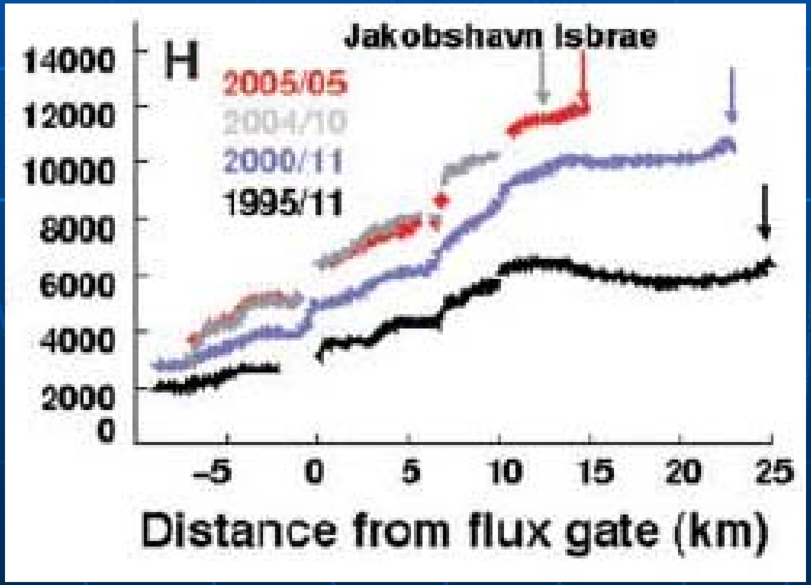
A New Ice Sheet Model for CCSM
Part 1: Surface mass balance and coupling

William Lipscomb
Los Alamos National Laboratory

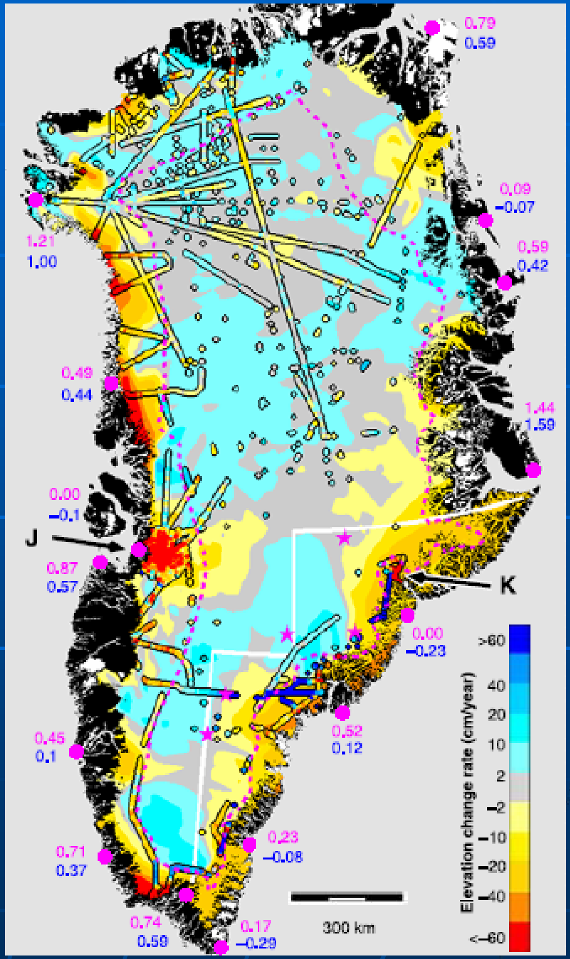
17 June 2008

Ice sheet mass balance: Greenland

- Significant and increasing mass loss (~100-200 Gt/yr) since late 1990s
- Attributed to increased surface melting (well understood) and to accelerating outflow from large outlet glaciers (not well understood)



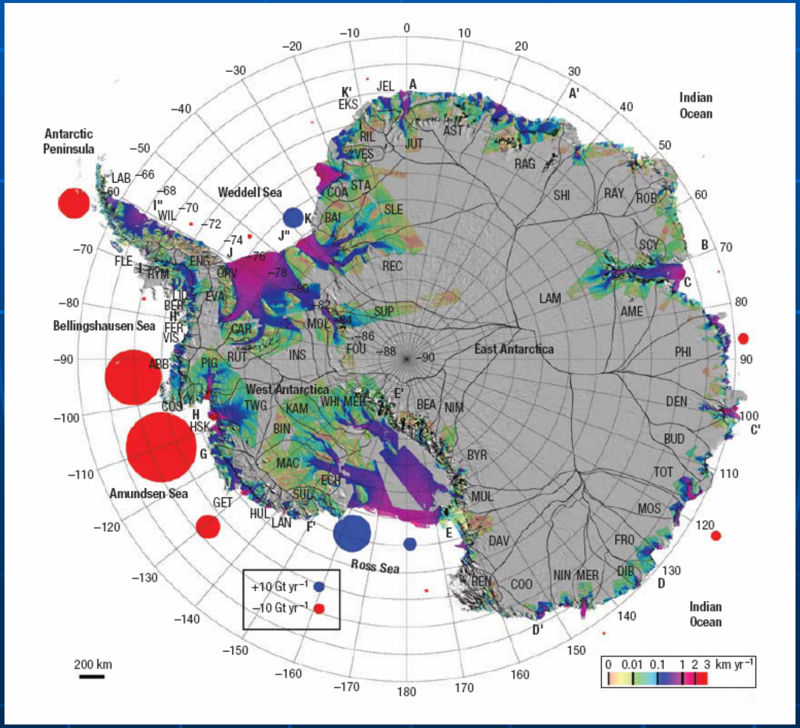
Rignot & Kanagaratnam (2006)



Ice elevation changes
Krabill et al. (2004)

Ice sheet mass balance: Antarctica

- Ice discharge estimates suggest a loss of ~200 Gt/yr from West Antarctica and the Antarctic Peninsula, with East Antarctica nearly in balance.
- Large losses are associated with the acceleration of outlet glaciers in the Amundsen Sea embayment, likely forced by the ocean.

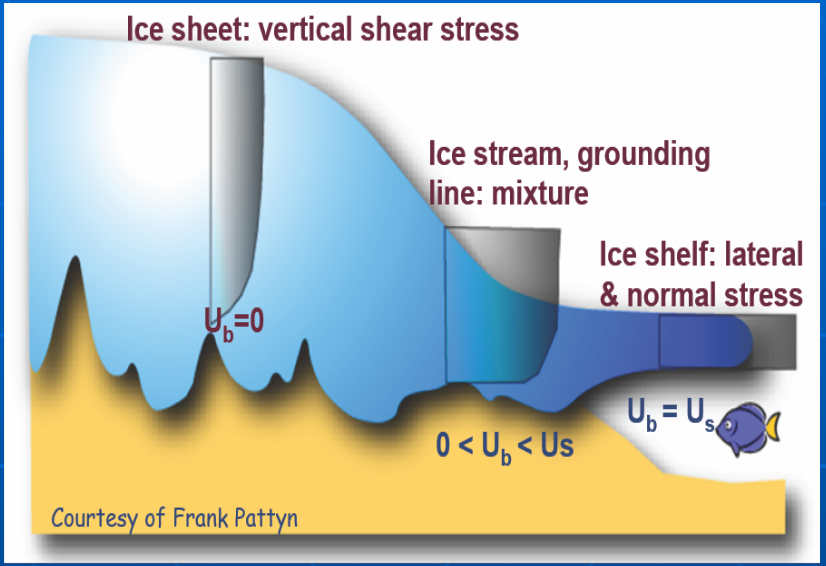


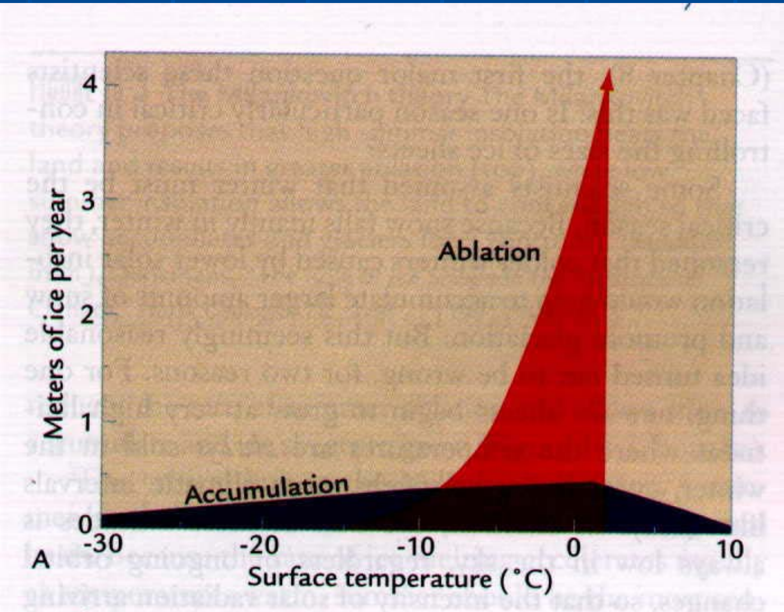
Rignot et al. (2008)

Improving ice sheet models

- Current ice sheet models are missing key **dynamic** processes that control fast flow in ice streams and outlet glaciers. Better flow models are needed. (Part 2: Steve Price)

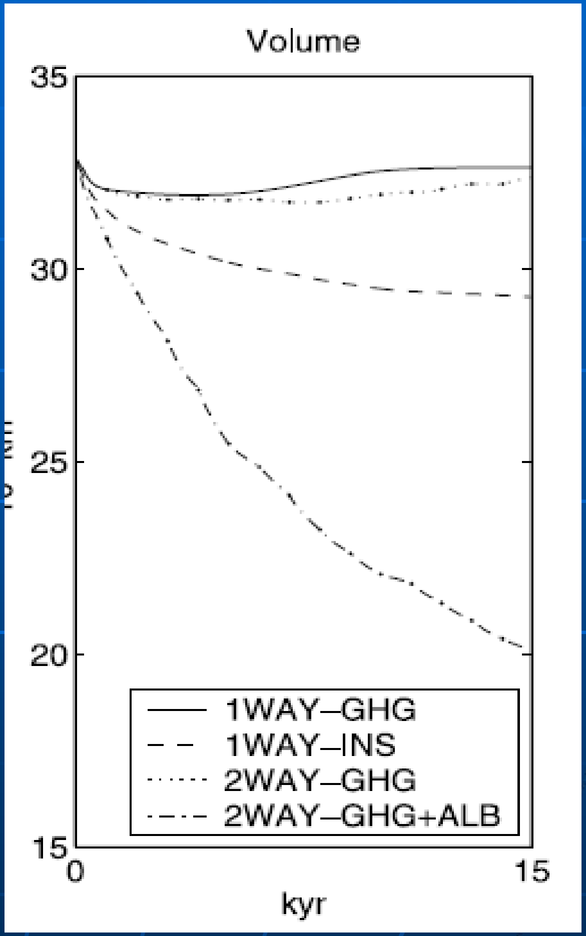
- We also need better models of the **surface mass balance**.
    - Accumulation increases with temperature.
    - Ablation increases strongly with temperature near the melting point and is critical to the mass balance (and possibly the dynamics).





Surface mass balance for climate change studies

- Many studies (e.g., Ridley et al. 2005) have computed ice-sheet surface ablation using a **positive-degree-day** (PDD) scheme based on present-day empirical parameters.
- For climate predictions it is better to use a **surface-energy-balance** scheme.
- A recent study (Pritchard et al. 2008) shows that surface albedo feedbacks from ice sheets warm the atmosphere and increase the rate of melting. These feedbacks need to be included during runtime.



Laurentide volume change

Pritchard et al. (2008)

Surface mass balance in CCSM

- Traditional approach: Pass surface radiation and temperature fields to the ice sheet model and compute the mass balance on the fine (~10 km) ice sheet grid.

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

We have introduced a new landunit type, ***glacier_mec*,** in addition to soil, glacier, wetland, urban, lake.

Glacier_mec landunits need not be associated with a dynamic ice sheet model.

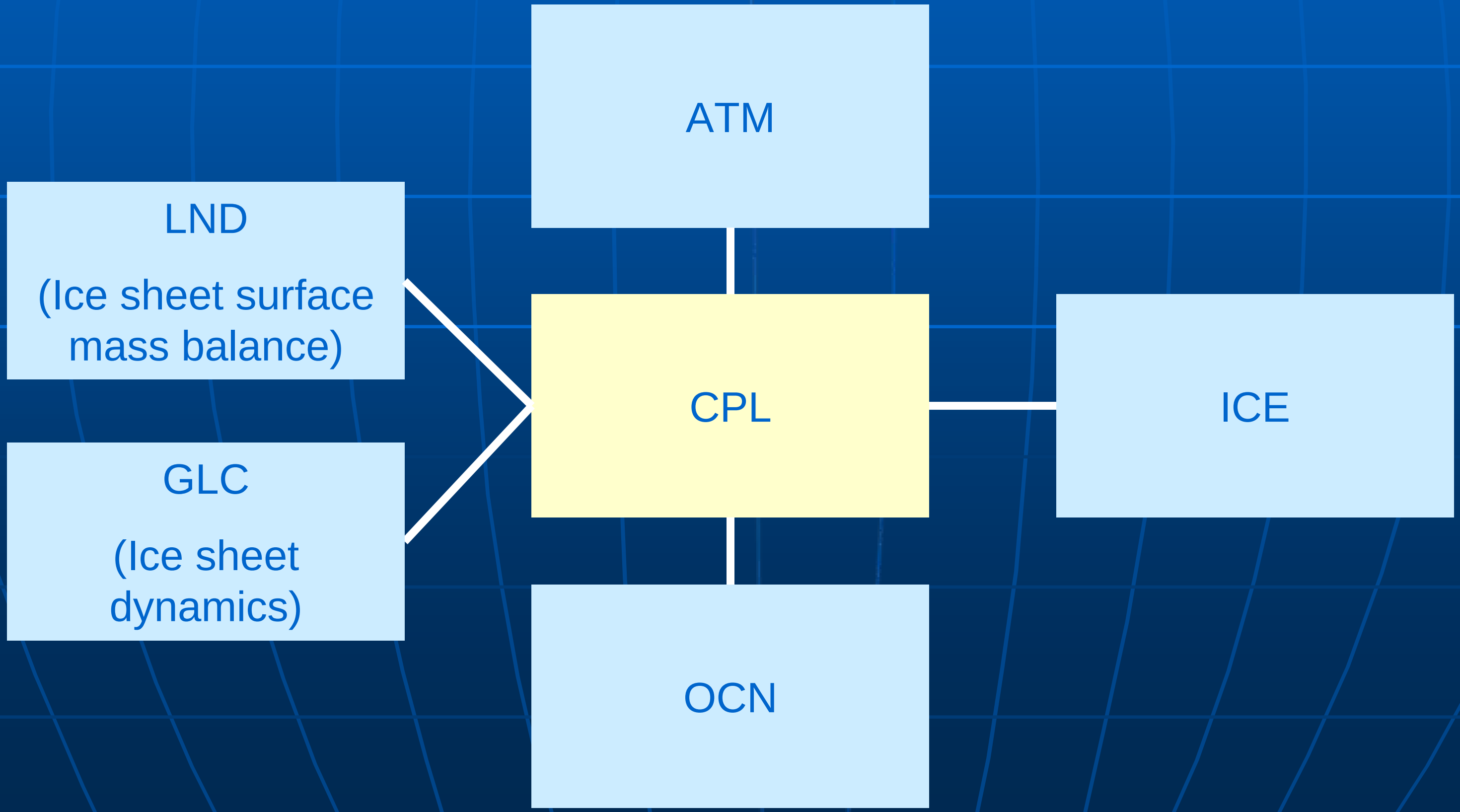
Ice-sheet coupling in CCSM

LND-> GLC (10 classes)

- surface temperature
- surface elevation
- ice accumulation/ablation

GLC -> LND (10 classes)

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



Two modes of coupling

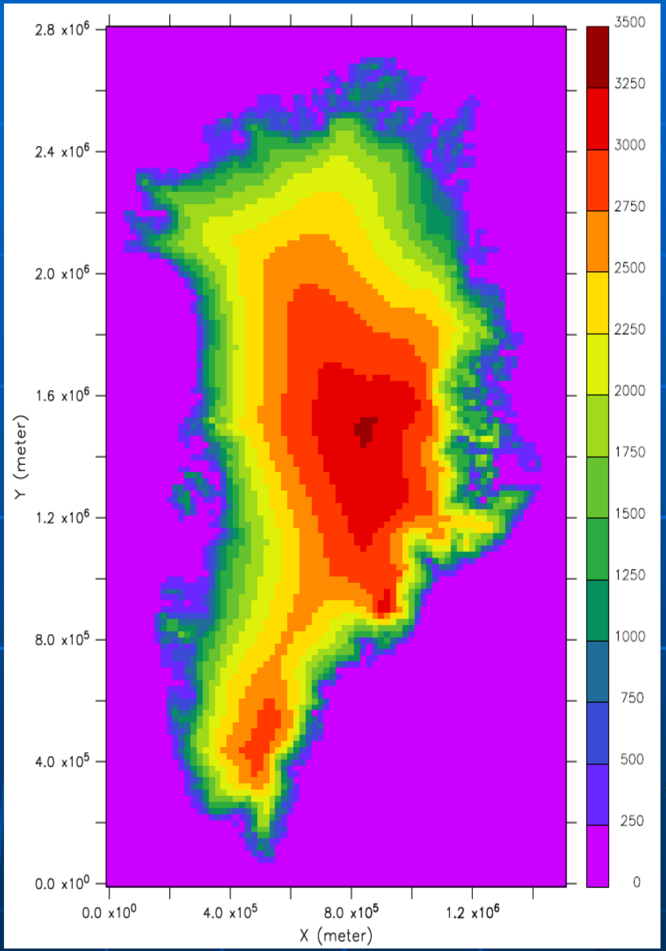
- **One-way coupling:**
  - CLM passes the surface mass balance to GLC, but land topography is fixed.
  - Ice sheets evolve dynamically. Accuracy of forcing fields is not much affected if changes in elevation and extent are small.
- **Two-way coupling:**
  - The CLM/CAM surface topography changes as the ice sheet evolves.

Issues:

- CLM landunits are fixed over time. What if the ice-sheet and land models disagree about where ice is present?
  - Create virtual glacier_mec cells in CLM with zero area; compute surface mass balance and pass to GLC without affecting CLM/CAM.
  - Initialize all of Greenland or Antarctica as glacier_mec; treat ice-free regions as bare rock.

Progress and plans

- We have coupled the GLIMMER ice sheet model to CCSM.
- We have implemented in CLM a surface mass balance scheme with multiple elevation classes for land ice.
- This summer we will test and tune the surface mass balance scheme in fully coupled simulations (pre-industrial and present-day).
- The goal is to get a realistic present-day Greenland ice sheet as a starting point for climate-change experiments.



More plans

- By September: Have an ice-sheet model ready for CCSM4
  - Land-ice changes merged into main version of CLM
  - Coupling using cpl7
  - GLIMMER ice-sheet dynamics
  - Greenland climate change experiments
- Longer term:
  - Parallel ice sheet model with improved dynamics
  - Coupled ice-sheet—ocean interactions
  - Experiments with Antarctic and paleo ice sheets

Division of labor

- I am funded by DOE to work fulltime on ice-sheet model development, including CCSM coupling and improved dynamics.
- Steve Price is working on first-order dynamics (GLAM model), improved basal physics, and science applications.
- Todd Ringler and Mat Maltrud will work on ocean model development and ice-ocean coupling as part of the abrupt climate change project. We will also hire a postdoc for this project (to be advertised soon).
- We have a number of outside collaborators:
  - Tony Payne (U. Bristol): ice sheet model development
  - David Holland (NYU): ice shelf—ocean interactions
  - Jesse Johnson (U. Montana) et al.: community model
  - We will meet with potential collaborators at an upcoming LANL workshop, *Building a Next-Generation Community Ice Sheet Model*, 18-20 August 2008.

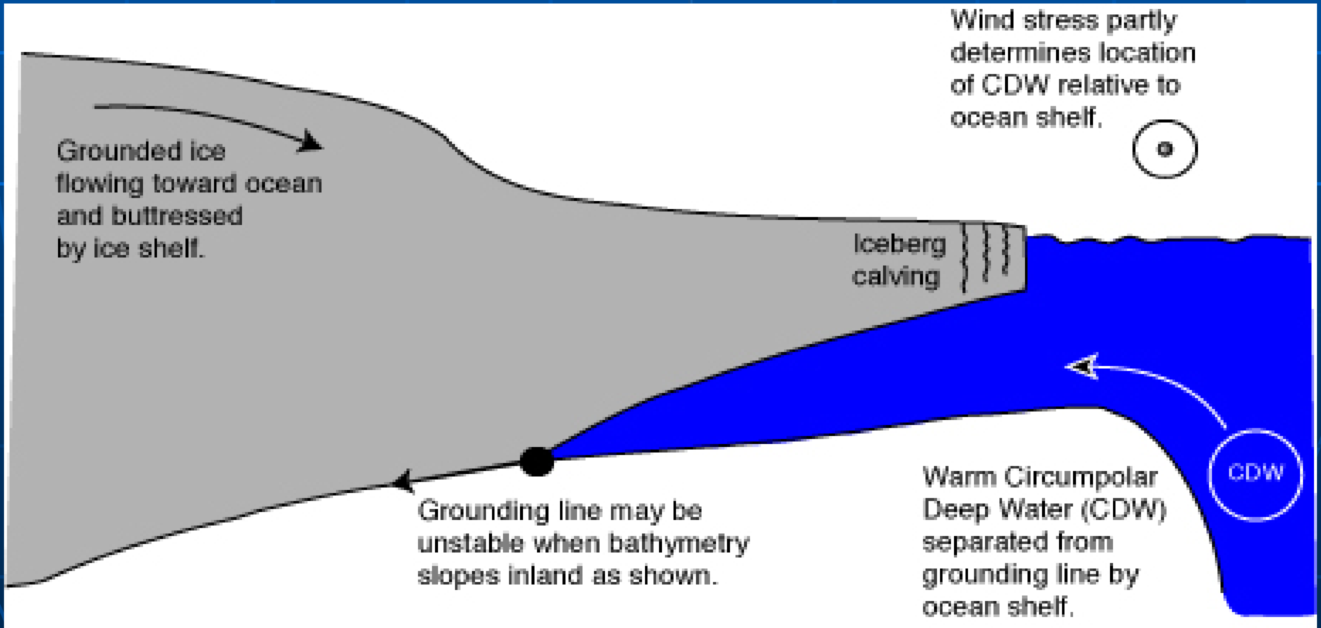
NCAR Acknowledgments

- Lawrence Buja
- Tony Craig
- Erik Kluzek
- David Lawrence
- Sam Levis
- Keith Oleson
- Haiyan Teng
- Mariana Vertenstein
- Jon Wolfe

Extra slides

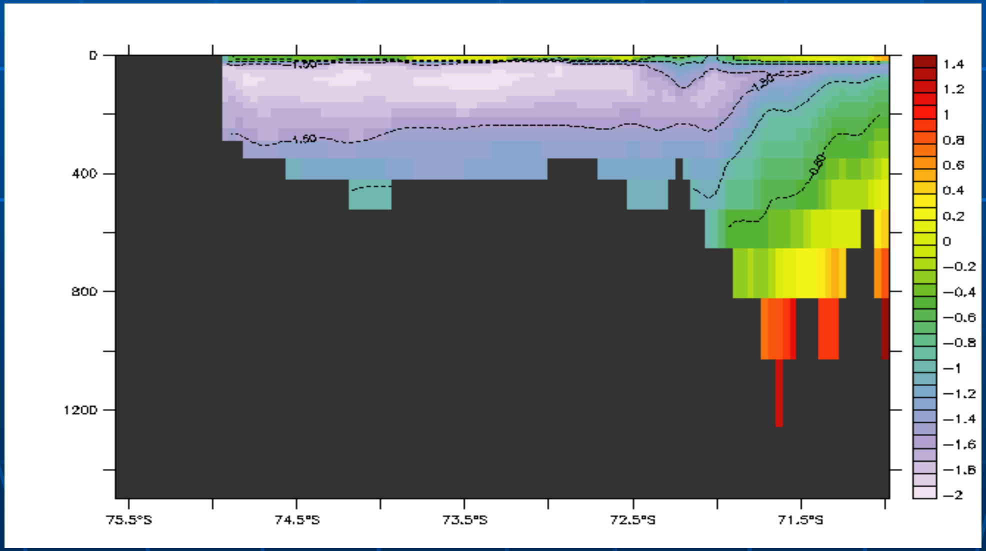
Abrupt ice sheet retreat in Antarctica?

- Recent mass losses in West Antarctica have been attributed to intrusions of warm Circumpolar Deep Water beneath small ice shelves, leading to reduced buttressing of grounded ice.
- There is theoretical evidence (Schoof 2007) for marine ice sheet instability in regions where the sea bed slopes downward in the inland direction, as is true for much of the West Antarctic ice sheet (~5 m sea level equivalent).



Abrupt ice sheet retreat

- 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.
  - This model could ultimately be added to CCSM.



Near-surface ocean density structure in Amundsen Sea, from POP ocean model

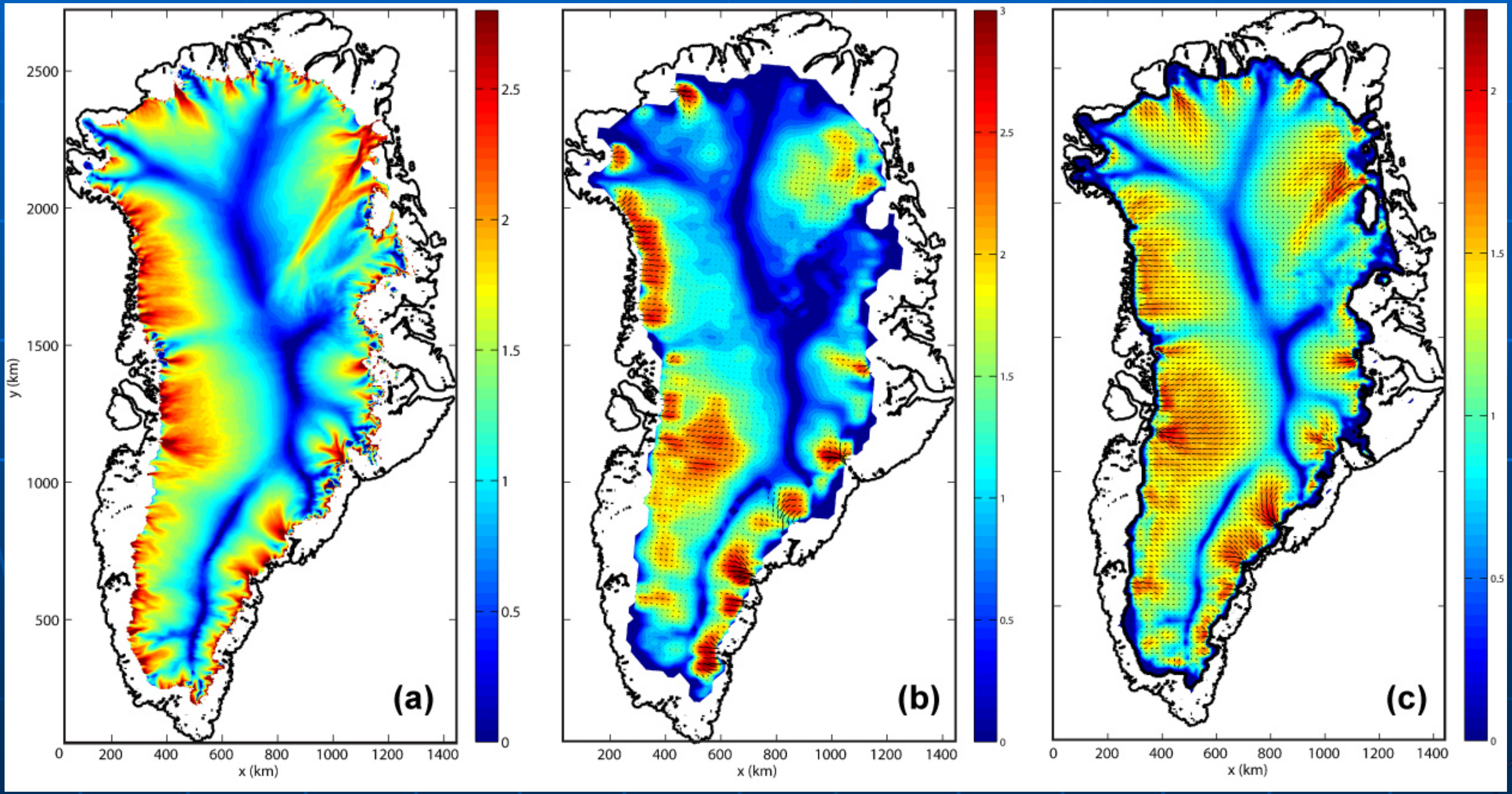
Ice sheet model development

We are developing a next-generation ice-sheet model:

- **Beyond the shallow-ice approximation**: All stresses (vertical shear as well as lateral and longitudinal) will be included in a unified way.
- **High resolution**: ~5 km or less (parallel codes, possibly with variable-resolution grids)
- **Improved basal physics**: subglacial water transport, plastic till deformation
- **Ice-shelf ocean interactions**: subshelf melting, iceberg calving, grounding line migration
- **Fully coupled** in CCSM

Ice sheet model development

- We are testing an improved "first-order" ice sheet model (Payne and Price) that will be used for Greenland climate change experiments.



Steady-state surface speed predicted for Greenland. (a) From remote sensing observations. (b) Zero-order flow model. (c) First-order flow model.

Ice sheets and sea level rise

- Global sea level is rising by ~30 cm/century
  - Thermal expansion: ~16 cm/century
  - Glaciers and ice caps: ~ 8 cm/century
  - Ice sheets: ~4 cm/century
- IPCC 2007: Sea level will rise by ~18-59 cm in the 21st century, excluding "rapid dynamical changes in ice flow."
- Understanding of ice sheet dynamic effects "is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise."