Ice Sheet Modeling Update

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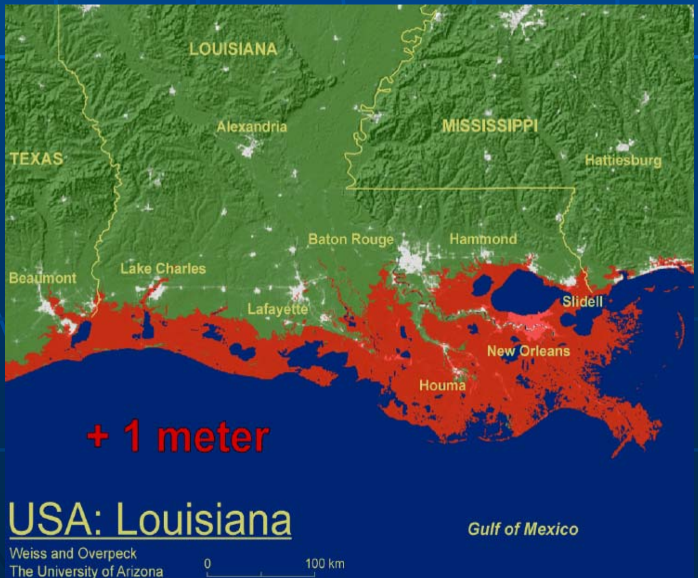
CCSM Polar Climate Working Group, 17 January 2008

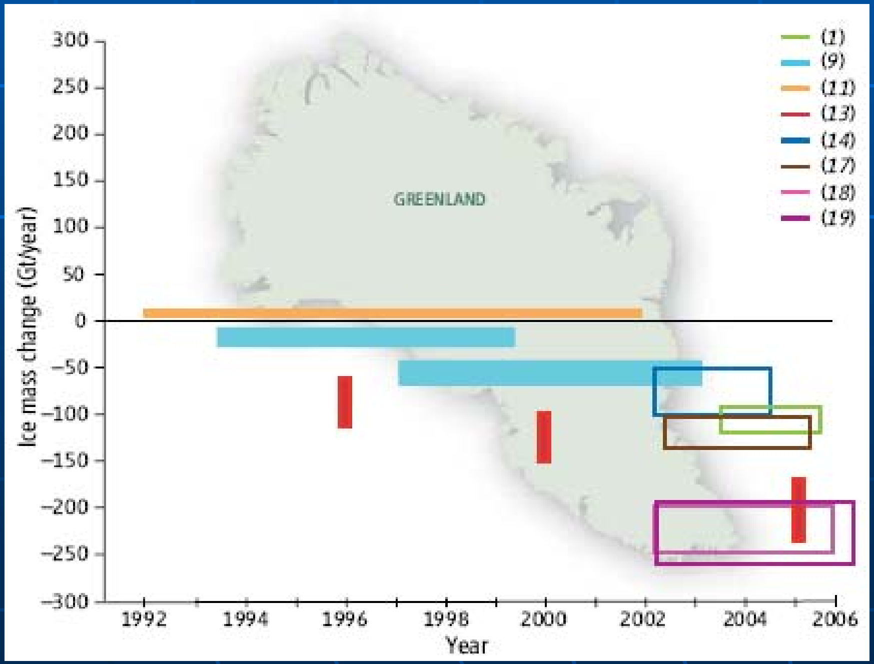
IPCC and sea level rise

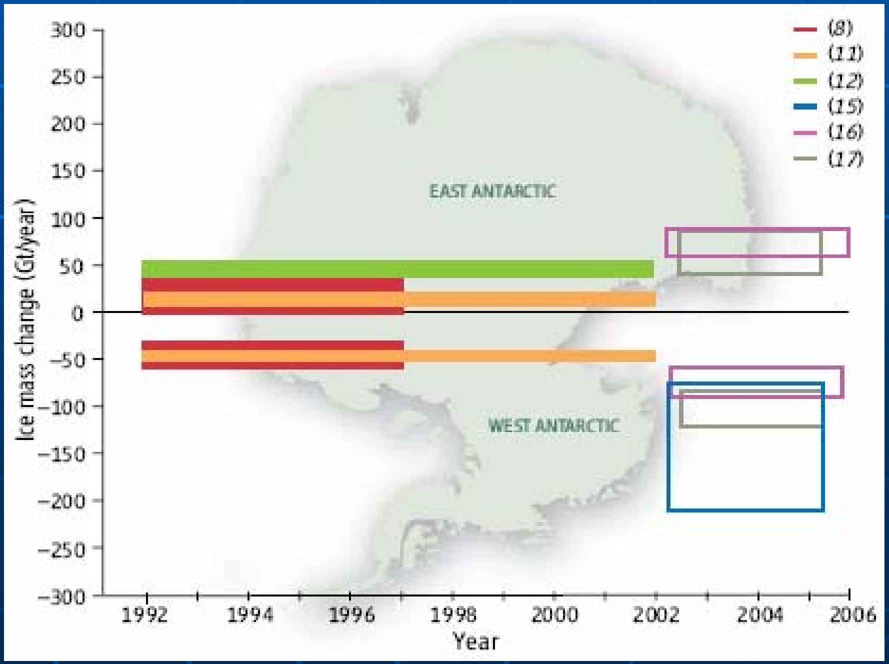
- Global sea level rose by ~31 cm/century, 1993-2003
  - Thermal expansion: ~16 cm/century
  - Glaciers and ice caps: ~ 8 cm/century
  - Ice sheets: ~4 cm/century
- Sea level will rise by ~18-59 cm in the 21st century, excluding "rapid dynamical changes in ice flow."
- Understanding of ice sheet dynamic effects "is too limited to assess their likelihood or provide a best estimate or an upper bound for sea level rise."



Ice sheet mass balance

- **Greenland**
  - Significant mass loss (~100-200 Gt/yr) since late 1990s; increased discharge from large outlet glaciers
- **Antarctica**
  - Loss of ~50-100 Gt/yr in West Antarctic; ice streams in Amundsen Sea embayment have accelerated and thinned
  - Small mass gain (~0-50 Gt/yr) in East Antarctica

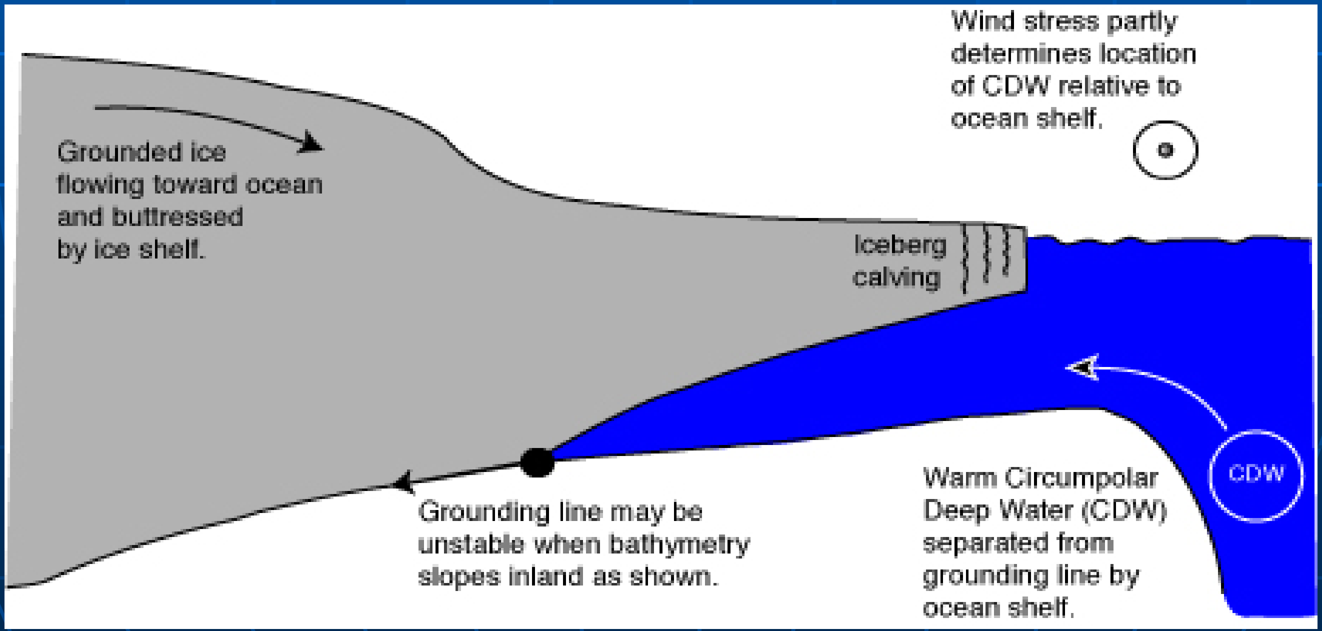




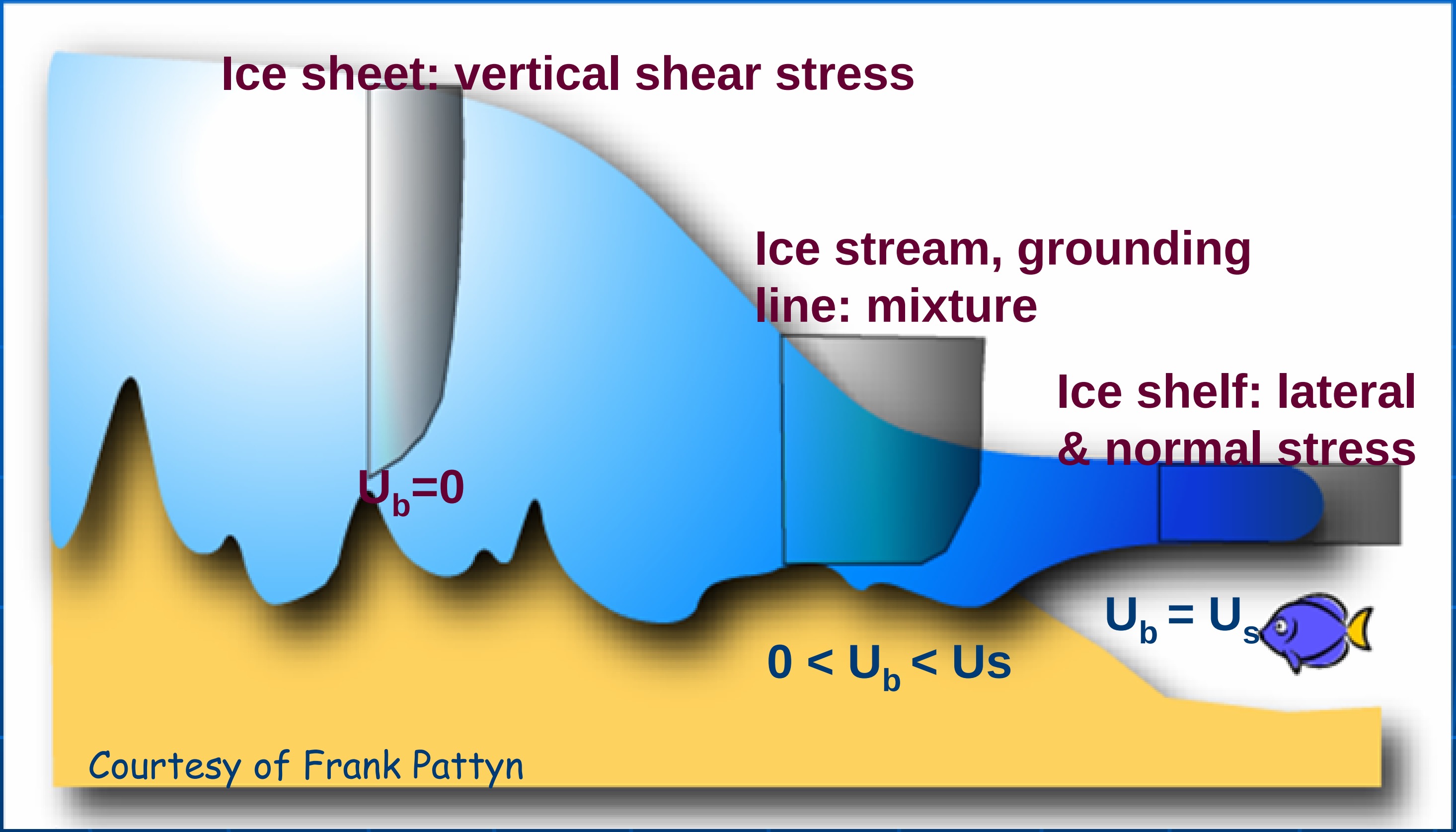
Cazenave, 2006

Abrupt ice sheet retreat in Antarctica?

- Mass loss in West Antarctica and the Antarctic peninsula is accelerating: ~200 Gt/yr in 2006, mainly in narrow channels occupied by outlet glaciers (Rignot et al. 2008)
- There is new theoretical evidence for marine ice sheet instability (Schoof 2007). Increased flow of warm intermediate waters beneath ice shelves could trigger abrupt retreat of the West Antarctic ice sheet.



Current ice sheet models



- Models do well in the cold interior where vertical shear stresses dominate ("shallow-ice approximation").
- There is a separate class of ice shelf models in which lateral/normal stresses dominate.
- Models fail in small-scale transition regions (ice streams, outlet glaciers) where basal sliding occurs and all stresses are important.

Toward a new generation of ice sheet models

EOS, Dec. 2007

- "Credible predictions of ice sheet evolution and sea level change will require a new generation of ice sheet models coupled to AOGCMs."
- Key processes are missing from current ice sheet models:
  - Interactions of ice sheets with the ocean (subshelf melting, freezing, and ocean circulation)
  - Grounding line migration
  - Ice streaming (higher-order dynamics, basal physics, increased resolution)
  - Iceberg calving
- Increased support is needed for coupled ice sheet modeling in GCMs (numerical algorithm development, software engineering, and analysis of model output).

Ice sheets in CCSM

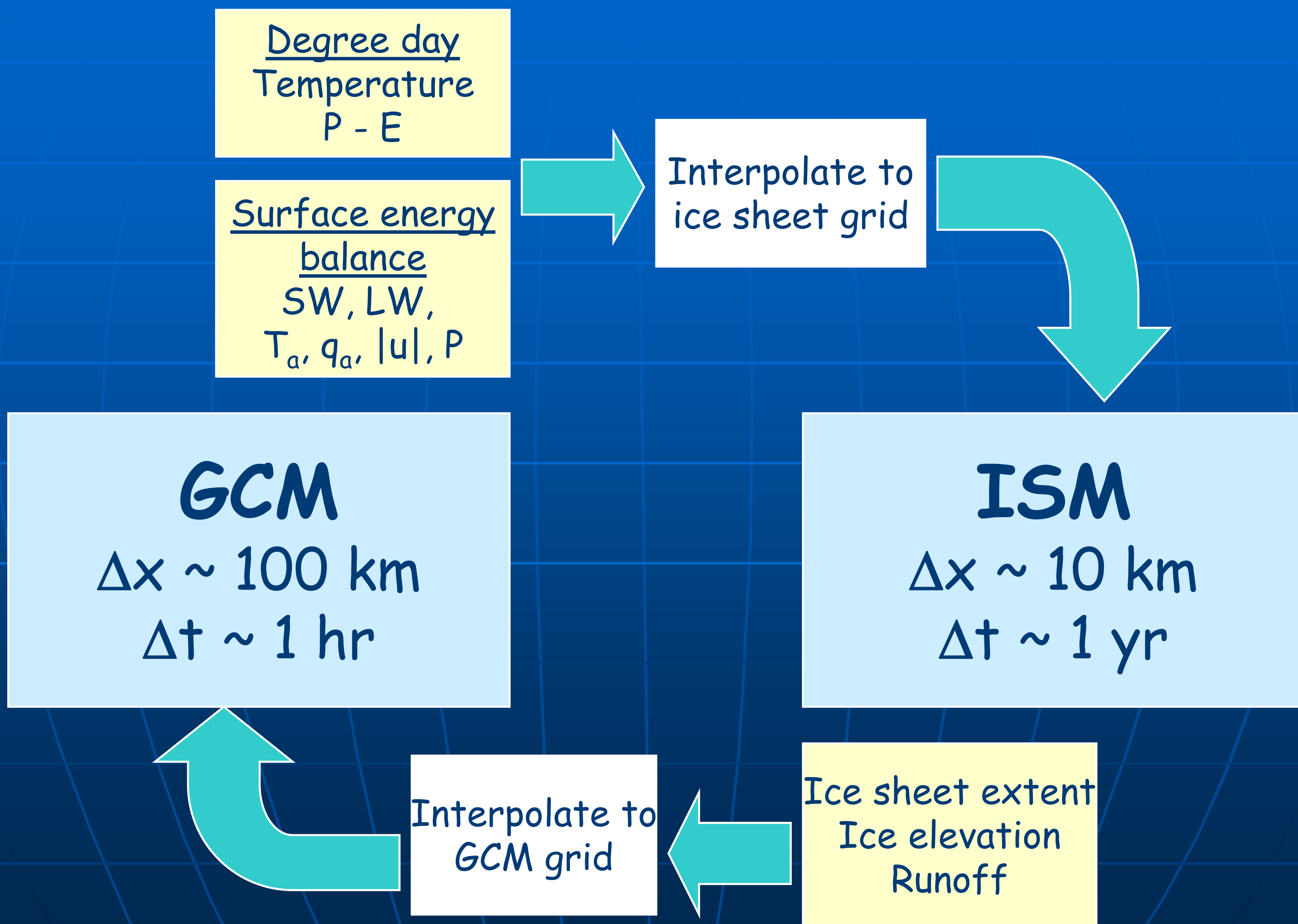
Phase 1:

- Incorporate the GLIMMER ice sheet model in CCSM (with shallow-ice dynamics).
- Use an energy-balance scheme to compute the ice surface mass balance (more accurate than positive-degree-day schemes).
- Run coupled experiments with a dynamic Greenland ice sheet.

Phase 2:

- Develop a next-generation ice sheet/shelf model that can realistically simulate rapid changes in ice sheet flow.
- Couple the ice sheets to the ocean.
- Run coupled experiments with the Antarctic and paleo ice sheets as well as the Greenland ice sheet.

Coupling ice sheet models and GCMs



New approach to surface mass balance

- The traditional approach is to 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 will compute the mass balance in CLM on a coarse (~100 km) grid in ~10 elevation classes. Ice thickness changes are then downscaled to the ice sheet grid.
  - Energetic consistency between land and ice sheet models
  - Cost savings (~1/10 as many columns)
  - Avoid code duplication; CLM already has a good snow model

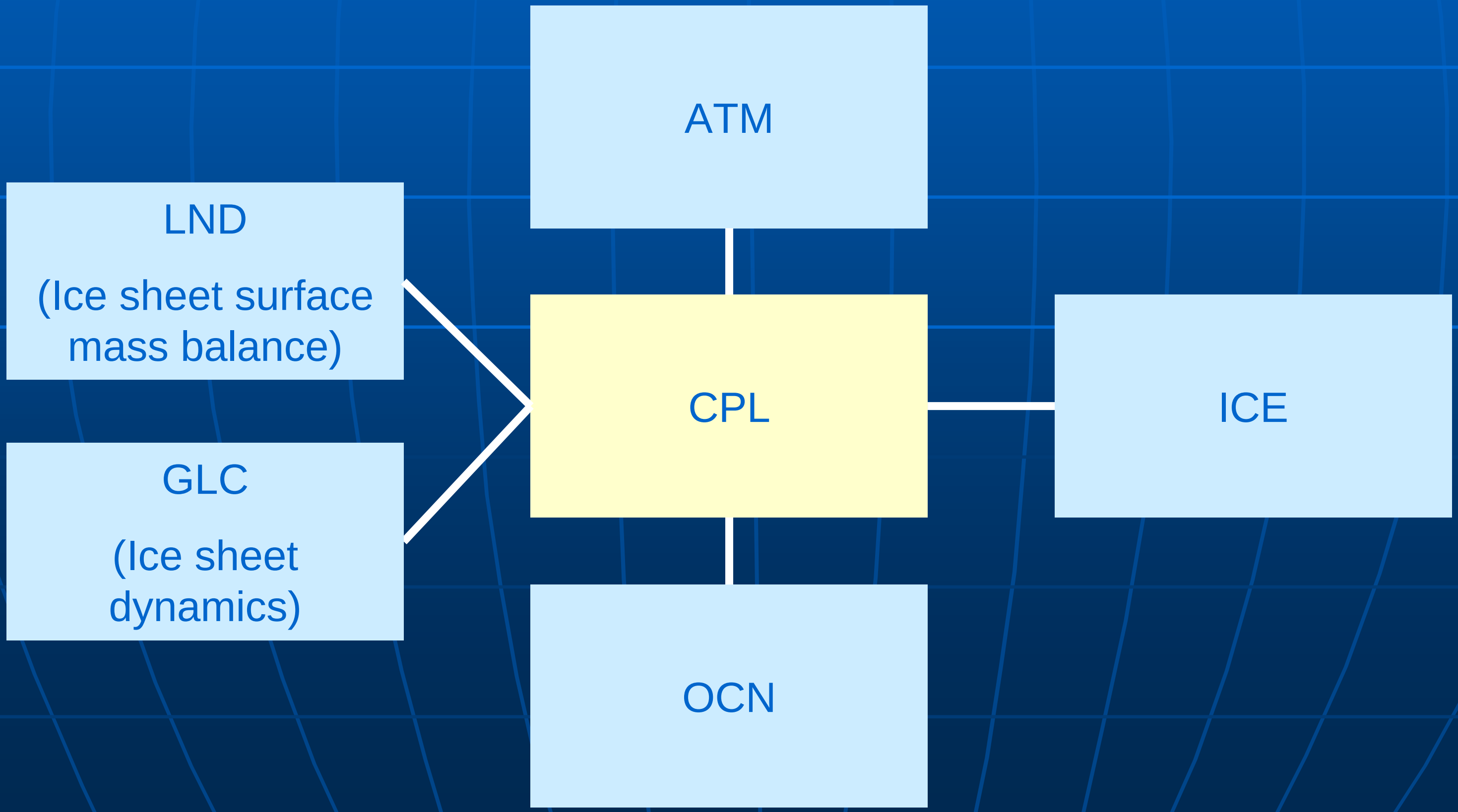
Ice sheet coupling in CCSM

LND -> GLC

- surface temperature
- surface elevation
- ice accumulation/ablation

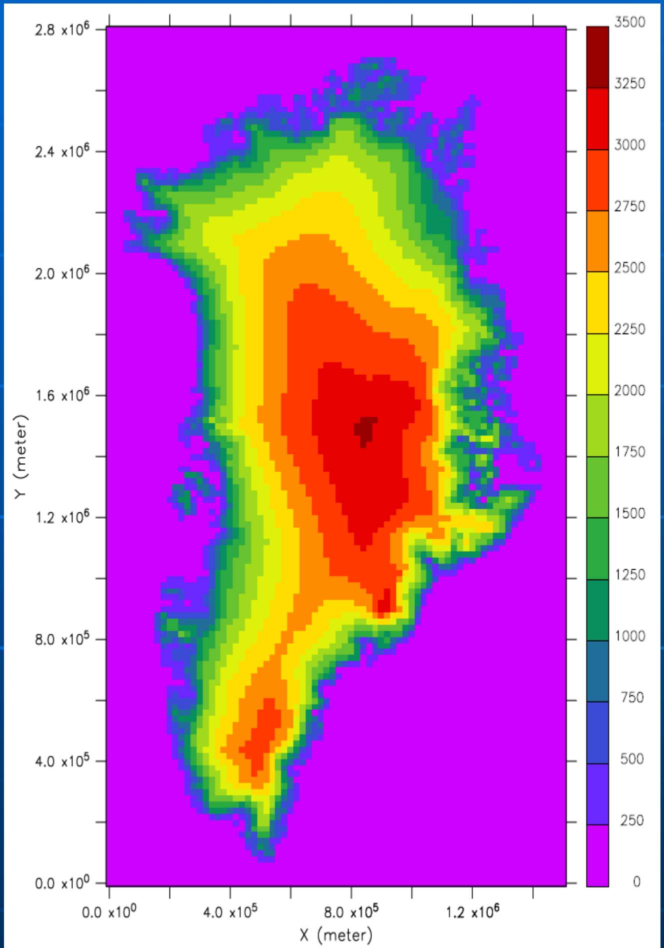
GLC -> LND

- ice fraction and thickness
- surface runoff
- heat flux to surface



Progress to date

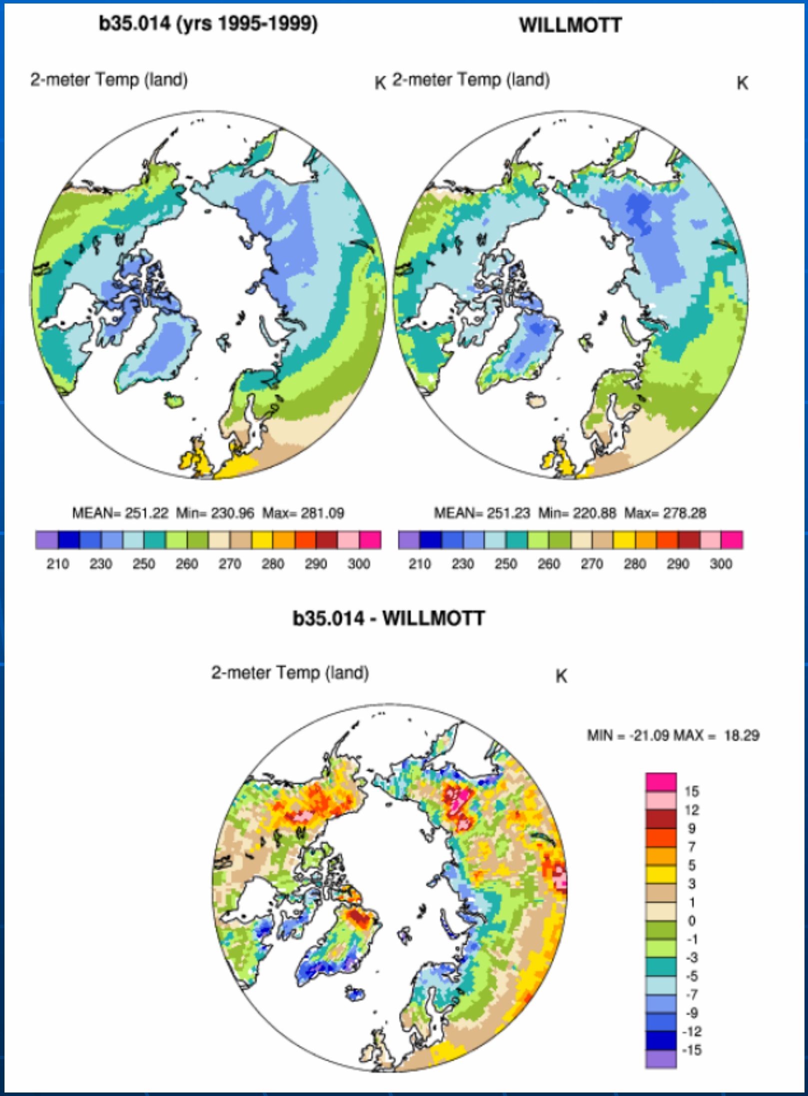
- Added GLIMMER to CCSM
- Created a new component, GLC, and added infrastructure for exchanging fields between GLC and the coupler. Coupling is now fully functional in concurrent CCSM (cpl6).
- Modified the land model, CLM, so that it computes and passes to GLC the surface mass balance in each glacier column



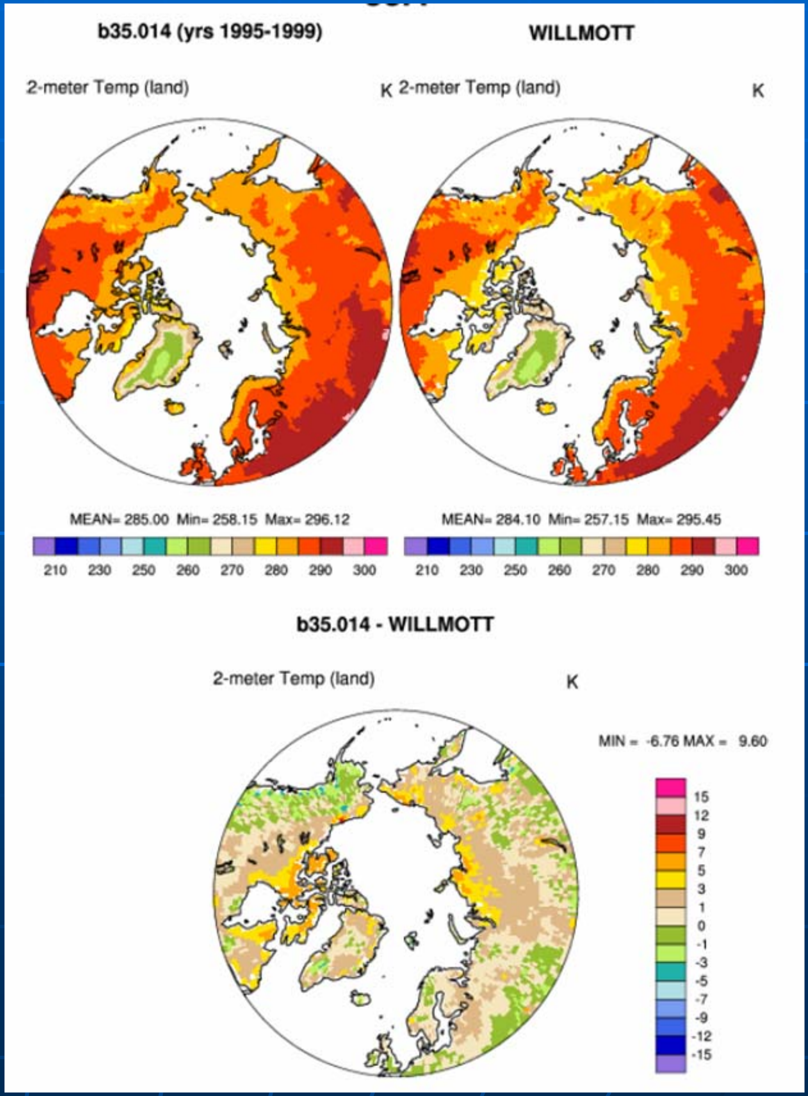
Work remaining in phase 1

- Compute the surface mass balance in CLM for multiple elevation classes (in progress).
- Redo the coupling for sequential CCSM (cpl7).
- Run the model with a dynamic Greenland ice sheet and tune as needed.
  - With the surface mass balance computed in CLM, the only obvious tuning knob is the land-ice albedo.
  - The energy-balance scheme is more physically based than PDD scheme, so more credible for different climates.

CCSM 3.5 versus observations



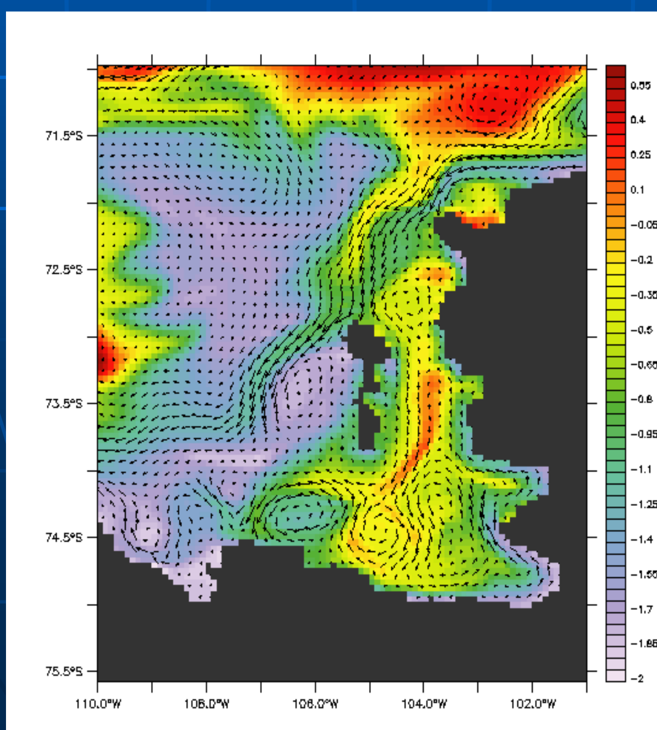
N. Hemisphere T_{2m}, DJF

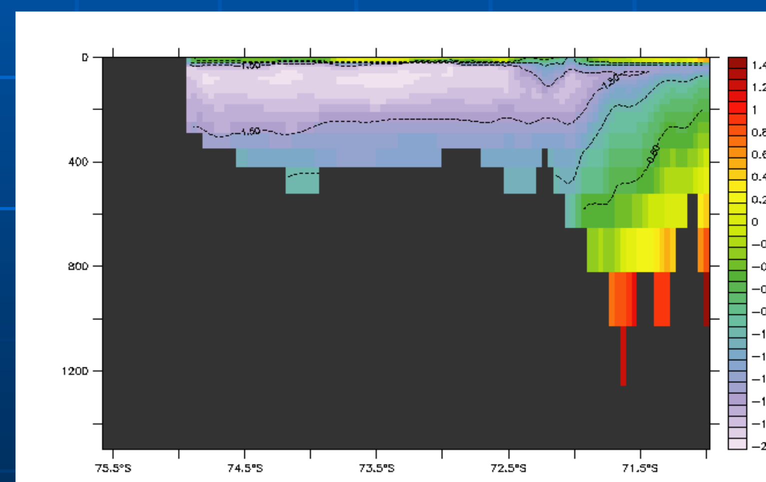


N. Hemisphere T_{2m}, JJA

Abrupt ice sheet retreat

- We have submitted a proposal 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 first develop a high-resolution (~5 km) regional ice sheet/shelf – ocean model, using HYPOP to model subshelf ocean circulation. Focus will be on West Antarctic ice sheet.
  - This model could ultimately be added to CCSM.





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

Left: Surface temperature and currents

Division of labor

- I am funded by DOE to work fulltime on ice sheet model development, including CCSM coupling and improved ice sheet dynamics.
- Steve Price will join the LANL climate modeling group in March 2008. He will focus on ice sheet physics (subglacial hydrology, basal sliding) and science applications.
- We hope to receive additional support (~1 FTE) to work on ice shelf-ocean interaction and marine ice sheet instability.
- We are collaborating with groups at the Univ. of Bristol group (Tony Payne) and NYU (David Holland), as well as the NSF Community Ice Sheet Model project (Christina Hulbe, Jesse Johnson).
- NCAR is providing support for software engineering (Tony Craig, Mariana Vertenstein, Jon Wolfe) and CLM development (Erik Kluzek, David Lawrence, Sam Levis, Keith Oleson).

Summary

- As the Greenland and West Antarctic ice sheets lose mass at an increasing rate, there is ever greater urgency to include realistic ice sheets in coupled climate models.
- We have made (slow) progress in adding the GLIMMER ice sheet model to CCSM.
- Much more work is needed before we can make credible predictions of ice sheet changes, especially in Antarctica.
- Fortunately, the resources devoted to ice sheet modeling are increasing, at LANL and elsewhere.

For more information, see the ice sheet SWIKI:
http://swiki.ucar.edu/ccsm/101