Progress in Ice Sheet Modeling

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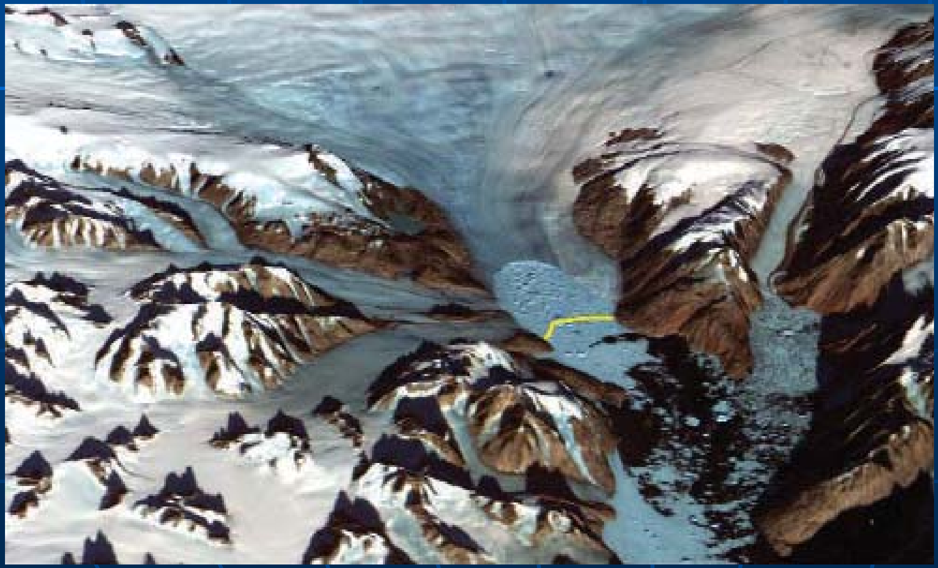
Greenland ice sheet

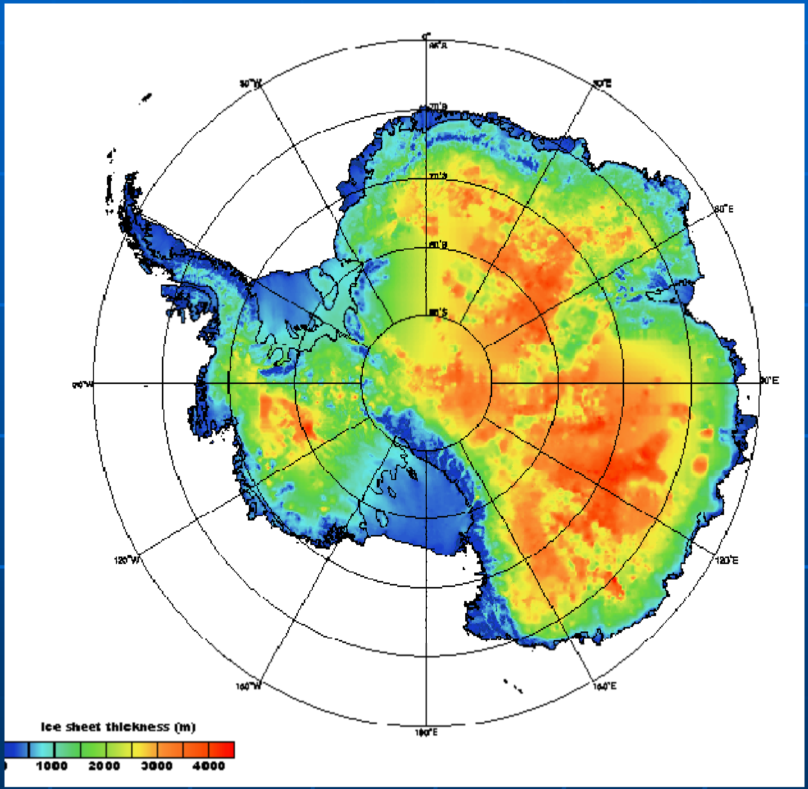
- 7 m sea level equivalent
- Accumulation (~500 Gt/yr) balanced by roughly equal amounts of iceberg calving and surface melting
- Outlet glaciers have accelerated and thinned since 1990s
- Losing mass at rate of 100-200 Gt/yr
- Likely to melt completely with sustained temperature increase of ~3°C



Kangerdlugssuaq glacier, 2000 v. 2005

Antarctic ice sheet

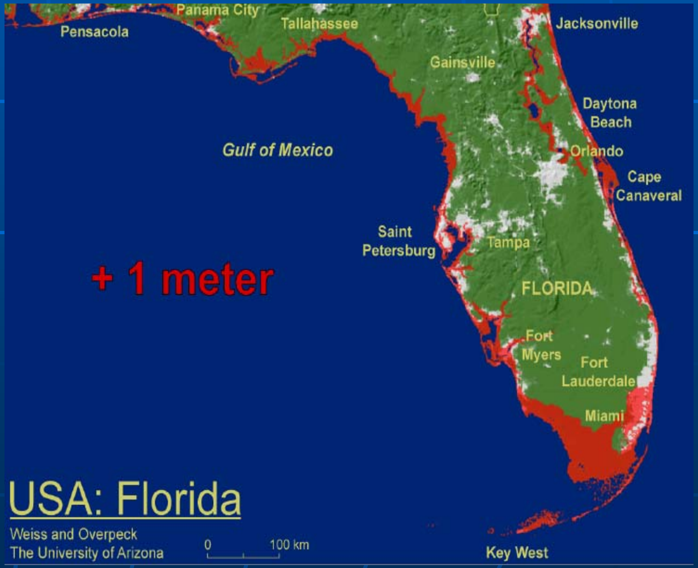
- ~60 m sea level equivalent (5 m in West Antarctica)
- Little surface melting
- Ice shelves have thinned and collapsed; ice streams have accelerated (esp. Antarctic peninsula, Amundsen Sea embayment)
- West Antarctica losing mass at rate of ~50-100 Gt/yr
- East Antarctica gaining mass at rate of ~0-50 Gt/yr



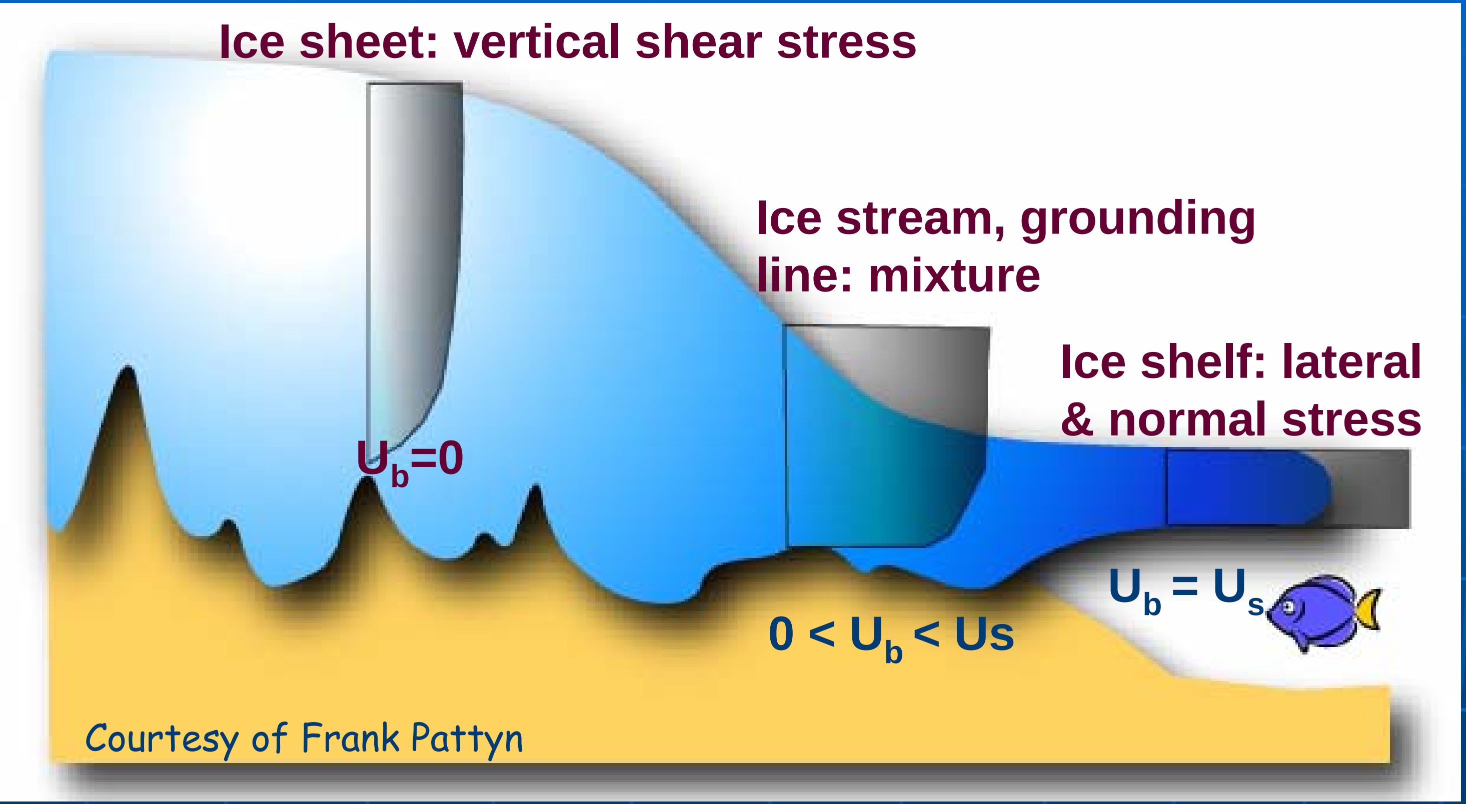
Ice sheets and sea level rise

- Global sea level rose at a rate of ~31 cm/century, 1993-2003, with a likely contribution from ice sheets.
- IPCC projects sea level rise of 18-59 cm in the 21st century, excluding "rapid dynamical changes in ice flow."

Source	Sea level rise, 1993-2003
Thermal expansion	16 cm/century
Glaciers, ice caps	8 cm/century
Ice sheets	4 cm/century



Ice sheet models



- Current ice sheet models are fairly reliable for slow-moving ice sheet interiors, but not for fast-moving ice streams and outlet glaciers.
- These models cannot reproduce recent observations!

Ice sheets in CCSM: Model development

Short-term goals (by summer 2007):

1) Port the GLIMMER ice sheet model to NCAR.
2) Run GLIMMER in standalone mode with a dynamic Greenland ice sheet.
3) Add glc as a 6th component of the coupled system (with **atm**, **ocn**, **ice**, **lnd**, **cpl**).
4) Run **glc** in CCSM with climate fields read from data files (precipitation and 2m temperature, downscaled to the ice sheet grid).
5) Run glc with fields passed through the coupler.
6) Return ice sheet fields to the coupler (land-ice fraction, elevation, and extent freshwater runoff).

Ice sheets in CCSM: Experiments

Short-term goals (2007-08):

1) Control climate runs with an interactive Greenland ice sheet
2) Climate change runs with Greenland, e.g. for IPCC AR5
3) Paleoclimate runs with Greenland, e.g. for the last (Eemian) interglacial

Long-term goals:

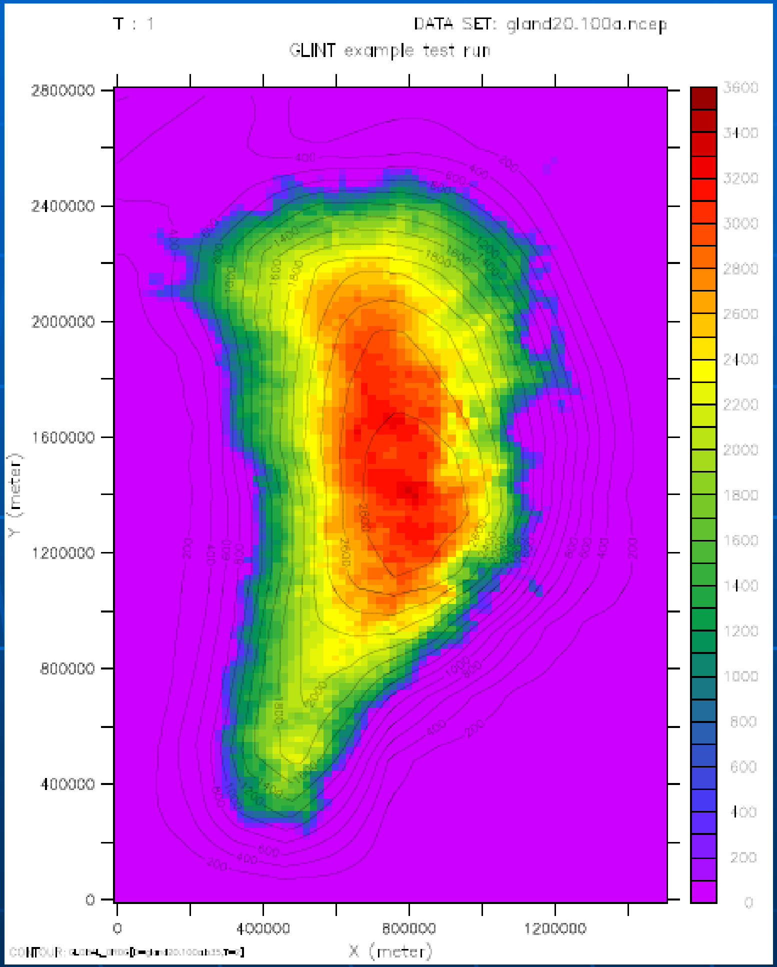
1) Add Antarctic ice sheet
2) Add paleo ice sheets (e.g., Laurentide) and run on millennial time scales

Cuffey and Marshall, 2000

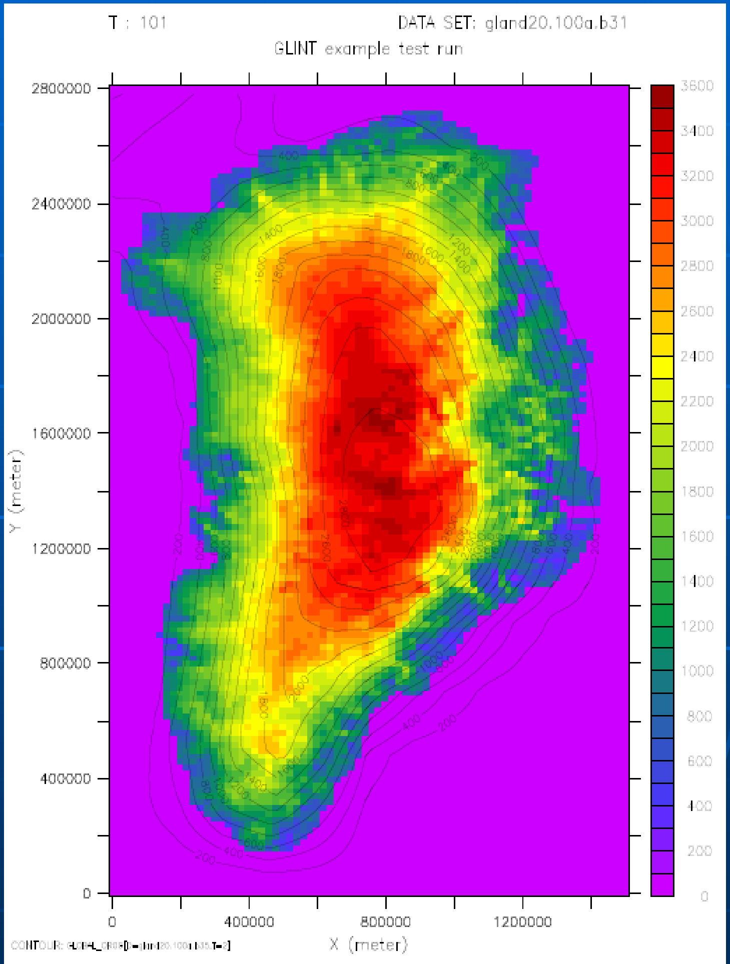
Preliminary results

- Initialize ice sheet model with observed thickness and extent.
- Force with temperature and precipitation data (interpolated to ice sheet grid):
    - NCEP climatology (provided with GLIMMER code)
    - b31.002 (FV 1.9x2.5 atmosphere, 1° ocean, present-day)
    - b35.001d (changes in snow, sea ice and clouds)
- Run ice sheet for 10,000 years and compare to observations.
- The ice thickness and extent are highly sensitive to input temperatures and model parameters.

b31 forcing

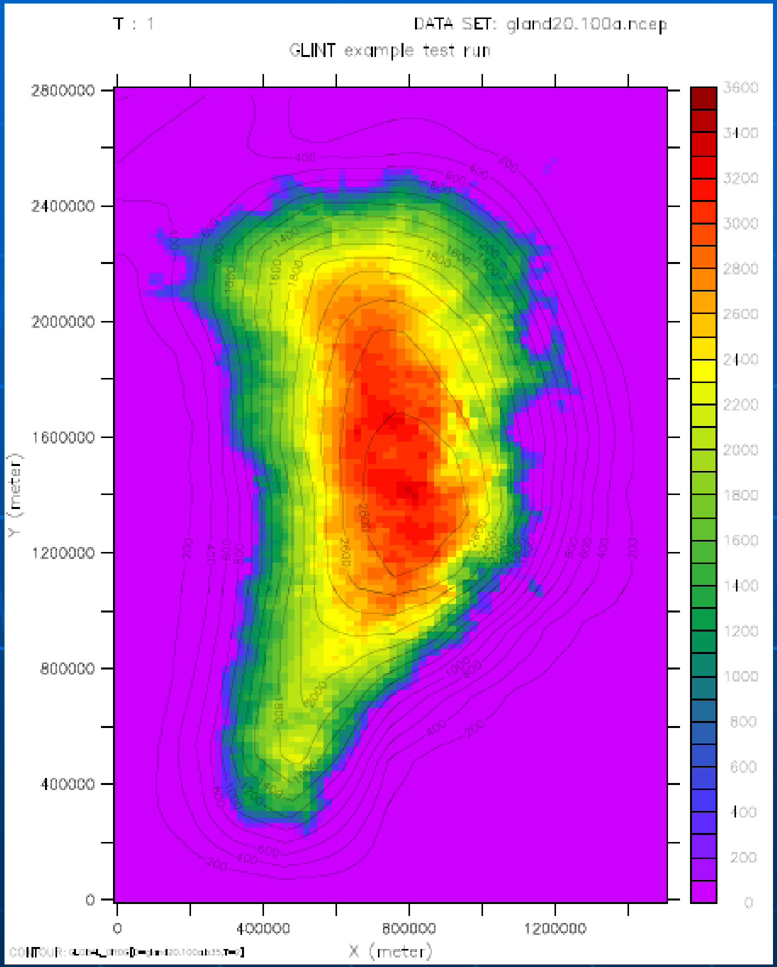


Observed ice thickness

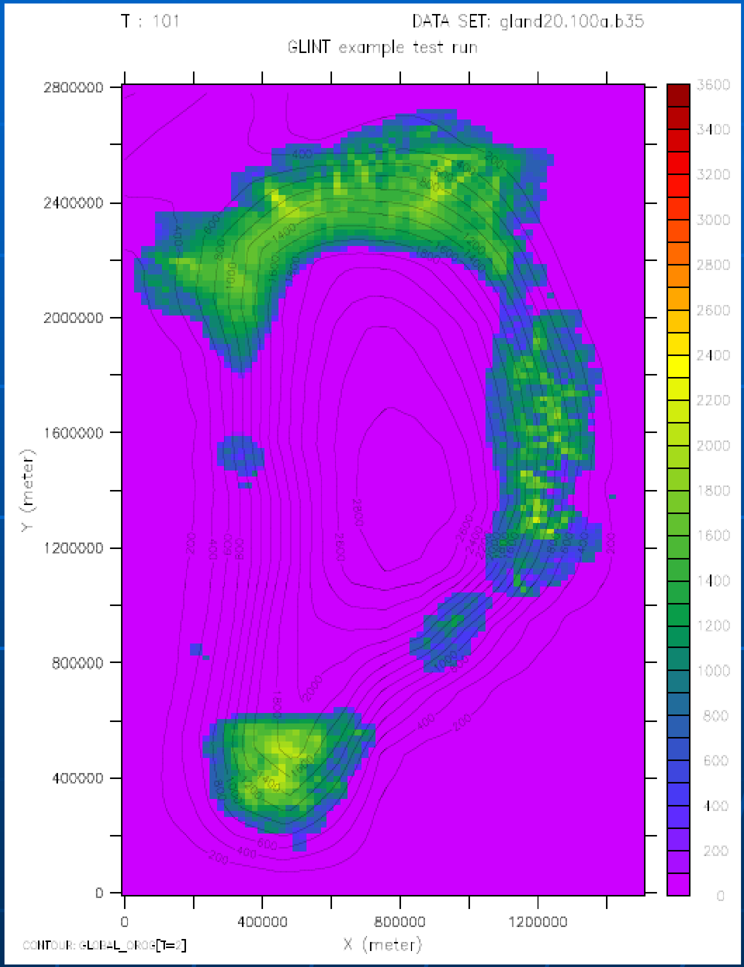


Ice thickness, b31 forcing

b35 forcing

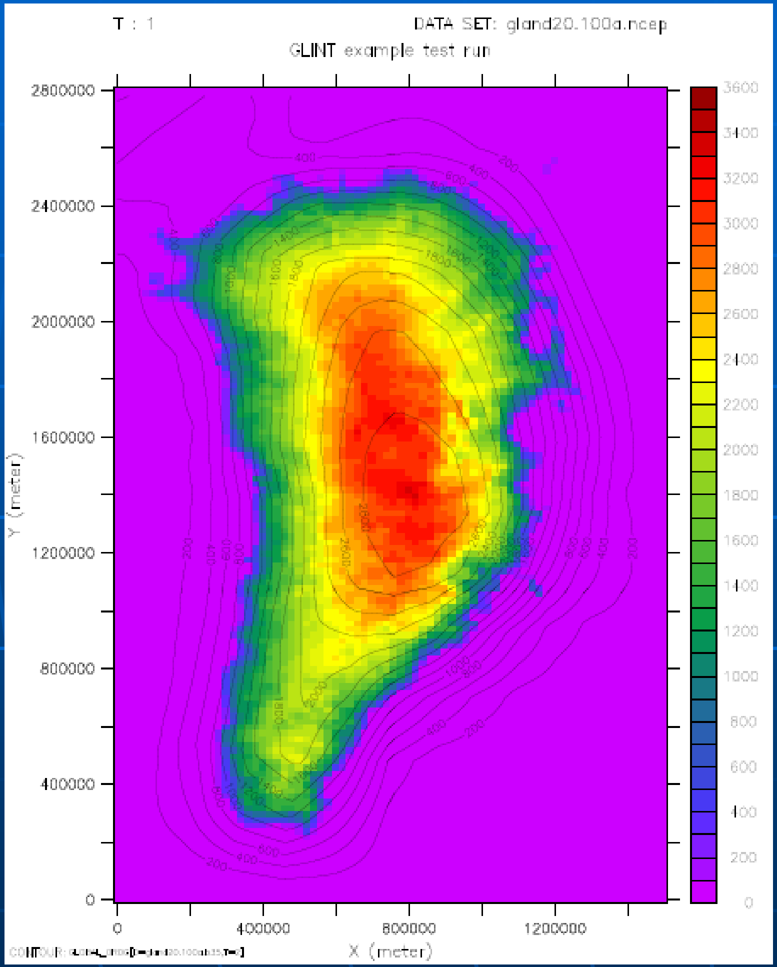


Observed ice thickness

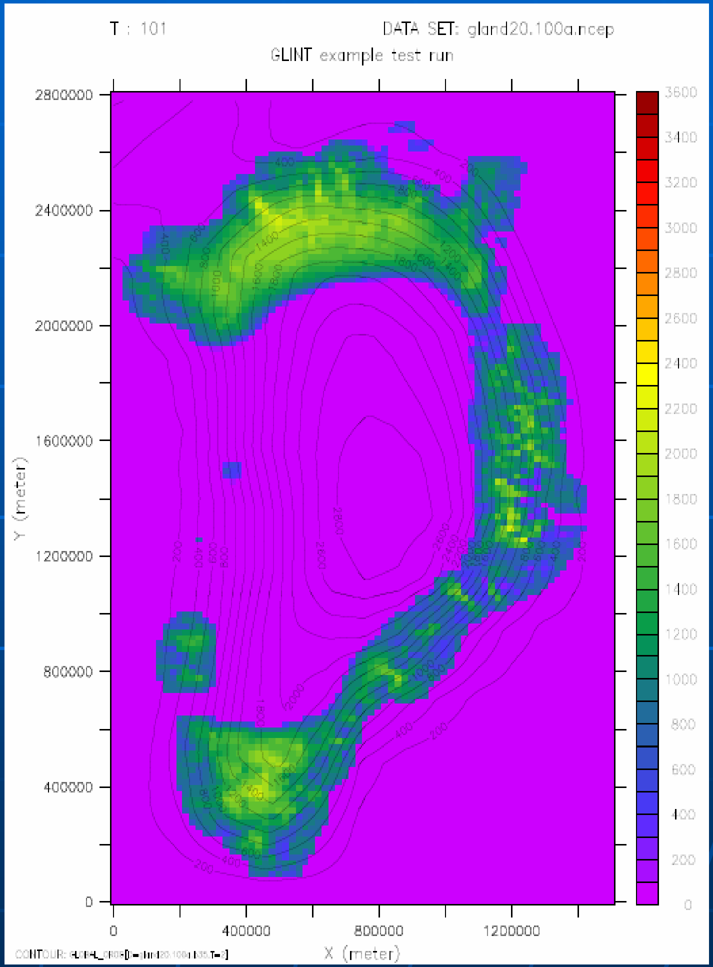


Ice thickness, b35 forcing

NCEP forcing

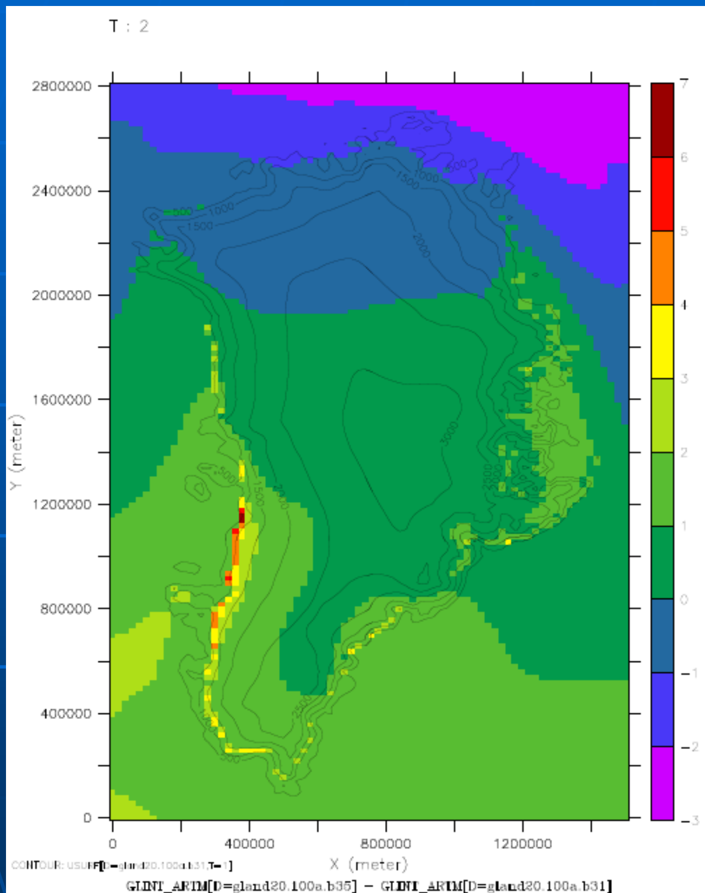


Observed ice thickness

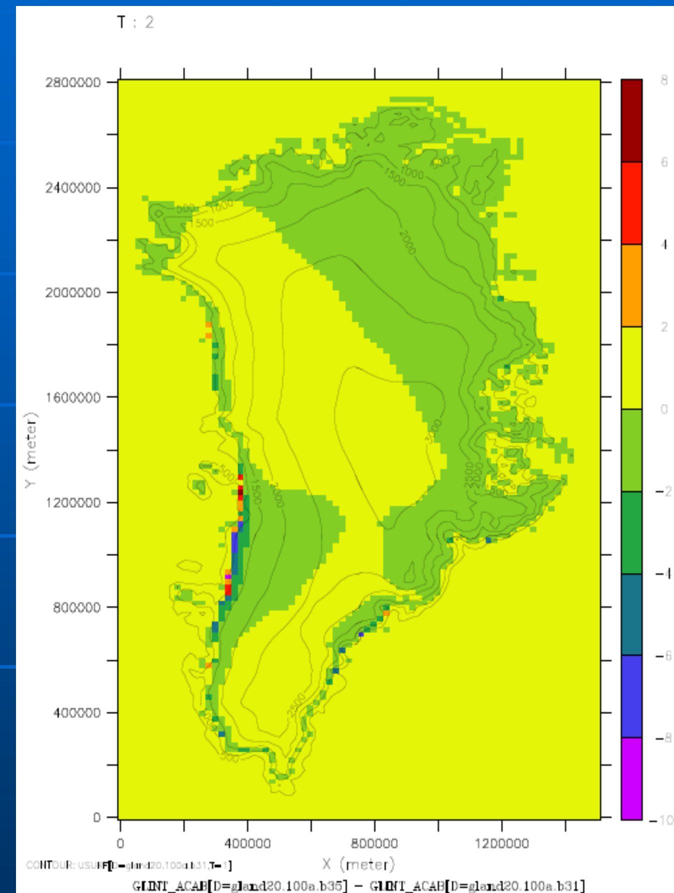


Ice thickness, NCEP forcing

b31 v. b35



Surface air temperature,
b35 - b31



Net annual accumulation,
b35 - b31

Greenland ice sheet, model v. observations

	Area ($\times 10^6$ km^2)	Volume ($\times 10^6$ km^3)	Maximum thickness (m)
Observational data set	1.60	2.91	3317
NCEP forcing	1.20	1.28	2188
b31 forcing	2.31	4.54	3566
b35 forcing	1.07	1.14	2197

Q: Does CCSM forcing produce too much ice or too little ice?

A: Yes!

How to improve the control simulation?

- Change parameters
  - Adjust positive-degree-day factors for snow (0.003 m/PDD) and ice (0.08 m/PDD)
  - Adjust air temperature lapse rate (8 deg/km; too high in summer)
  - Prescribe mean temperature and force with anomalies.
- Change topography
  - Input GLIMMER bedrock topography has zero elevation contour out at sea.
  - CAM FV lower surface has smoothed topography that can differ by ~100 m from true topography.
- Change the surface mass balance scheme
  - PDD -> surface energy balance (SW, LW, turbulent fluxes)
  - Compute surface fluxes and mass balance in land model with subgrid elevation classes.
- Improve ice dynamics
  - Increased resolution (20 km -> 5 km)
  - Improved treatment of basal sliding, hydrology
  - Shallow ice approximation -> full stresses

What are the long-term goals?

1. Make credible projections of the response of the Greenland and Antarctic ice sheets to climate change on decadal to century time scales.
2. Understand and model the role of ice sheets in orbitally driven climate change on millennial time scales.

What are the major challenges?

What resources are needed to meet these challenges?

Ice sheet modeling challenges

1) Increased model resolution (~5 km or less)
2) Full stresses (instead of shallow ice)
3) Subglacial hydrology and basal sliding
4) Ice shelf-ocean interactions and calving

Coupling challenges

- Downscaling
  - How can we accurately interpolate surface forcing fields to an ice sheet grid with rough topography? This may be best done in the land model.
- Ice surface elevation
  - CAM assumes fixed surface elevation. How do we deal with time-varying surface topography? Can we run the atmosphere on a grid which is a better approximation to the true topography?
- Ice shelves and oceans
  - POP assumes that the upper ocean is bounded by the atmosphere and that surface topography does not change. How do we model the circulation under ice shelves? Can we run the ocean with ice shelves whose thickness and extent evolve in time?

Workshop on Ice Sheet Modeling
GFDL, January 2007

Recommendations:

- Increased support for ice sheet modeling in GCMs
    - ~3 ice sheet modelers per GCM (software, model development, applications and analysis)
- Shared modular framework (e.g., GLIMMER) with diverse dynamics/physics
- Stronger links between labs and universities
- Better coordination between models and observations

Summary

- The GLIMMER model with a dynamic Greenland ice sheet is running in concurrent CCSM with climate data files.
- Fully coupled climate runs with an interactive ice sheet model will begin this summer.
- With a positive-degree-day mass balance scheme, the ice sheet is very sensitive to input temperatures and model parameters. It may be difficult to generate a realistic ice sheet without arbitrary tuning.
- Much work remains.
  - Current emphasis is on model and software development.
  - Will need increased efforts in downscaling, tuning and analysis
- For more information, see the ice sheet SWIKI: http://swiki.ucar.edu/ccsm/101