Toward a next-generation community ice sheet model: Progress and plans

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An IPCC-ready ice sheet model

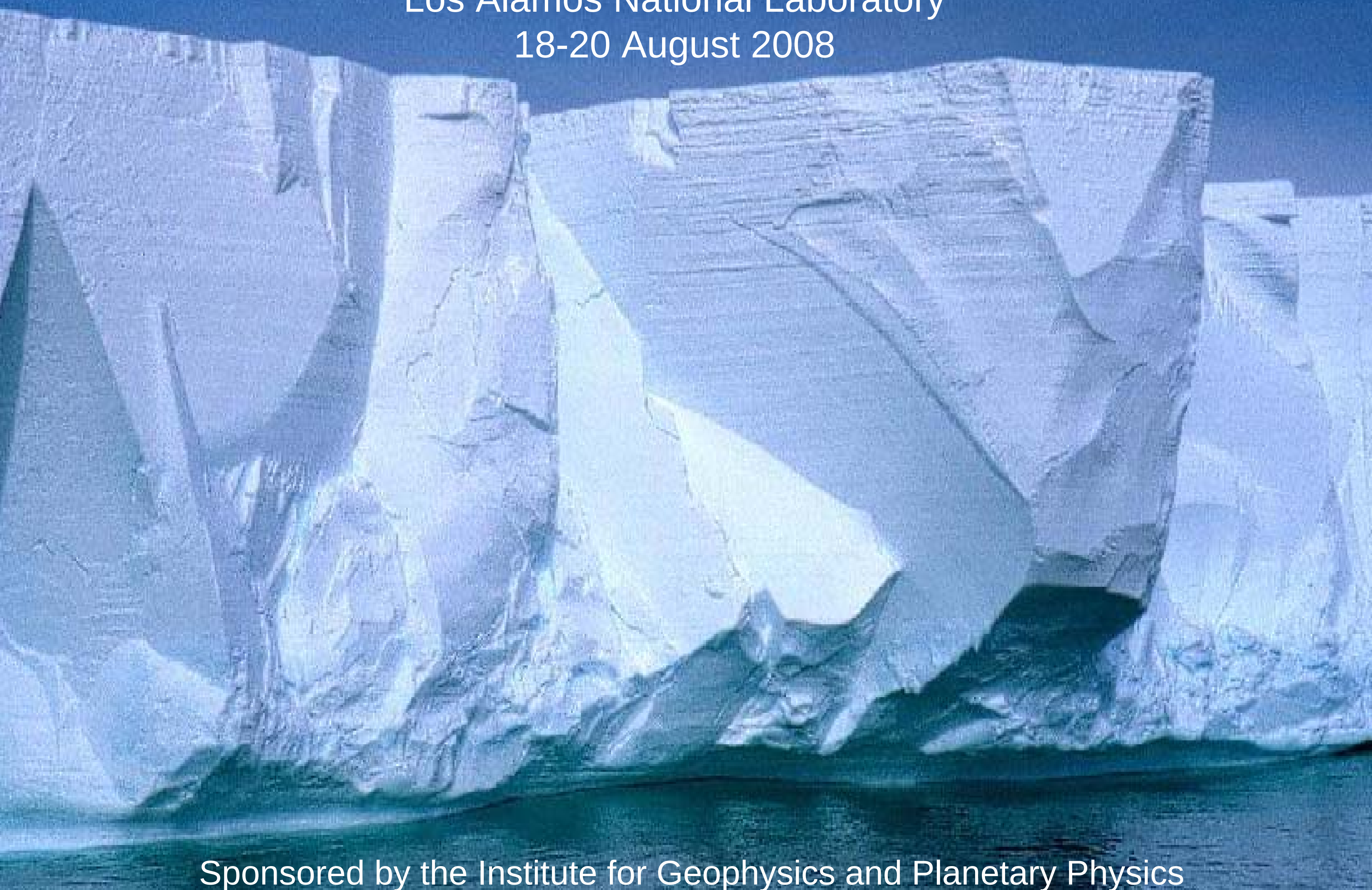
- For climate and sea-level projections it is highly desirable to have **coupled**, **high-resolution**, **whole-ice-sheet** models with **higher-order flow dynamics** and **improved physical processes**.
- Such a model does not exist (although many of the pieces do). How do we get from here to there in time for IPCC AR5?

An ice sheet model for IPCC AR5

- Time is of the essence. We have < 2 years to produce a working model.
  - 2010: Climate change runs
  - 2011: Papers submitted and accepted
  - 2012: Analysis and report-writing
  - 2013: IPCC AR5 scheduled for release

Building a Next-Generation Community Ice Sheet Model

Los Alamos National Laboratory
18-20 August 2008



Sponsored by the Institute for Geophysics and Planetary Physics

Workshop goal

- To create a detailed plan for developing and testing a next-generation **community ice sheet model (CISM)** that can be used for climate and sea level projections.
- This model will serve as the ice sheet component of the Community Climate System Model (CCSM) and will be freely available to the climate and glaciology communities.

Working assumptions

- Ice sheet modelers should say something more definite about ice sheets in AR5 than in AR4.
- The ice sheet modeling community is relatively small. We will succeed only by integrating our efforts and involving a large fraction of the community, including early-career scientists.

Keep it simple

- Higher-order approximations for ice flow; full-Stokes later
- Start on a rectangular grid with ~3 to 5 km resolution and apply brute computational force; adaptive grids later
- Relatively simple physical parameterizations for hydrology, calving, etc.
- One-way coupling with ocean GCM; full coupling later

Write modular code

- Define the essential elements of a dynamical core:
  1. Velocity solver
  2. Mass evolution
  3. Temperature evolution

- Develop standard calling interfaces

- Plug and play different codes that serve the same function (e.g. higher-order velocity solvers).

Steal code

- Use infrastructure from POP and CICE
  (the ocean and sea ice components of CCSM)
  - Built-in MPI communications
  - Block data structure for load balancing and cache optimization
  - Standardized routines for restarts, time management, grid interpolation, coupling, etc.
  - CCSM-compliant
  - Efficient scaling to thousands of processors

Organize

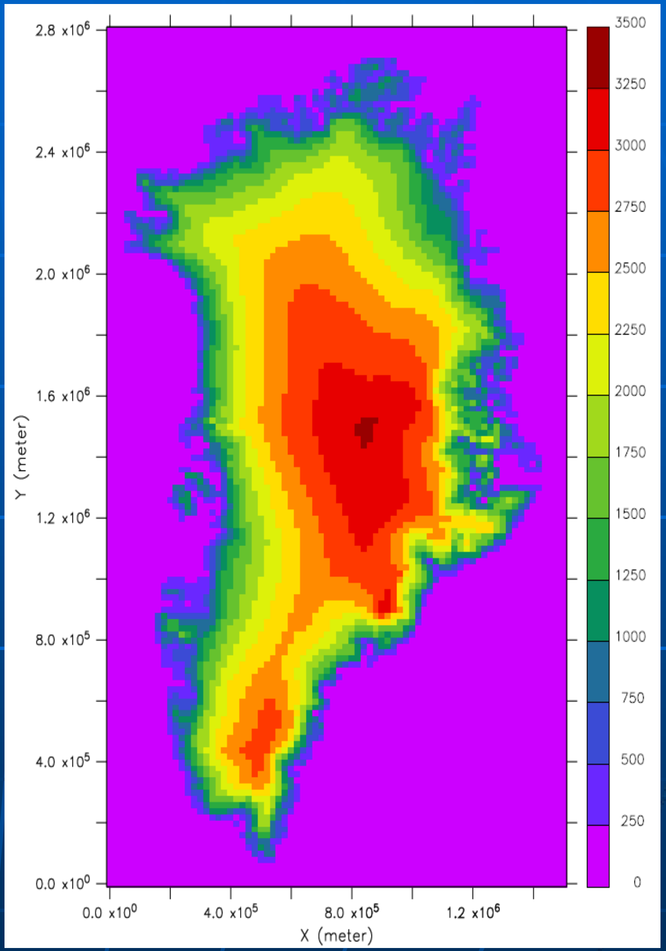
- Identify a group responsible for ongoing CISM development, and meet regularly.
  - CCSM Land Ice working group
- Post-workshop focus groups
  - Software development (Bill Lipscomb)
  - Datasets (Jesse Johnson)
  - Hydrology (Steve Price)
  - Ice-ocean coupling (David Holland)
  - Calving (Christina Hulbe)
  - Assessment (Bob Bindschadler)
- These groups are open to anyone who's interested.

CISM development path

- Modularize GLIMMER and export to CISM framework based on POP/CICE. Couple to CCSM. **(CISM 1.0)**
- Better dynamics **(CISM 1.5)**
  - Shallow-shelf approximation to complement SIA
  - New transport options for non-diffusive flow
- Much better dynamics **(CISM 2.0)**
  - Higher-order flow model
  - Basal hydrology
  - Sub-shelf ocean circulation
  - Stable, accurate grounding line migration
  - Stable calving law
- Fully coupled to ocean GCM

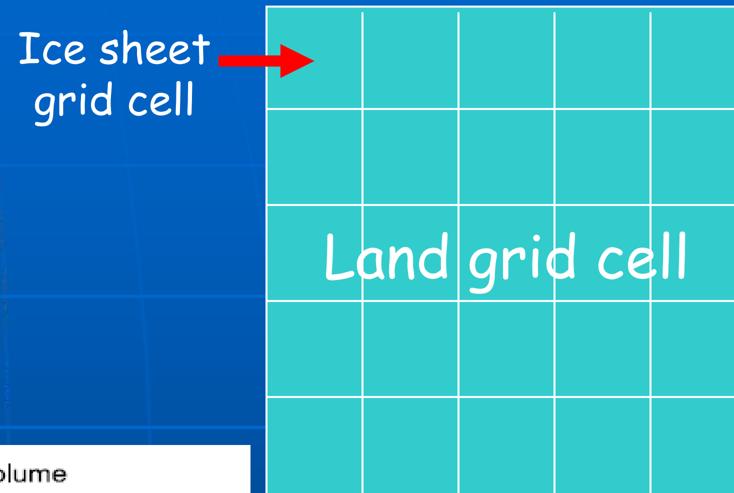
Coupling an ice sheet model to CCSM

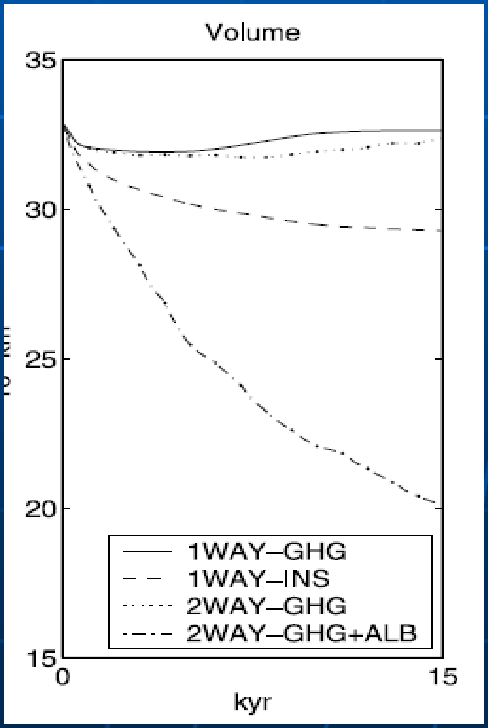
- I have coupled the GLIMMER ice sheet model to the Community Climate System Model (CCSM).
- In the CCSM land model I have implemented a surface mass balance scheme for land ice.
- This fall we will test and tune the mass balance scheme in coupled simulations.
- The goal is to get a realistic present-day Greenland ice sheet as a starting point for climate-change experiments.



Surface mass balance in CCSM

- We are computing the surface mass balance in the land model (CLM) on a coarse (~100 km) grid in ~10 elevation classes.
- The mass balance is then interpolated to the fine (~10 km) ice sheet grid.
  - Energetic consistency
  - Cost savings (~1/10 as many columns)
  - Avoid code duplication
  - Surface albedo changes feed back on the atmosphere





Laurentide deglaciation

(Pritchard et al. 2008)

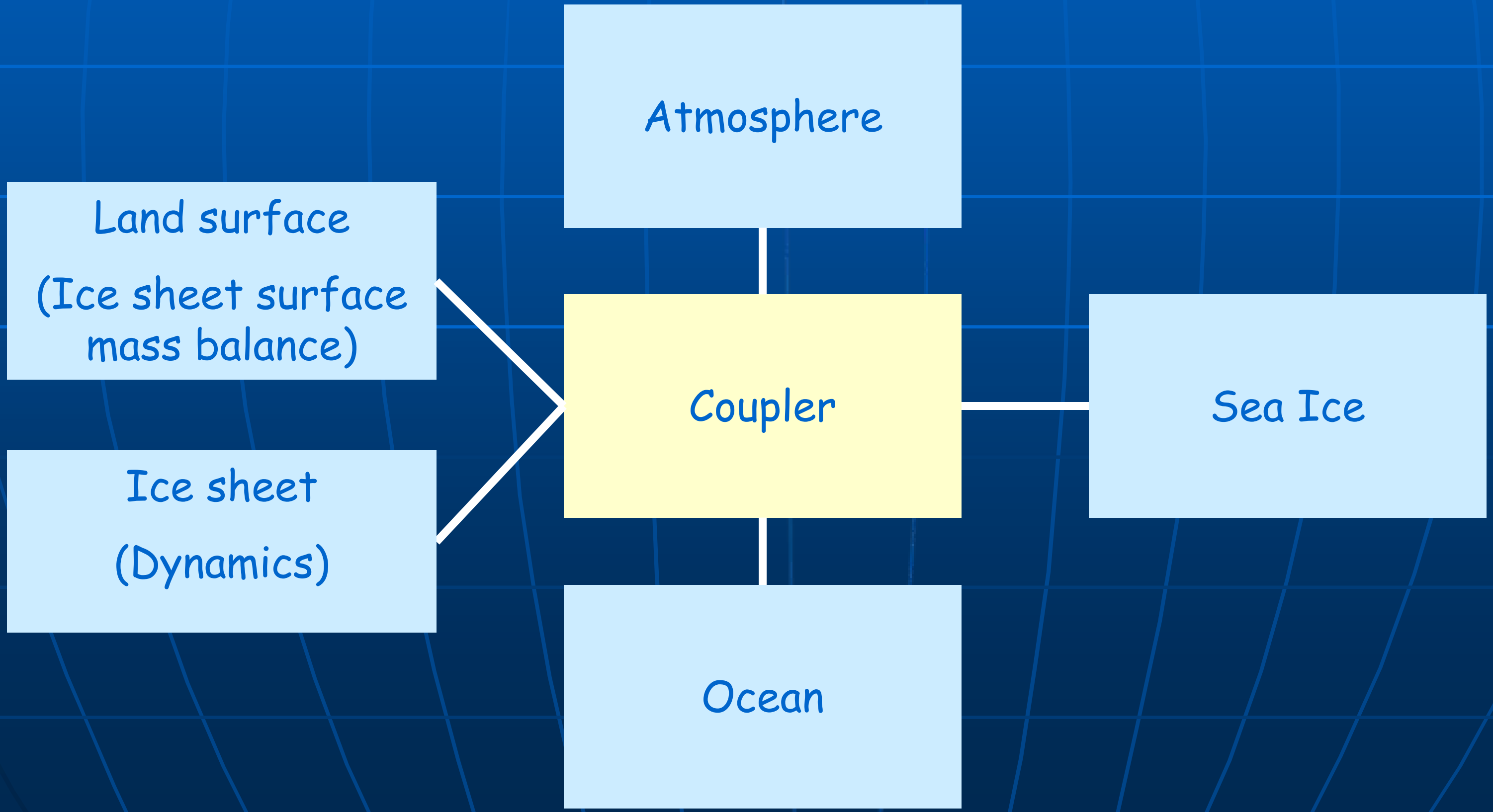
Ice sheet coupling in CCSM

Land -> Ice sheet (10 classes)

- surface temperature
- surface elevation
- ice surface mass balance

Ice sheet -> Land (10 classes)

- ice fraction, elevation, thickness
- runoff/calving flux
- heat flux to surface



Higher-order stress balance

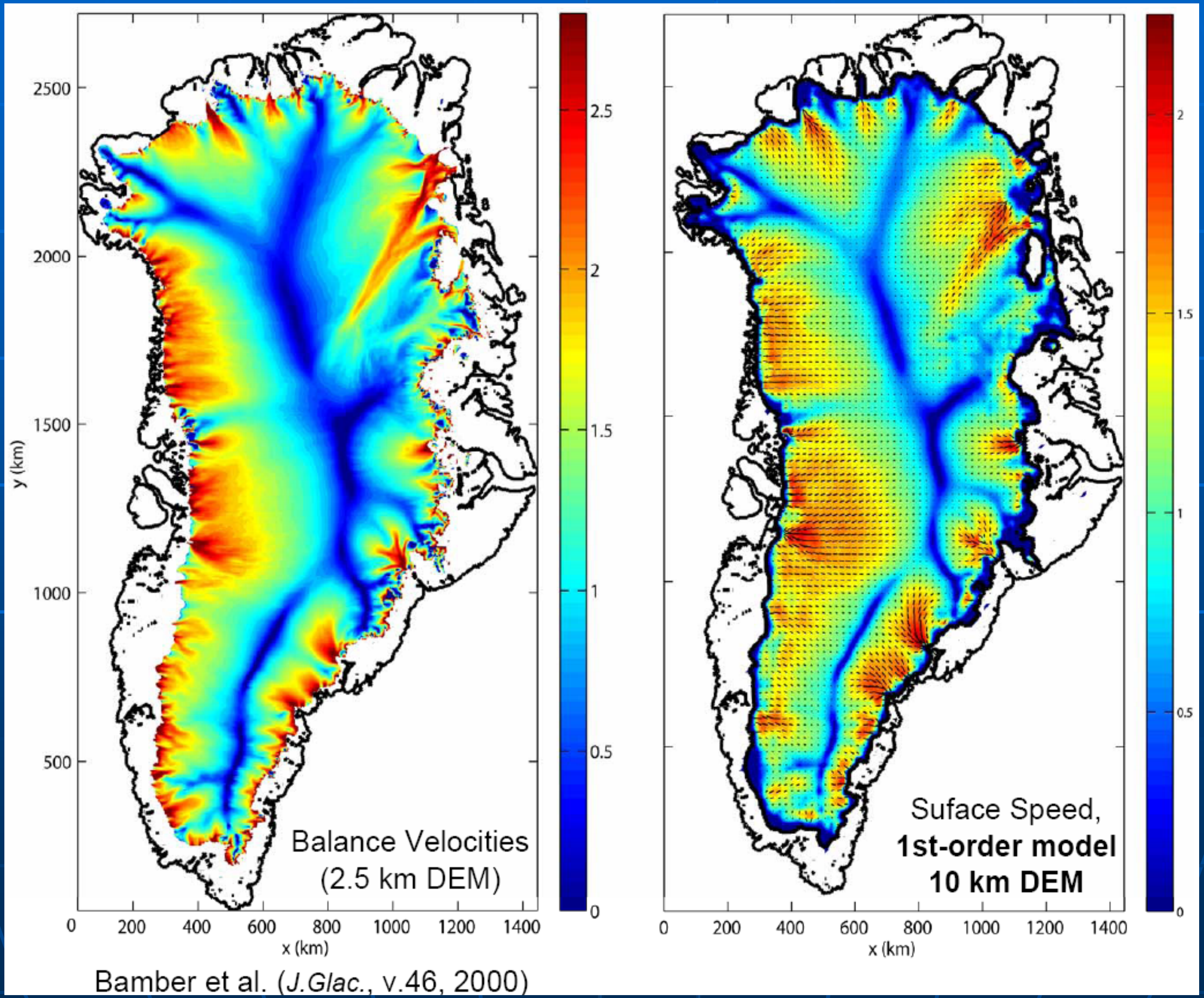
$$x: \quad \frac{\partial \tau_{xx}}{\partial x} - \frac{\partial P}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z} = 0$$

$$y: \quad \frac{\partial \tau_{yy}}{\partial y} - \frac{\partial P}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yz}}{\partial z} = 0$$

$$z: \quad \frac{\partial \tau_{zz}}{\partial z} - \frac{\partial P}{\partial z} + \cancel{\frac{\partial \tau_{zy}}{\partial y}} + \cancel{\frac{\partial \tau_{xz}}{\partial x}} = \rho g$$

Blatter (1995), Pattyn (2003)

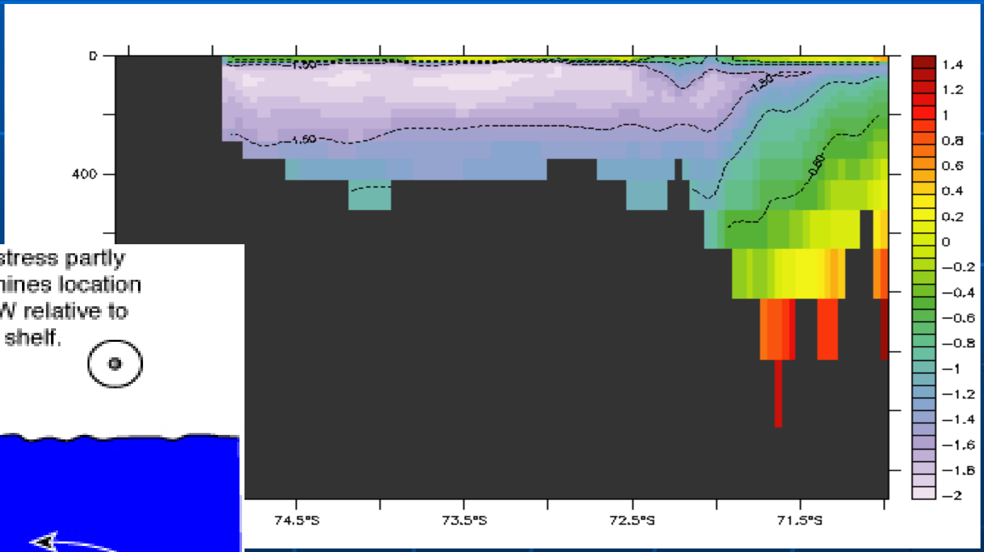
Diagnostic Greenland velocities

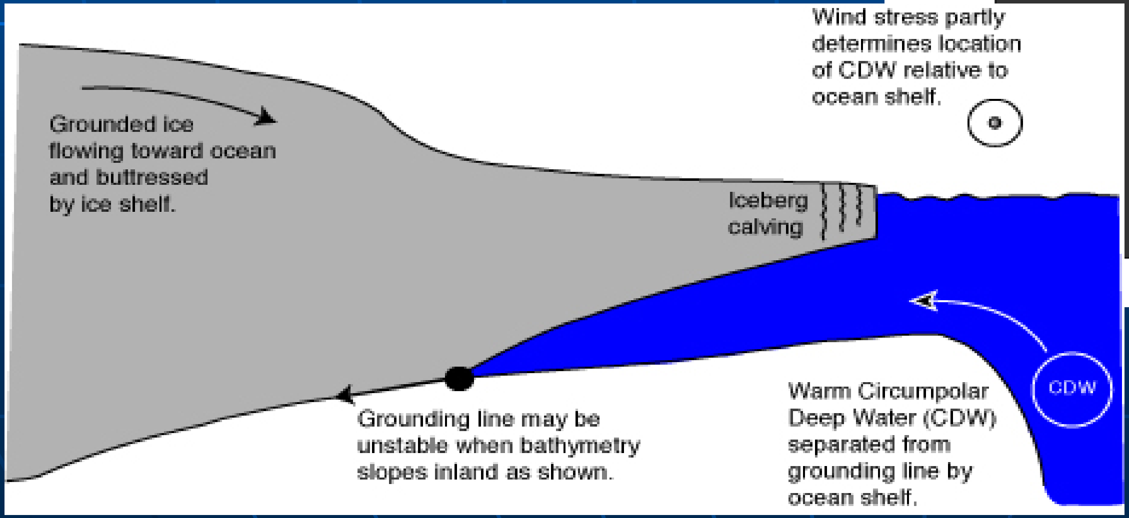


Price and Payne, in prep.

Ice-ocean coupling

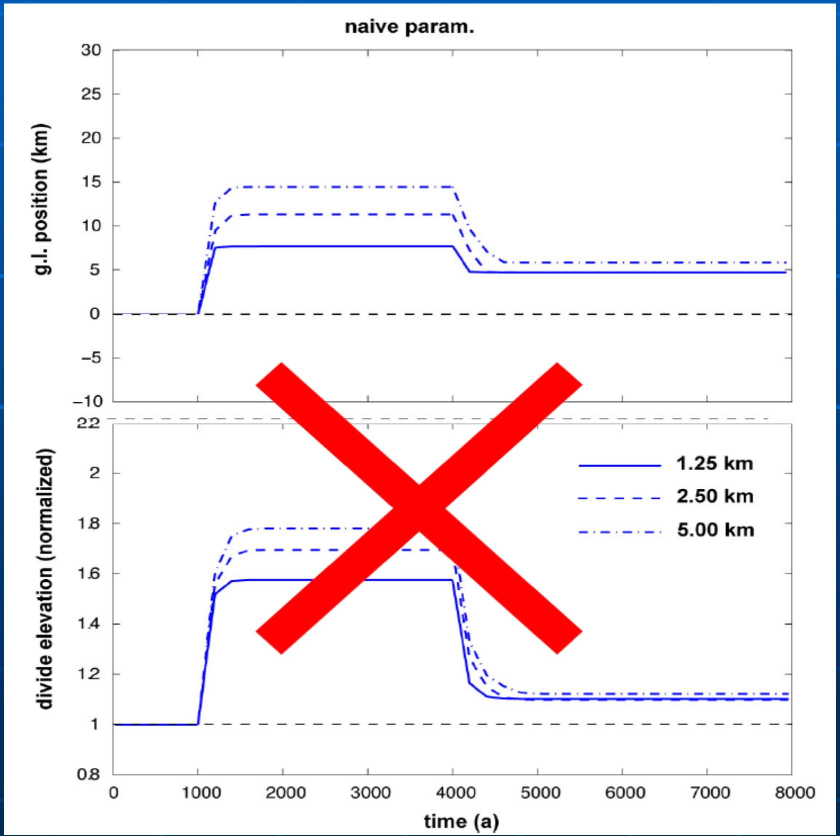
- We recently received funding to model ocean-ice shelf interactions that could trigger marine ice sheet instability (part of DOE multi-lab proposal on abrupt climate change).
  - We will develop a high-resolution (~5 km) regional ice sheet/shelf – ocean model, using HYPOP to model subshelf ocean circulation.



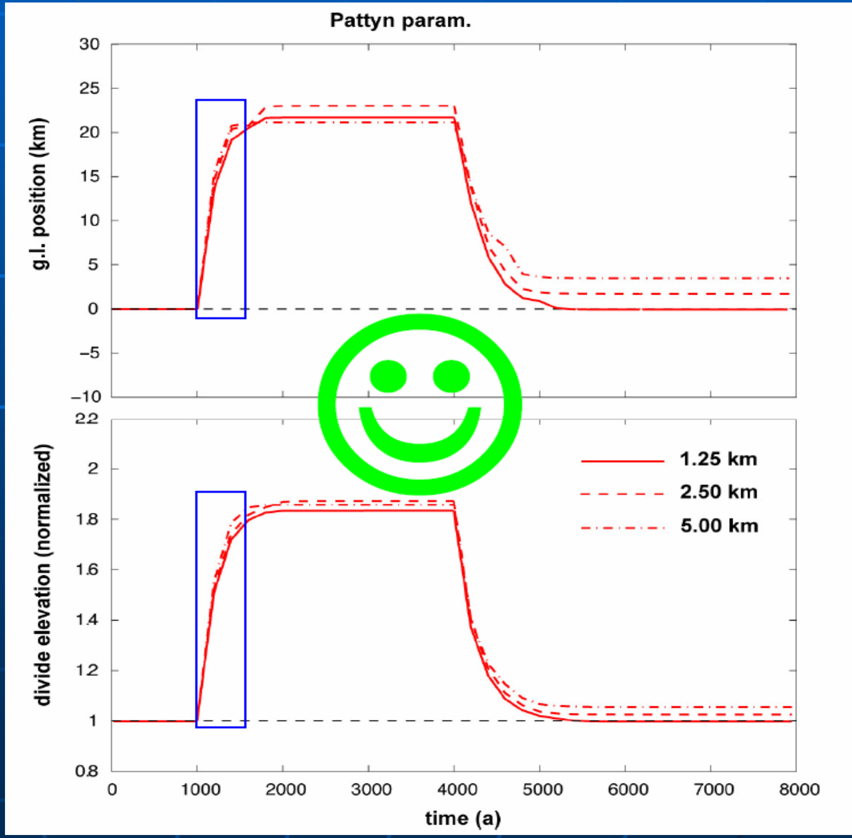


Grounding line migration

We would like to parameterize basal boundary conditions in a way that leads to "*reasonable*" grounding line behavior in large-scale models on structured, fixed grids (at least in the regions we care about).



"Naïve" floating criterion



Linear interpolation (Pattyn et al. 2006)

Summary

- To optimize our contribution to AR5, we will need to develop relatively mature ice sheet models on a very short time scale.
- This may be possible (even fun) if we're well organized, if we adapt existing codes, and if we're not perfectionists.
- Your participation and suggestions are welcome!