Ice Sheets in the Community Climate System Model

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The Community Climate System Model

- **A comprehensive climate model to study the Earth's climate.**
- **Widely used to investigate the mechanisms of seasonal, interannual and longer-term variability.**
- **Explore the history of Earth's climate.**
- **Estimate the future of the environment for policy formulation.**

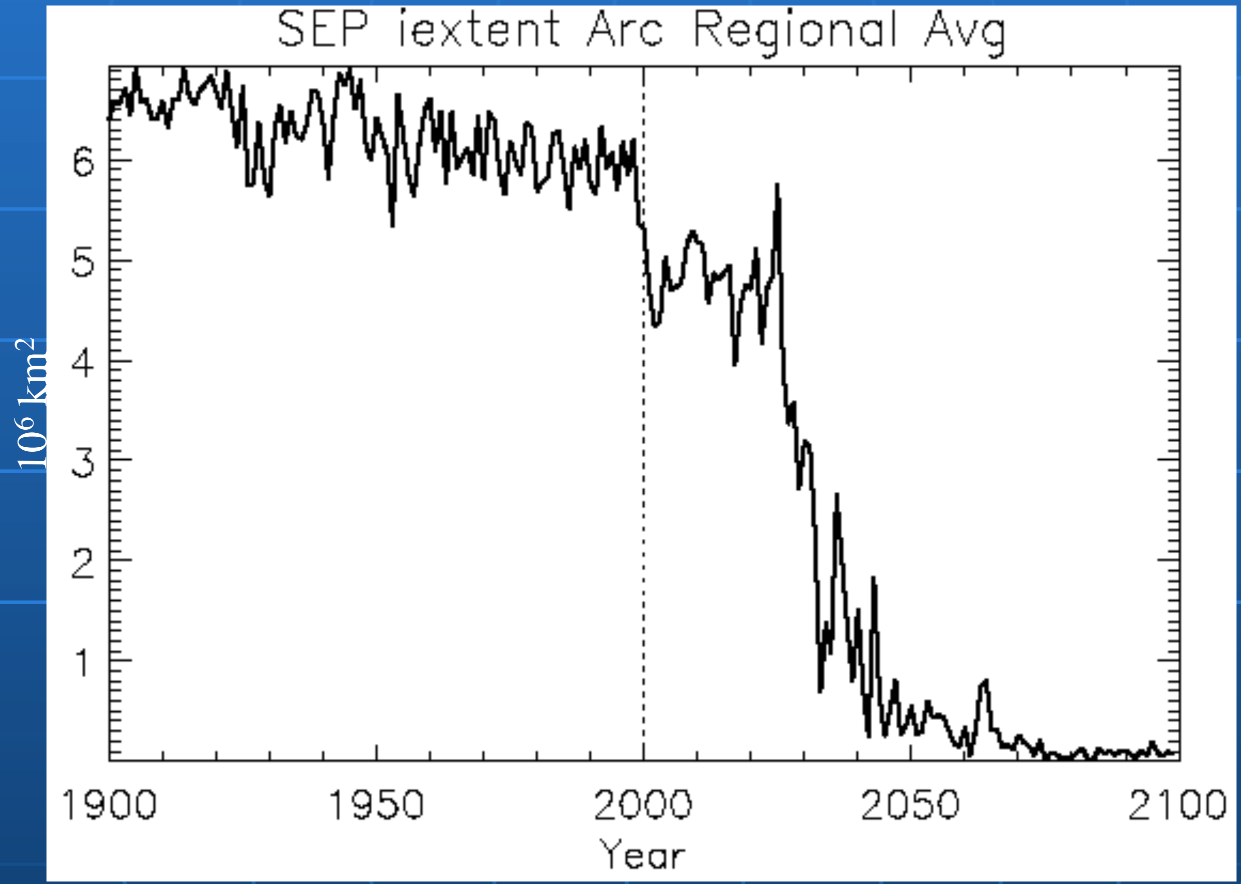
http://www.ccsm.ucar.edu

Courtesy of Peter Gent

NCAR

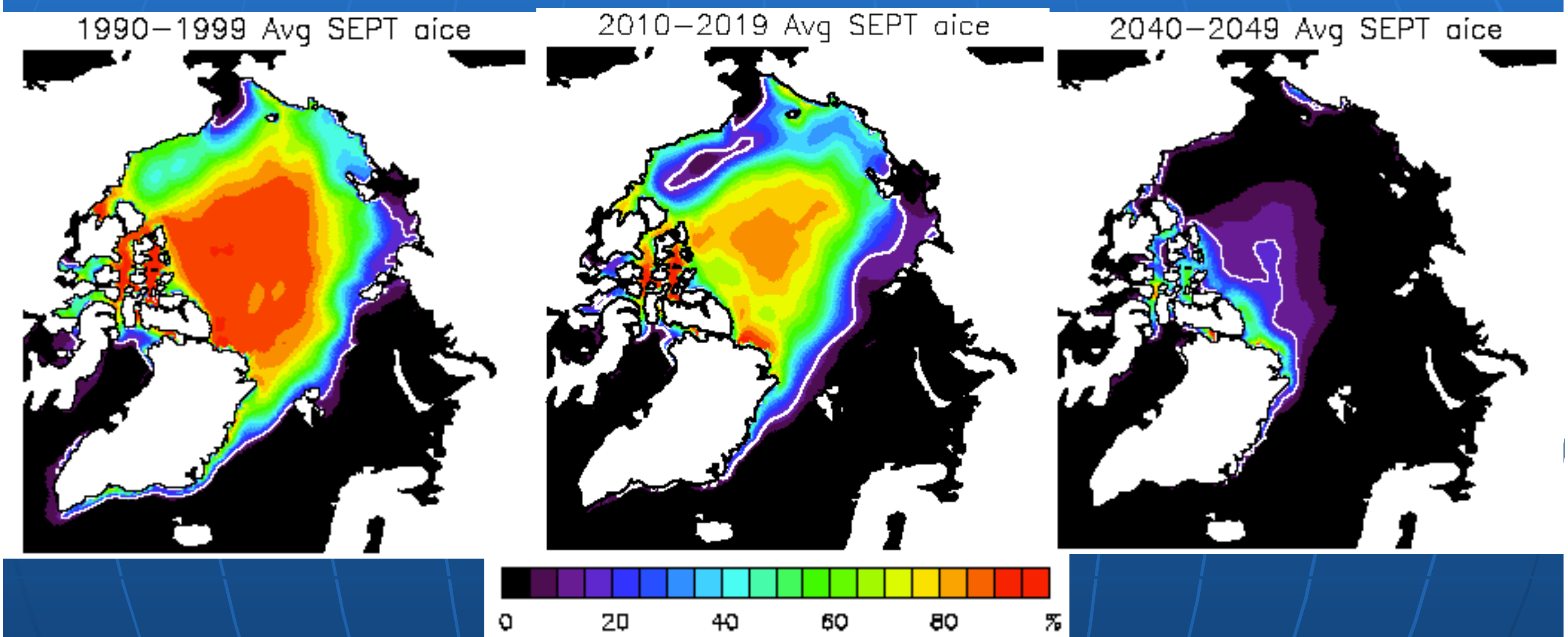
Abrupt transitions in Arctic Sea Ice

September ice extent timeseries



Although A1B greenhouse gas forcing is gradually increasing, abrupt transitions in sea ice do occur in most simulations.

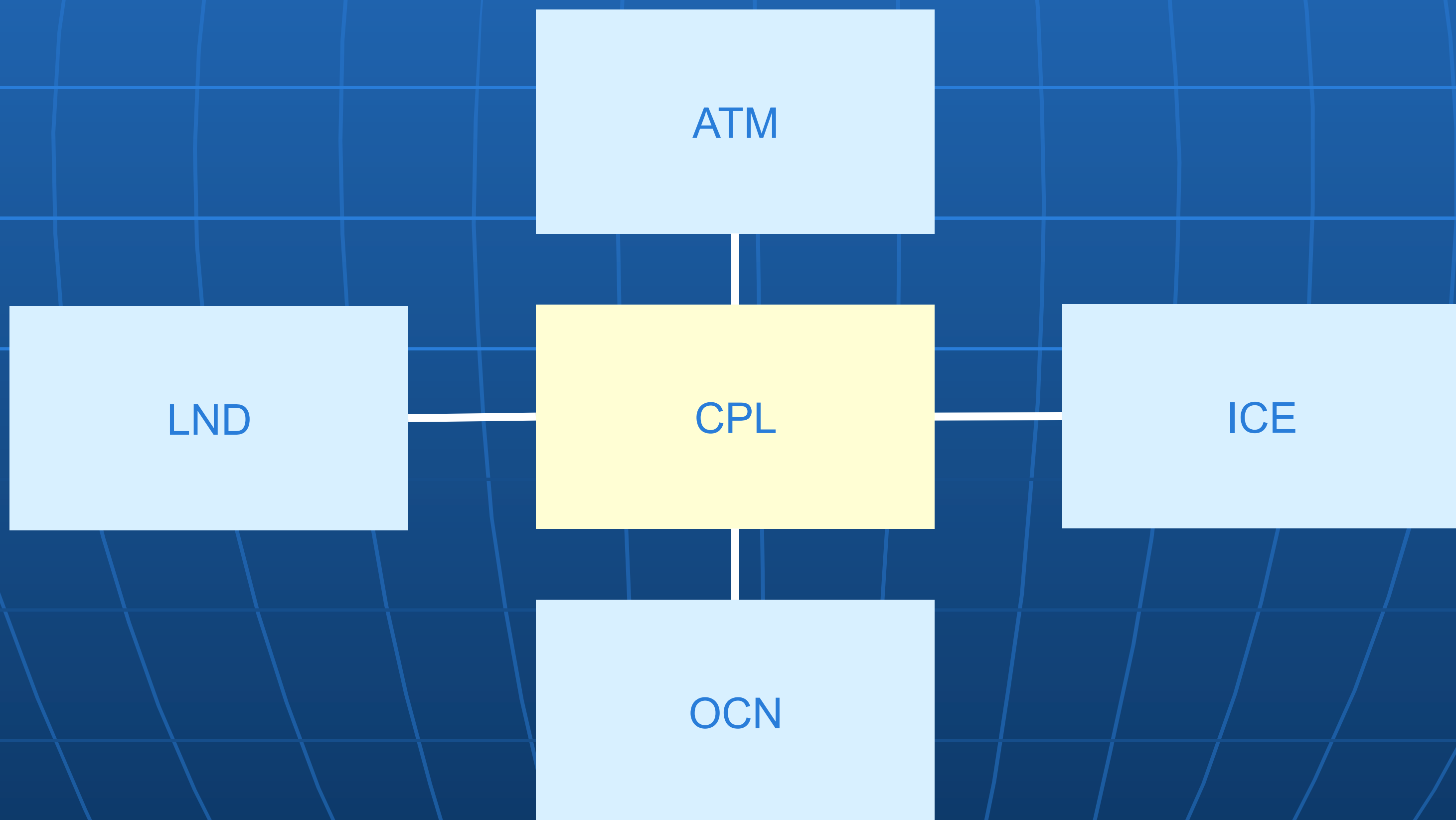
Arctic Sea Ice Concentration



September is mostly ice free by 2050 for A1B scenario

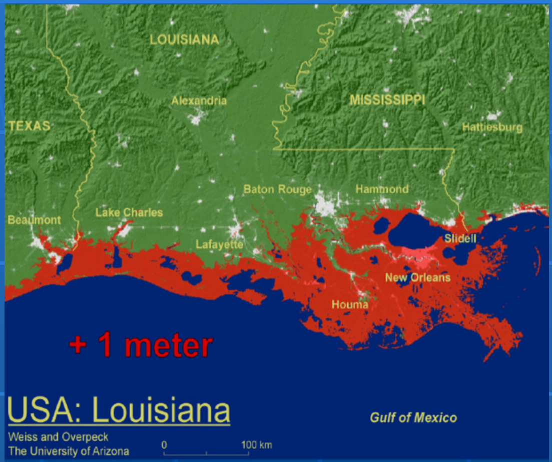
CCSM design

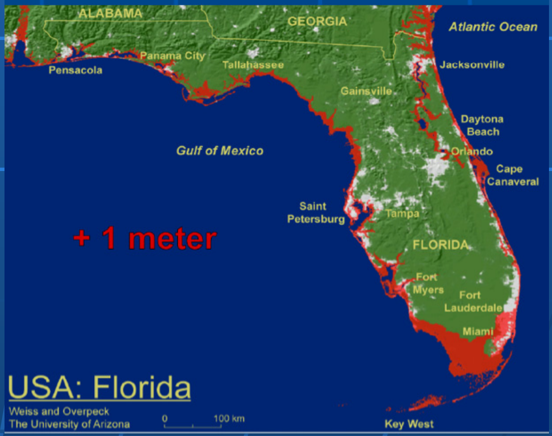
- Spectral or finite-volume atmosphere, ~1° or 2°
- POP/CICE ocean and sea ice models, 1° displaced pole
- Community Land Model (CLM) on land grid with multiple surface types



Ice sheets and the IPCC

- Global mean sea level is rising by ~3 mm/ year, with a significant and growing contribution from the Greenland and Antarctic ice sheets (as well as mountain glaciers and small ice caps).
- IPCC AR4: Sea level will rise by ~18-59 cm in the 21st century, excluding "*rapid dynamical changes in ice flow.*"
- Ice sheet models used for AR4 were inadequate for sea level assessment (shallow-ice dynamics, crude physics, coarse resolution, not coupled to GCMs).
- There is considerable pressure for ice sheet modelers to do better for AR5.

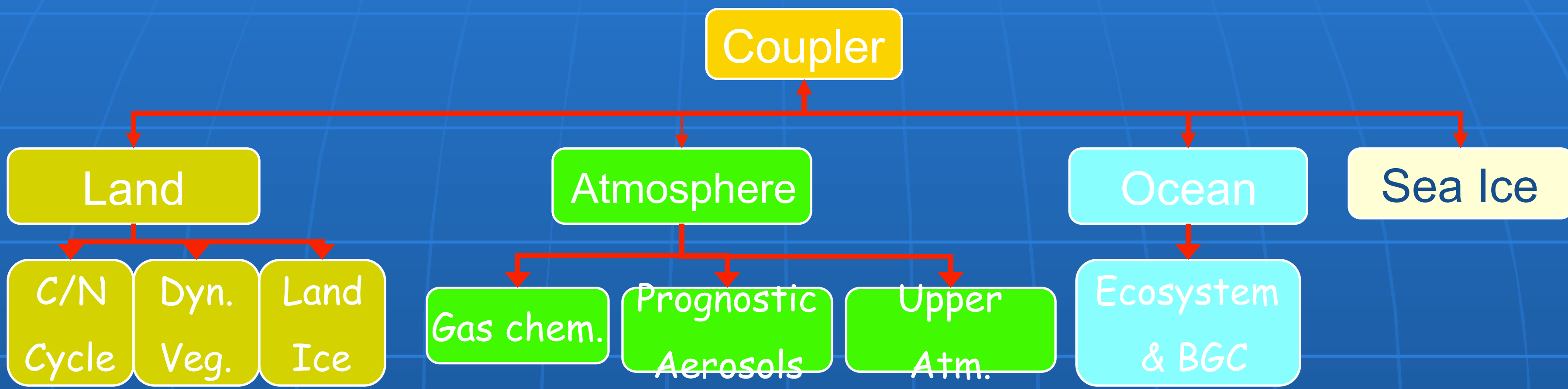




•200 million people in regions <1m

•Raising California Central Valley levees by 0.15 m, will cost over $1 billion

Potential Configuration of CCSM4



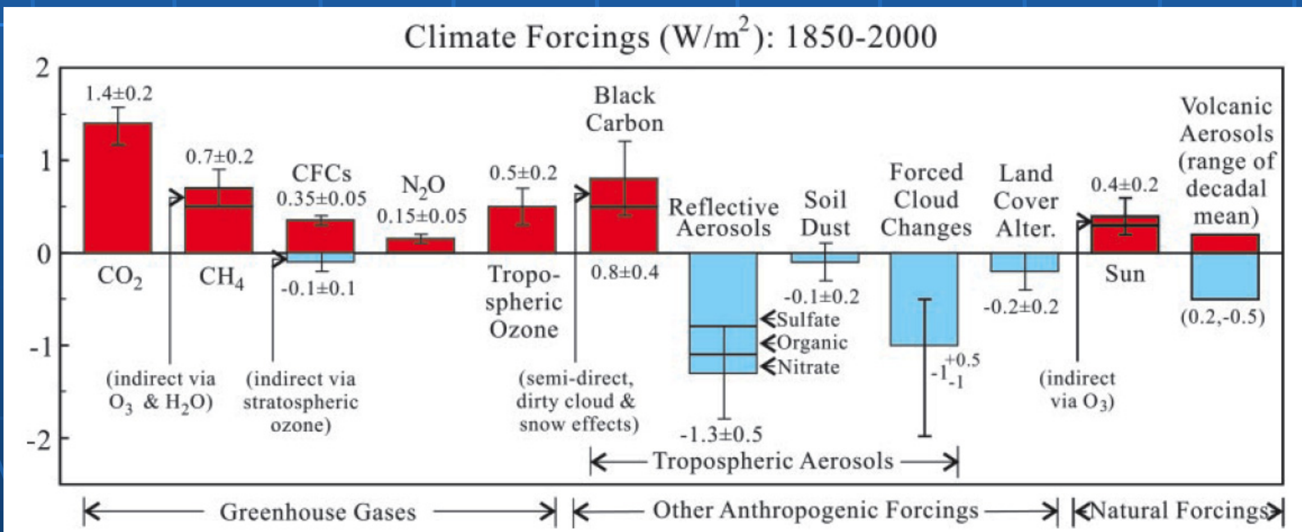


Fig. 1. Estimated climate forcings; error bars are partly subjective 1σ uncertainties.

Hansen and Sato, 2001

CCSM Working Groups

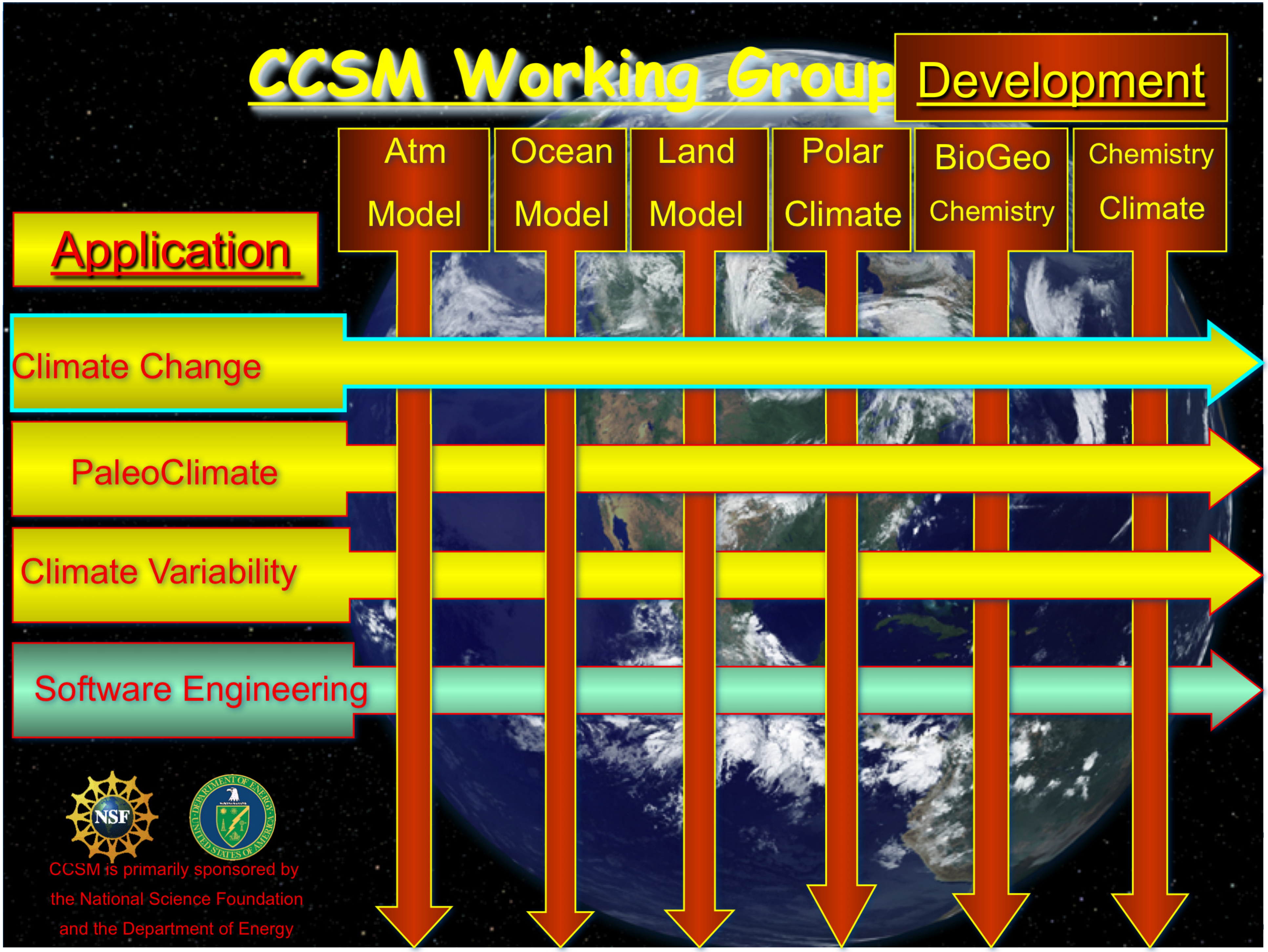
From the CCSM web page:

- The CCSM Working Groups are relatively small teams of scientists that work on individual component models or specific coupling strategies.
- Each team takes responsibility for developing and continually improving its component of the CCSM.
- Each team will decide their own development priorities and work schedules, consistent with the overall goals of CCSM, and subject to oversight by the CCSM Scientific Steering Committee (SSC).

Current working groups:

- Atmosphere model
- Land Model
- Ocean Model
- Polar Climate
- Biogeochemistry
- Chemistry-Climate
- Climate Variability
- Climate Change
- Paleoclimate
- Software Engineering
- Whole Atmosphere
- **Land Ice**

http://www.ccsm.ucar.edu/working_groups/



CCSM Working Group
Development
Atm Model
Ocean Model
Land Model
Polar Climate
BioGeo Chemistry
Chemistry Climate
Application
Climate Change
PaleoClimate
Climate Variability
Software Engineering
NSF
CCSM is primarily sponsored by
the National Science Foundation
and the Department of Energy

CCSM Land Ice Working Group

- Primary goals:
  - To couple a well validated, fully dynamical ice sheet model to the CCSM
  - To determine the likely range of decade-to-century-scale sea-level rise associated with the loss of land ice
- Organization:
  - Co-chairs Jesse Johnson (U. Montana) and Bill Lipscomb (LANL), liaison Steve Price (LANL)
  - Two meetings per year: Summer (Breckenridge) and winter (Boulder in 2010)
  - Web site and email list: http://www.ccsm.ucar.edu/working_groups/Land+Ice/

Key questions for the Land Ice Working Group

- Scientific
  - How fast will sea level rise during the next one to two centuries as a result of mass loss from ice sheets and glaciers?
  - What model improvements are needed to predict changes in ice sheets?
    - Better ice-flow dynamics, improved physics, finer grid resolution, ice-ocean coupling, etc.
  - What coupled climate experiments are needed?
    - How do we make optimal use of CCSM?

Key questions for the Land Ice Working Group

- Management
  - Given limited resources, how do we provide policymakers with useful information on short time scales (e.g., IPCC AR5)?
    - How do we interact with others in the CCSM community?
    - How should we collaborate with other ice sheet modeling groups?
    - How do we coordinate model development in a growing community?
    - How do we decide which model versions to release and which experiments to run?

An ice sheet model for IPCC AR5

- 2013: IPCC AR5 scheduled for release

An ice sheet model for IPCC AR5

- 2012: Analysis and report-writing
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An ice sheet model for IPCC AR5

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An ice sheet model for IPCC AR5

- 2010: Climate change runs
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- 2012: Analysis and report-writing
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An ice sheet model for IPCC AR5

- Time is of the essence. We need to start now.
  - End of 2009: Ice sheet model development largely complete
  - 2010: Climate change runs
  - 2011: Papers submitted and accepted
  - 2012: Analysis and report-writing
  - 2013: IPCC AR5 scheduled for release

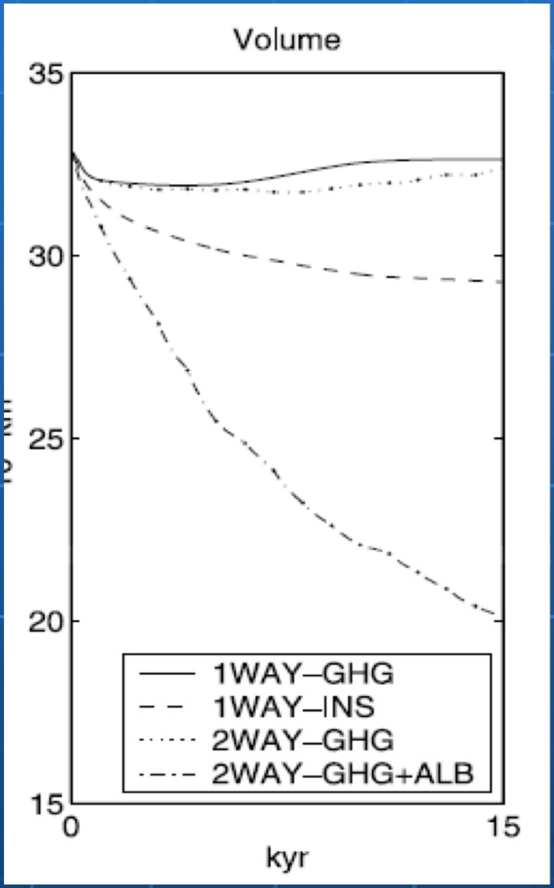
Glimmer-CISM development path

- Start with Glimmer
- Develop a more modular dynamical core
- Extend the dynamical core to include higher-order stresses and other numerical improvements
- Parallelize the model, using POP/CICE infrastructure as appropriate
- Add physics parameterizations (e.g., basal hydrology and iceberg calving)
- Develop useful data products and tools
- Conduct experiments (e.g., IPCC AR5)

Schematic model framework

Coupling ice sheet models and GCMs

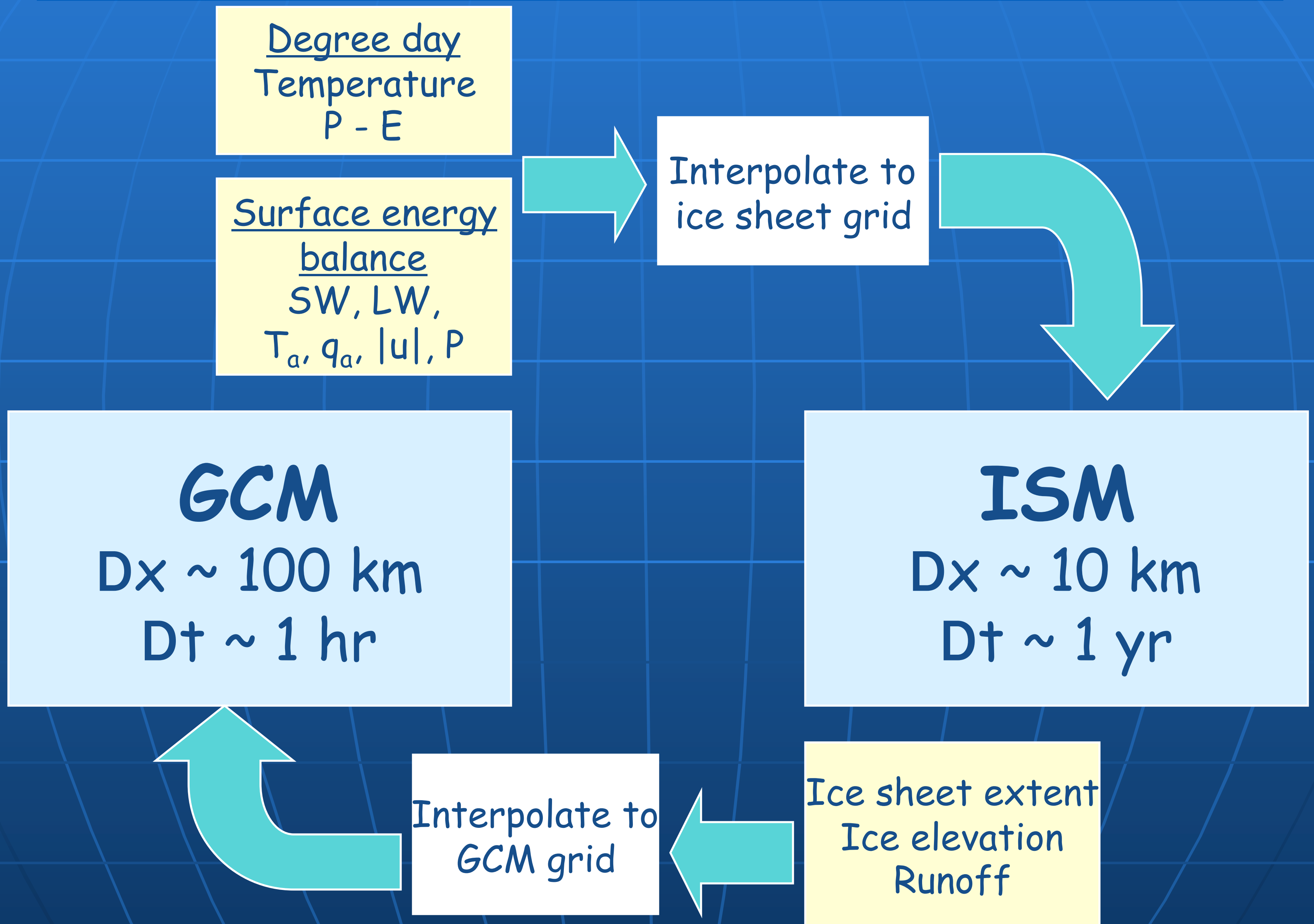
- Until recently, the major GCMs had static ice sheets. AR4 ice sheet models were run in standalone mode.
- Motivation for coupled ice sheet-climate models:
  - Interactive ice sheets are needed for paleoclimate studies.
  - Ice sheet changes could alter other parts of the climate system, such as the thermohaline circulation.
  - As ice sheets melt and retreat, the local climate can change, modifying the rate of retreat.



Laurentide volume change

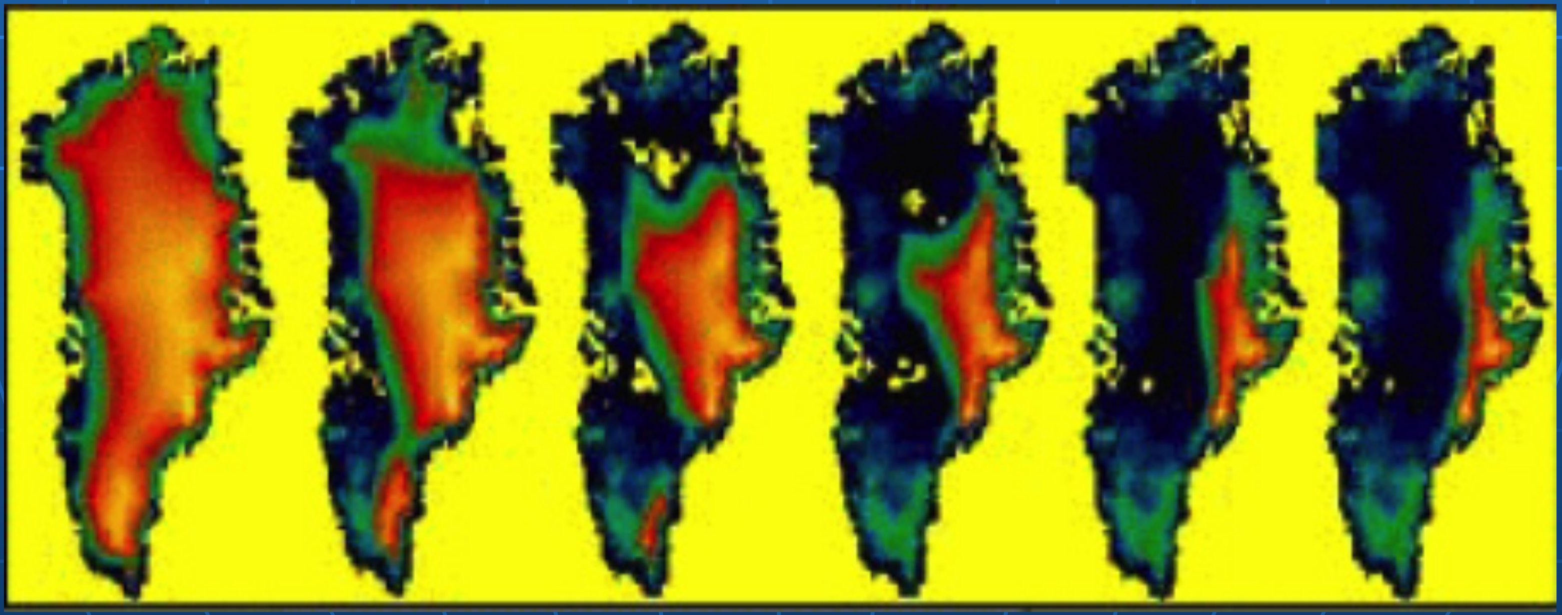
Pritchard et al. (2008)

Coupling ice sheet models and GCMs



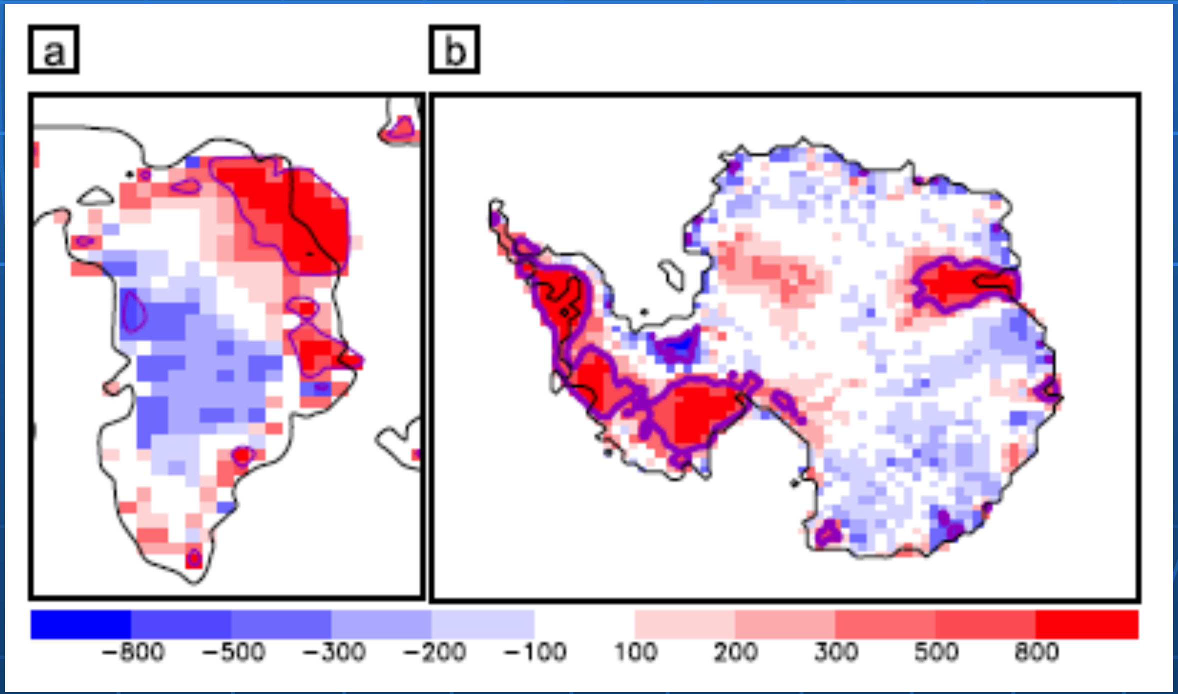
Coupled climate-ice sheet modeling

- Ridley et al. (2005) coupled HadCM3 to a Greenland ice sheet model and ran for 3000 ice sheet years with 4 x CO_2.
- After 3000 years, most of the Greenland ice sheet melted. Sea level rise ~7 m, with max rate ~50 cm/century early in simulation.
- Shallow-ice approximation, positive-degree-day scheme, anomaly temperature forcing with prescribed mean.



Coupled climate-ice sheet modeling

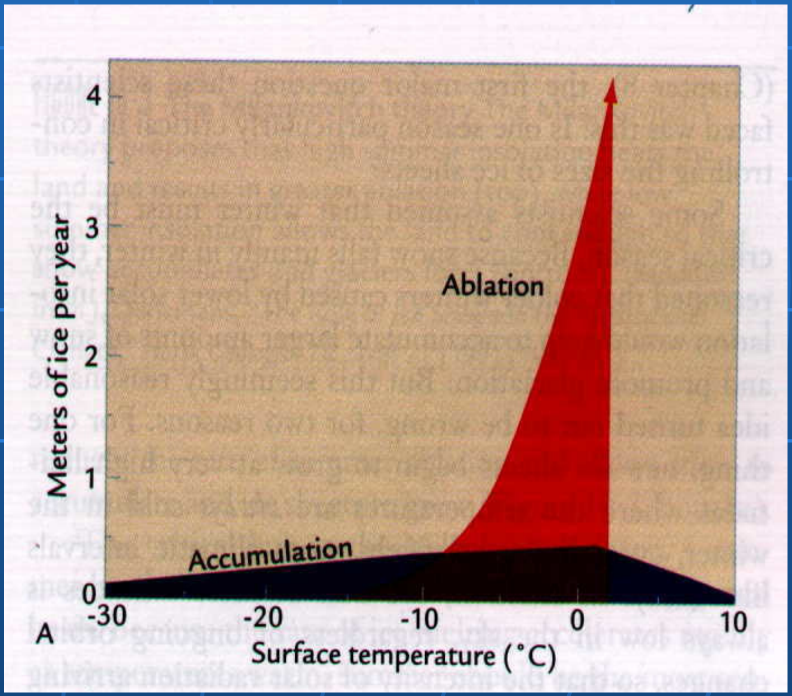
- Vizcaino (2006) coupled Max Planck Institute earth system models to a model of the Greenland and Antarctic ice sheets (80 km, SIA)
  - ESM1: T21, PDD
  - ESM2: T31, surface energy-balance, no flux corrections
- Relatively slow melt rates with modest freshwater fluxes



Difference in elevation (m), model control v. ETOPO5

Surface mass balance

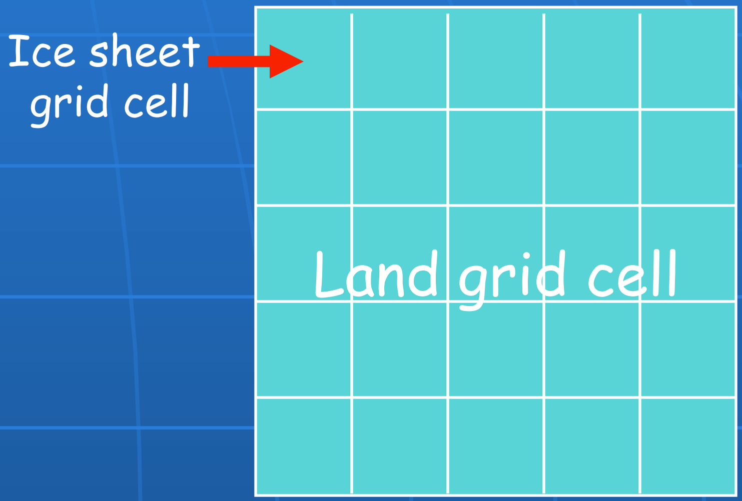
- Ablation increases rapidly with temperature near the melting point and is critical to the mass balance (and possibly the dynamics).
- **Positive-degree-day** (PDD) schemes are not ideal for climate prediction. (Empirical PDD factors can change with the climate.)
- Better to use a physically based **surface-energy-balance** scheme. Melting is computed as a function of surface radiative and turbulent fluxes.



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 changes feed back on the atmosphere



Surface mass balance in CLM

- The land model, CLM, has multiple landunits (vegetated, wetland, lake, urban, glacier) in each gridcell and allows multiple columns in each landunit.
- I have introduced a new landunit type, **glacier_mec**, with multiple(~10) elevation classes in each gridcell. Each elevation column has its own surface fluxes and vertical temperature/snow profile.
- The surface temperature and specific humidity are downscaled to each column based on an assumed lapse rate. (Might try something fancier later.)
- CLM has fairly sophisticated surface energy-balance and snow models, which are used with modest modifications.

Glacier surface mass balance in CCSM

Standard CLM

- Snow in excess of 1 m LWE runs off instantly to the ocean
- Melted ice remains in place until refrozen.

Modified CLM

- Snow in excess of 1 m LWE is converted to new ice.
- Melted ice runs off.
- The net ice growth/ melt rate in each elevation class is passed to GLINT and downscaled to Glimmer.

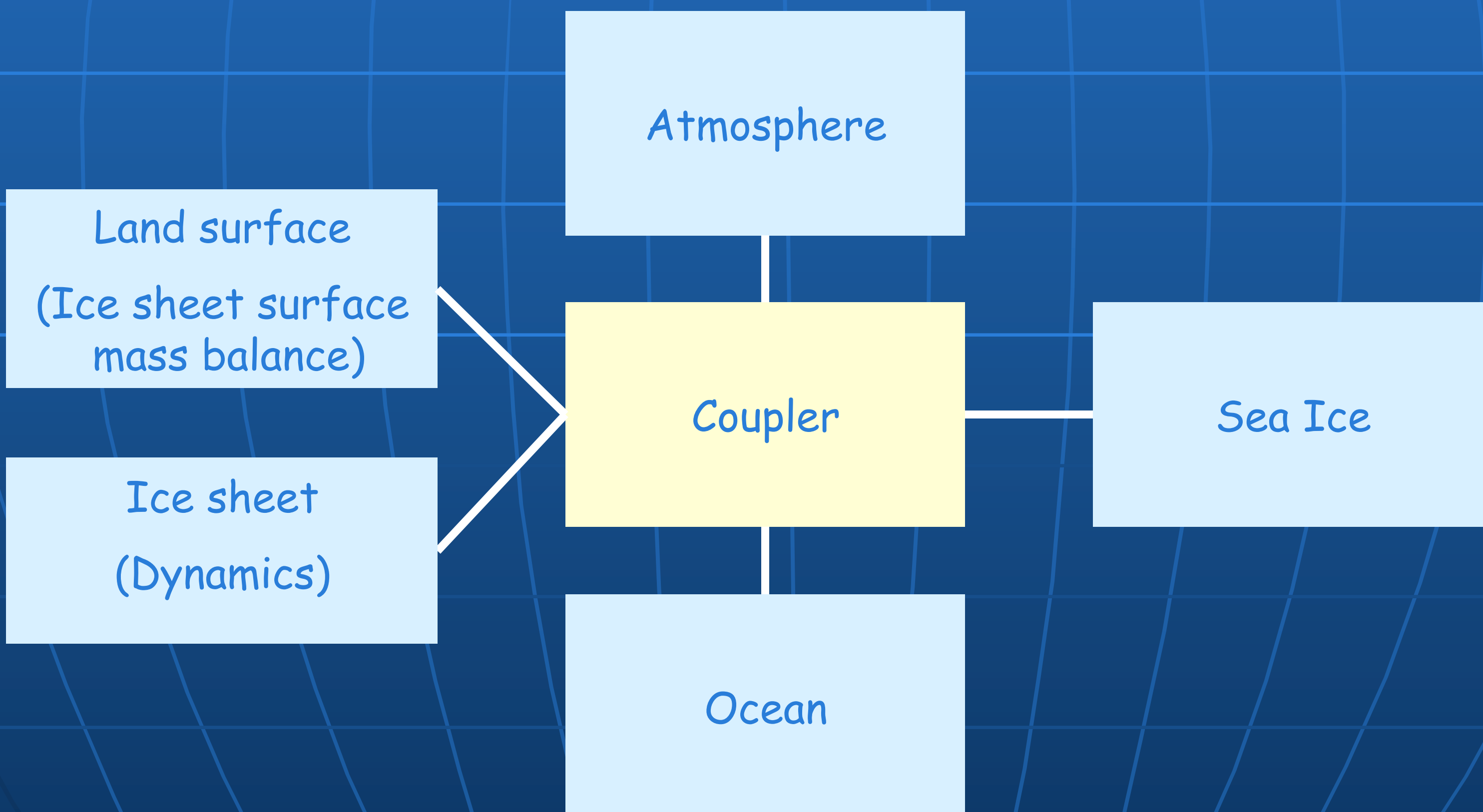
Ice sheet coupling in CCSM

Land -> Ice sheet (10 classes)

- Surface mass balance
- Surface elevation
- Surface temperature

Ice sheet -> Land (10 classes)

- Ice fraction, elevation, thickness
- Runoff/calving flux
- Heat flux to surface



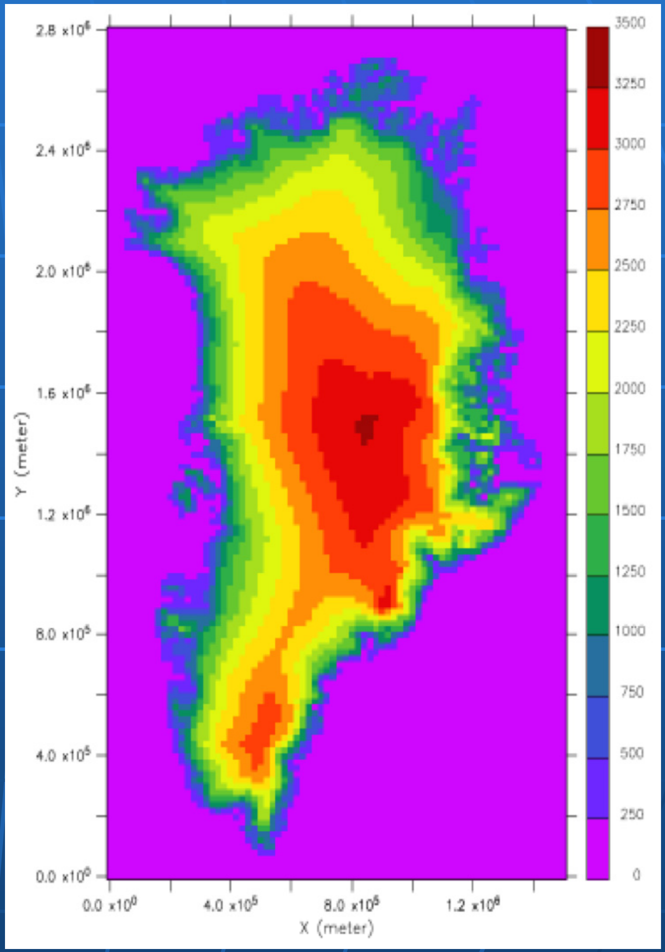
Two modes of coupling

- **One-way coupling:**
  - The land model (CLM) passes the surface mass balance to the ice sheet model, 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 surface topography changes as the ice sheet evolves.

The ice sheet model supplies a freshwater flux that is routed to the ocean, but the ocean topography does not evolve (yet).

CCSM ice-sheet model status

- The Glimmer ice sheet model has been coupled to CCSM 4.0 (Greenland for now; Antarctica and Laurentide later).
- A surface-mass-balance scheme with multiple elevation classes for land ice has been added to CLM.
- Fields are exchanged between CLM and GLIMMER via the coupler. The surface mass balance is downscaled from the land grid to the finer ice sheet grid.



An ice sheet model in CCSM

Work remaining:

- Modify the land topography on the fly.
- Develop a parallel code using POP/ CICE infrastructure.

Climate change experiments:

- Begin with Greenland. IPCC climate-change experiments, Eemian interglacial.
- Add Antarctica when a better ice sheet model is available.

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

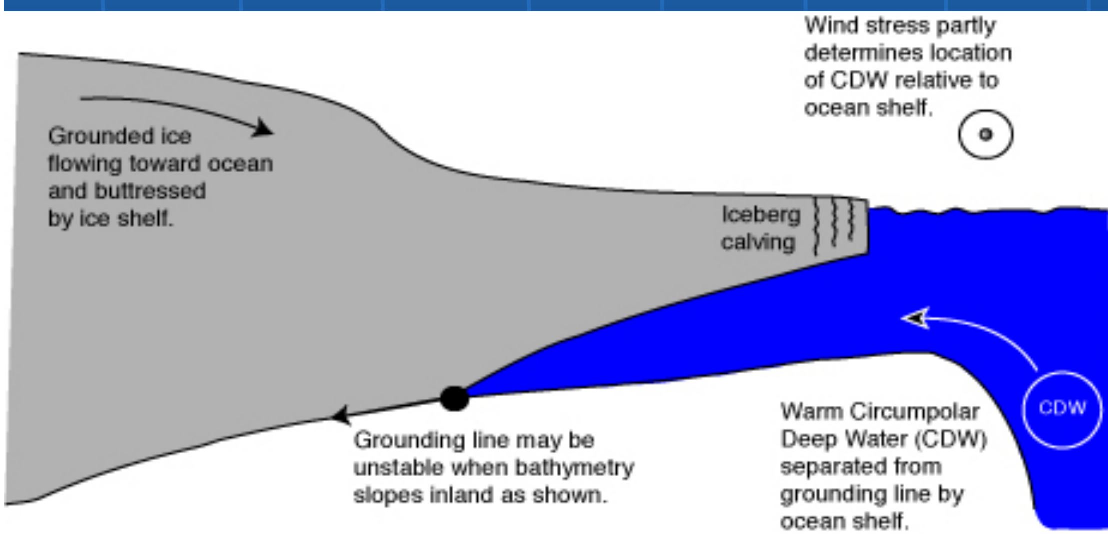
Miren Vizcaino (UC Berkeley) et al. will analyze these runs.

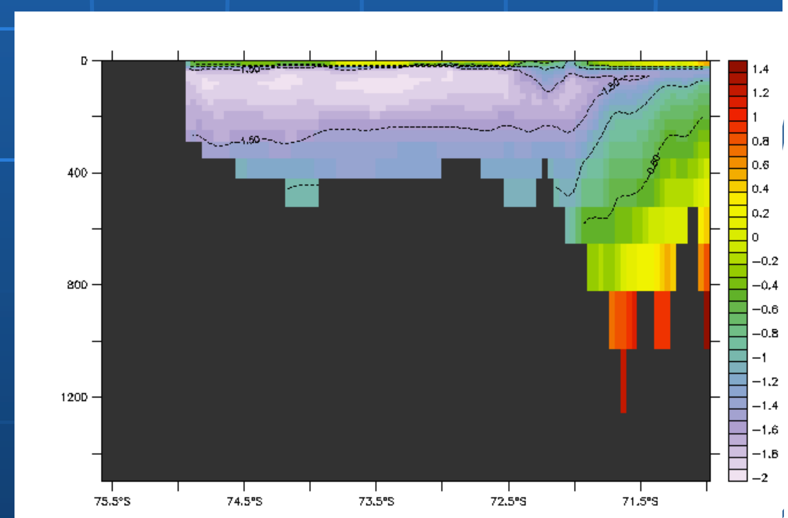
Summary

- The new CCSM ice sheet model (with Glimmer dynamics and a new SMB scheme in CLM) is ready for CCSM4 climate applications.
- Glimmer is of limited value for climate change simulations because it is is missing critical physical processes.
- We aim to have a new and improved Glimmer-CISM implemented in CCSM by 2010, in time for IPCC AR5.
- CCSM will be one of a small number of GCMs making significant contributions to ice-sheet modeling and prediction during the next couple of years.

Preview of coming attractions

- Ice-ocean coupling (DOE IMPACTS project)
  - Couple Glimmer-CISM to the HYPOP ocean model, which has a hybrid vertical coordinate
  - Model ocean circulation beneath dynamic ice shelves

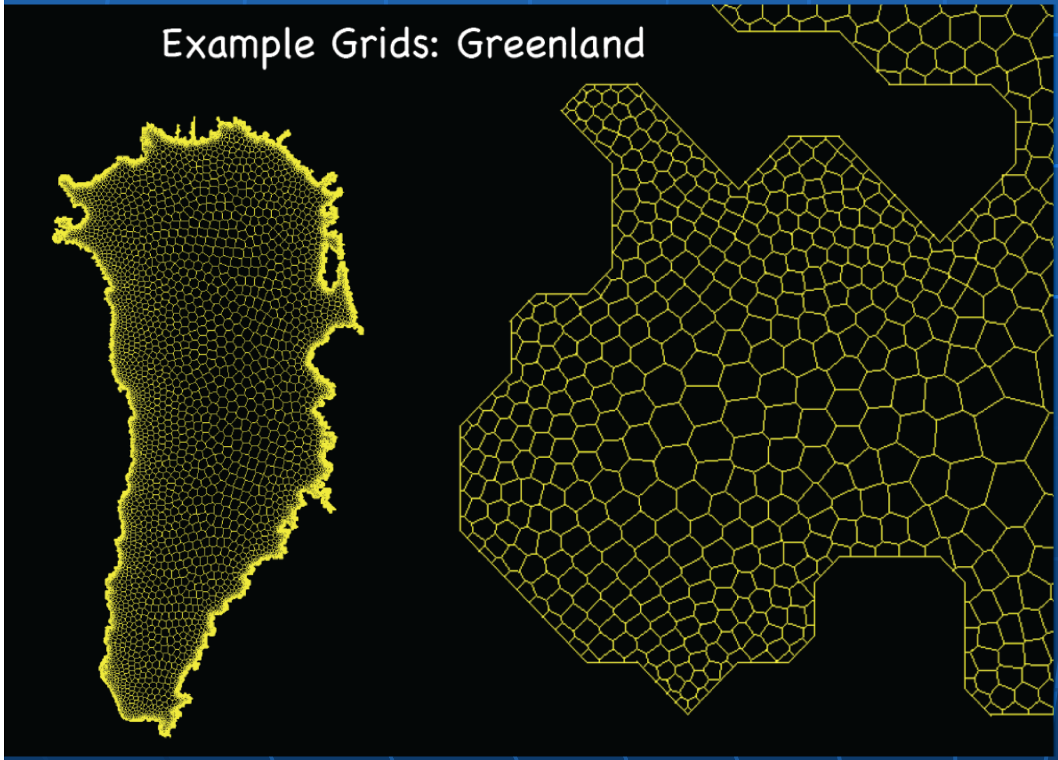


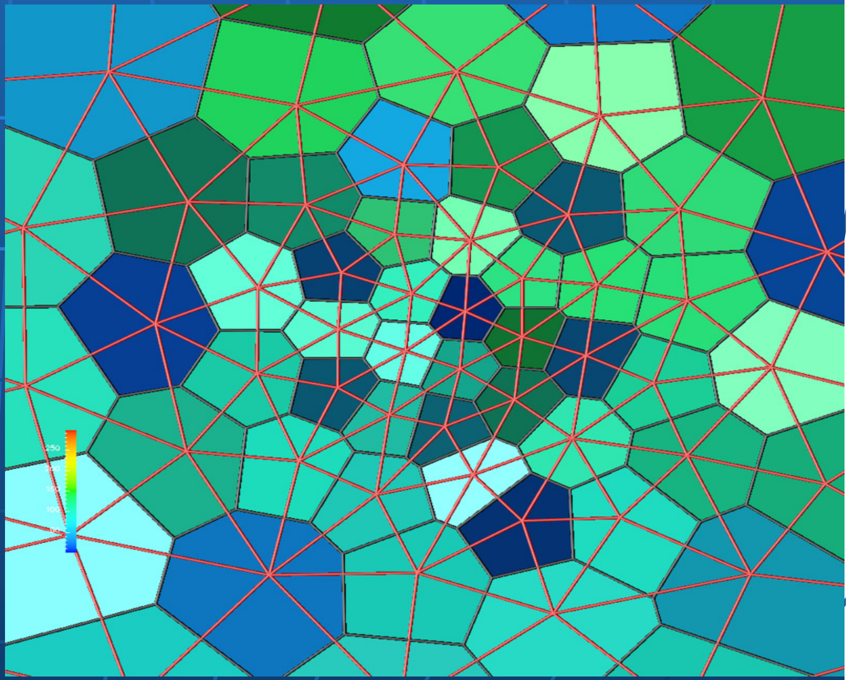


Amundsen sea temperature cross section from POP ocean model

Preview of coming attractions

- Computational advances (DOE ASCR projects)
  - Scalable solvers (e.g., Newton-Krylov)
  - Nested and adaptive meshes






The End