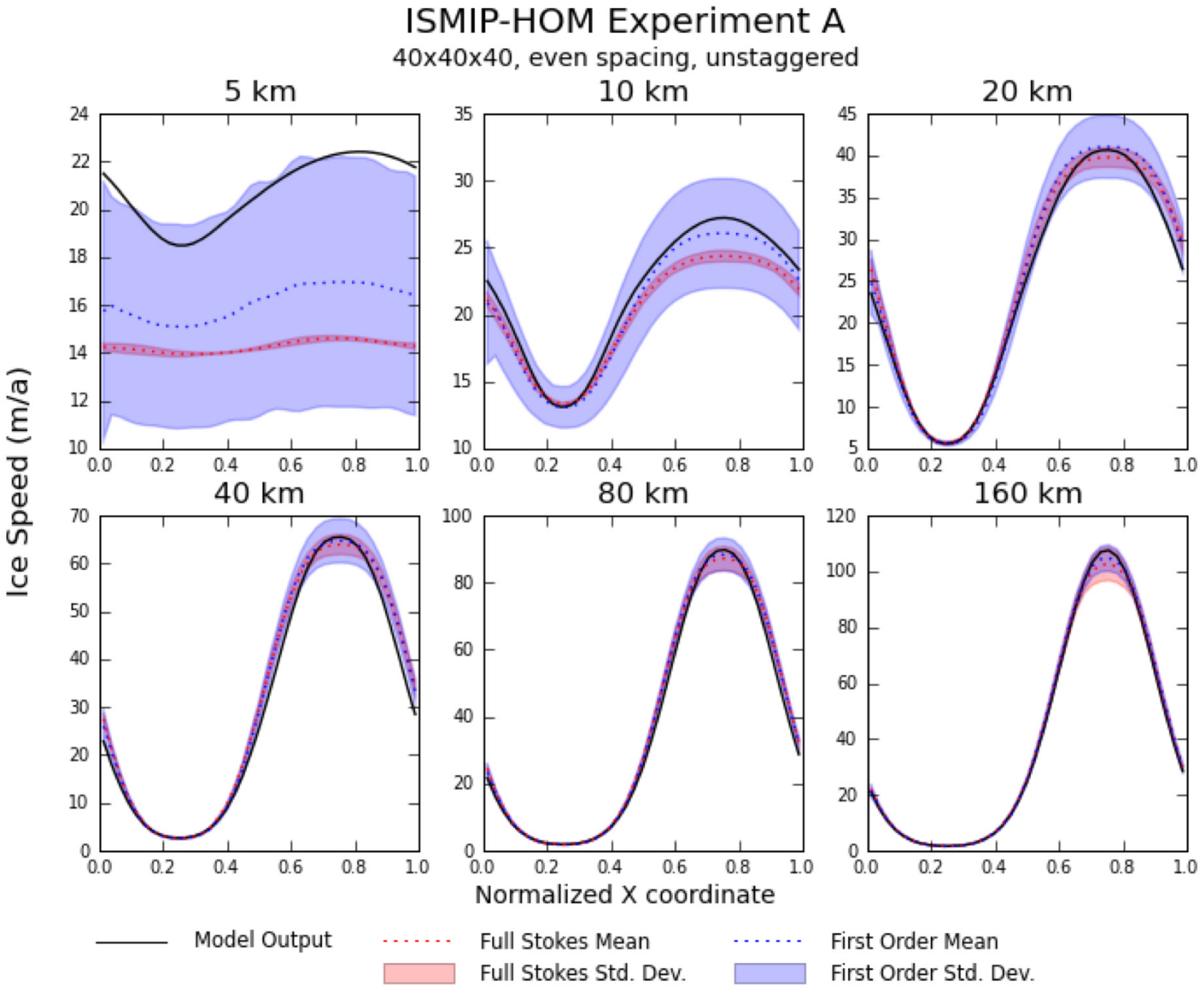
3. Long-term (asynchronous)

- Continuation of RCP4.5, 200 yrs (AOGCM), 2000 yrs (ice sheet)
- Branch runs of RCP4.5 and/or RCP8.5 (study irreversibility)
- Eemian interglacial: 1000 yr AOGCM w/ 10x accelerated Milankovich; 10,000 yr ice sheet

Miren Vizcaino (UC Berkeley) et al. will analyze these runs.

Ice stream dynamics




ISMIP-HOM Experiment A
40x40x40, even spacing, unstaggered
5 km
10 km
20 km
40 km
80 km
160 km
Ice Speed (m/a)
Normalized X coordinate
Model Output
Full Stokes Mean
Full Stokes Std. Dev.
First Order Mean
First Order Std. Dev.

Tuning Statistics