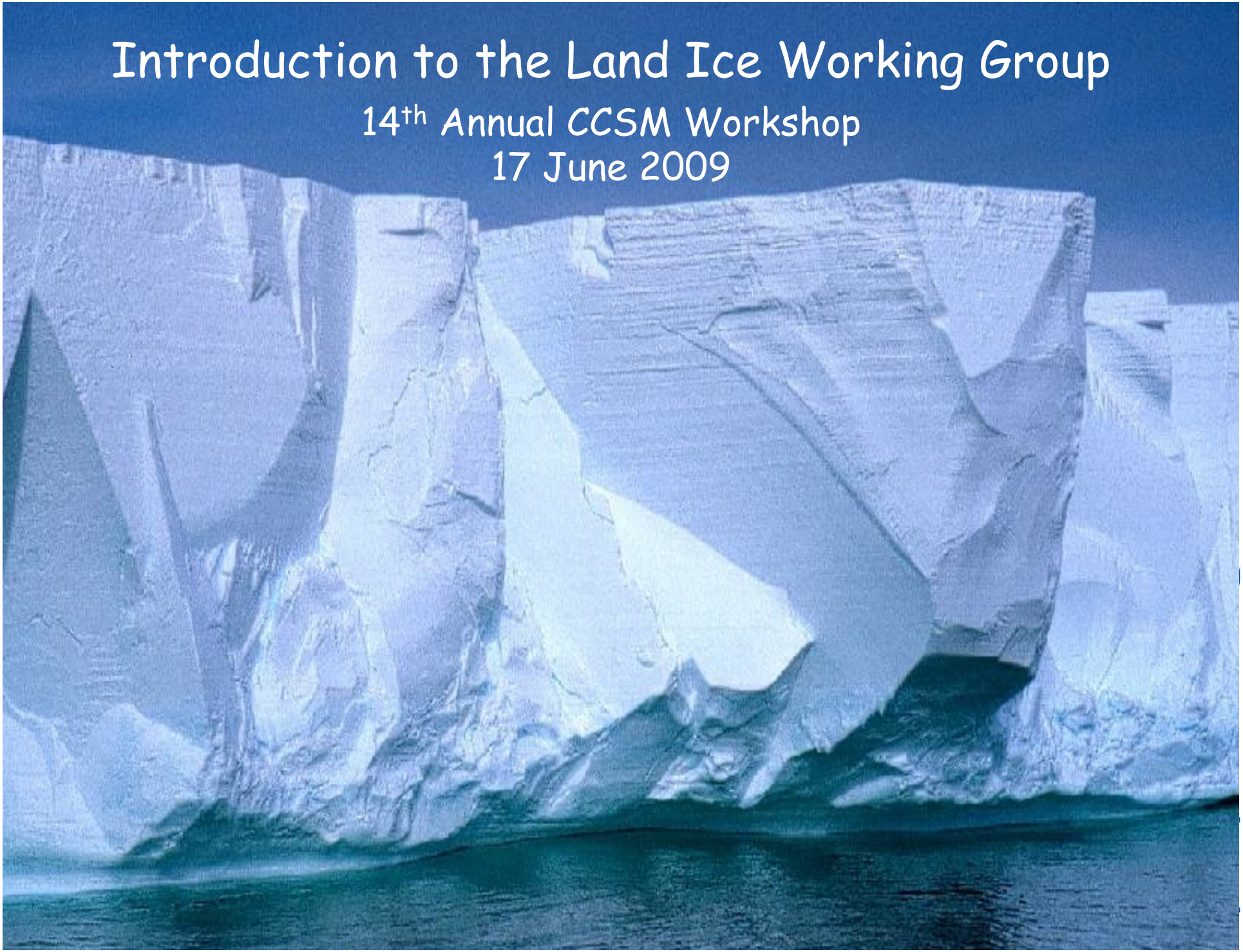
Introduction to the Land Ice Working Group

14th Annual CCSM Workshop

17 June 2009



Outline

- Objectives of the new working group
- Progress in implementing an ice sheet model in CCSM
- Plans for developing an improved community ice sheet model (GLIMMER/CISM)

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

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

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 or Santa Fe?)
  - 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?

Complementary activities

- **DOE/NSF Community Ice Sheet Model (CISM)**
  - NSF IPY: Project to develop a community ice sheet model based on GLIMMER; led by Jesse Johnson (U. Montana), Christina Hulbe (Portland State) et al.
  - DOE SciDAC/IMPACTS: Effort to improve algorithms and couple an ice sheet model to CCSM; led by Bill Lipscomb, Steve Price et al. (LANL)
  - CISM focus groups: Software, datasets, hydrology, calving, ice-ocean coupling, assessment. (Grew out of LANL-sponsoreworkshop, Aug. 2008)
  - Wiki sites:

    http://oceans11.lanl.gov/trac/CISM

    http://websrv.cs.umt.edu/isis/index.php/Main_Page

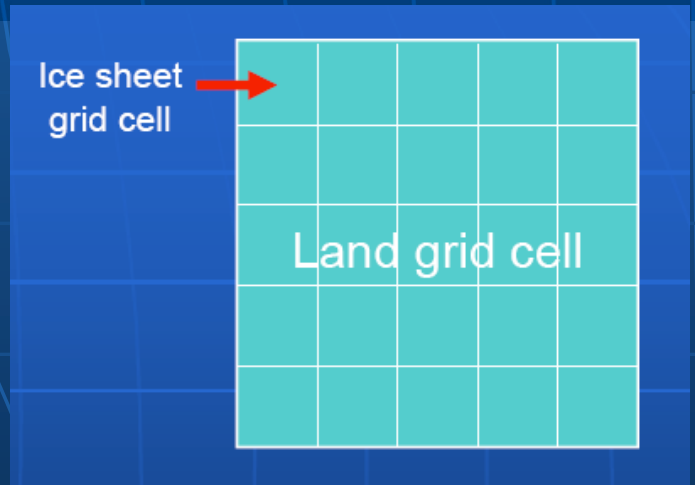
Complementary activities

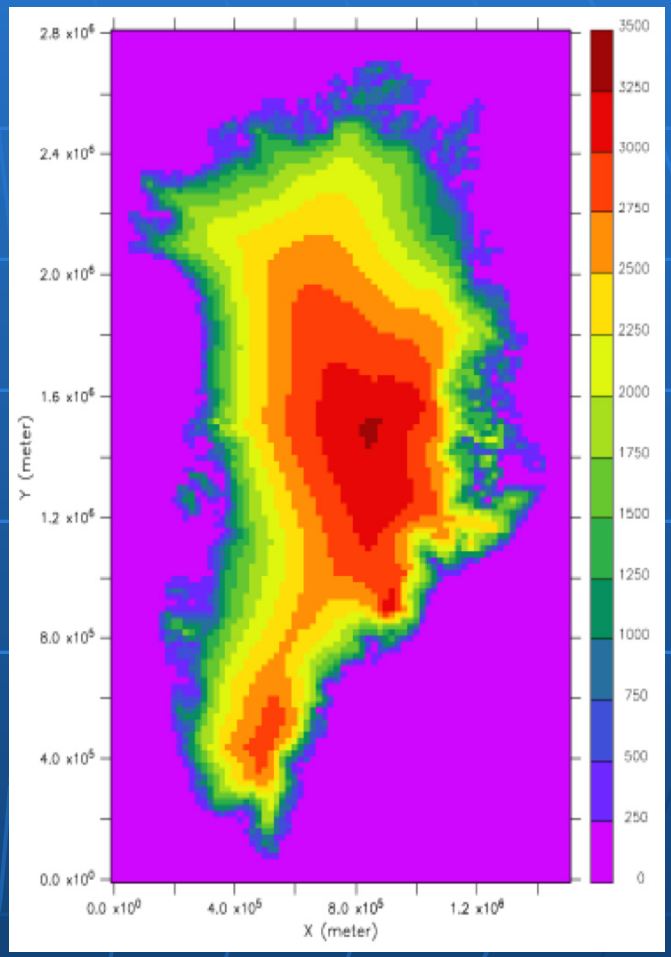
- Other model development groups
  - GLIMMER: UK model developed by Tony Payne, Ian Rutt, Magnus Hagdorn et al.; will be used in CCSM and Hadley Centre model
  - Parallel Ice Sheet Model (PISM): NASA-funded model developed at UAF by Ed Bueler, Jed Brown et al.
  - Many others: e.g., JPL, GFDL, Penn State, Portland State, U. Maine, U. Chicago, NYU, FSU, U. Texas, UC Irvine, U. Toronto, ETH, ULB, LGGE, . . .
- Sea-level assessment efforts
  - SeaRISE: U.S. effort led by Bob Bindschadler

    Thursday, 11:00 – 5:00 Tarn room
  - Ice2sea: European effort (details from Jeff Ridley)

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.





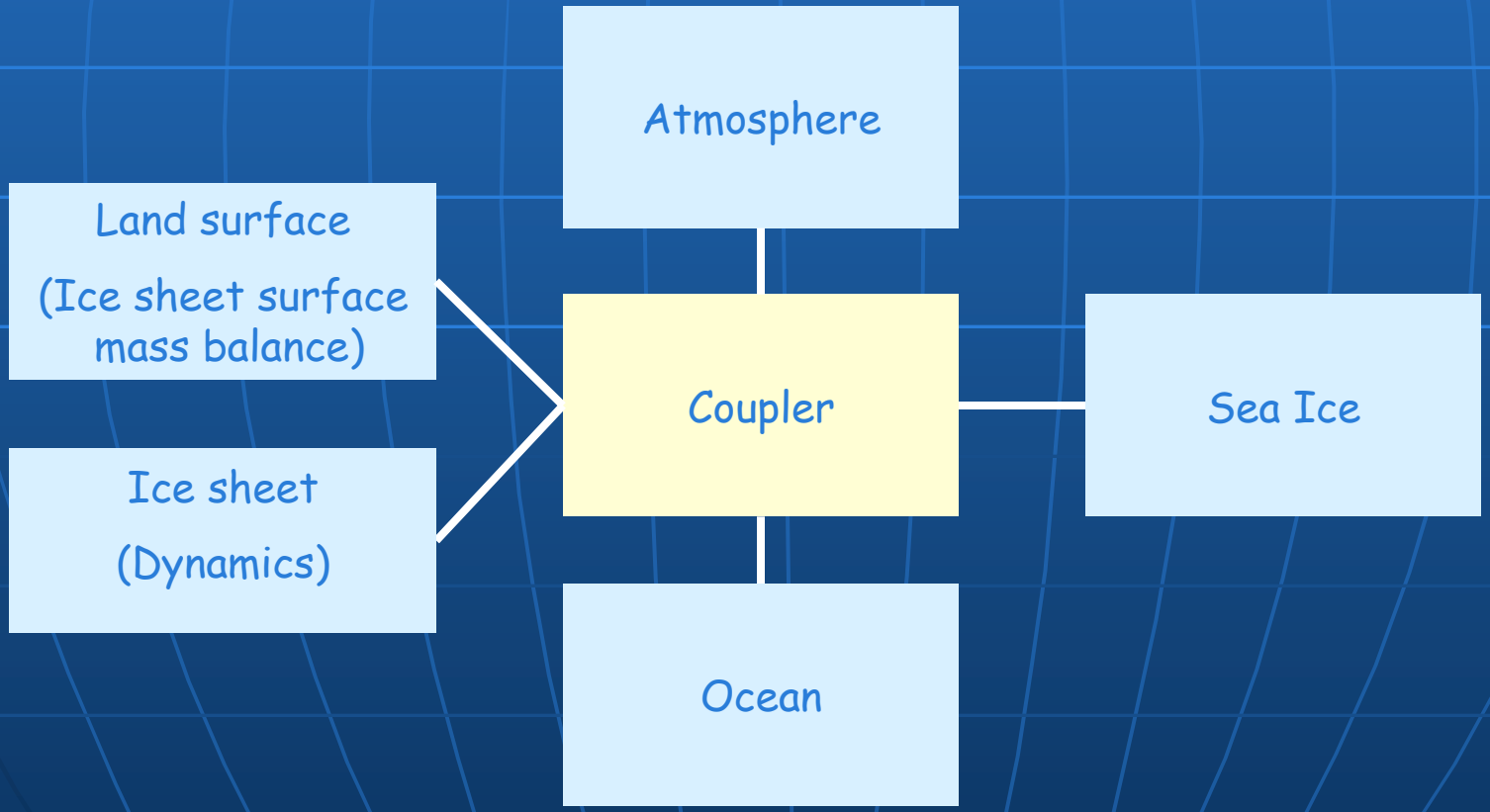
Ice sheet coupling in CCSM

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 land surface



Proposed CCSM4 experiments with GLIMMER
(1° atm, 1° ocn)

1. Control

- Pre-industrial control, 230+ 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

Ice sheet modeling challenges

- GLIMMER is currently a serial code with shallow-ice dynamics, not valid for fast-flowing regions (ice streams and outlet glaciers) and near grounding lines.
- We aim to develop a next-generation Community Ice Sheet Model (CISM):
  - **Beyond the shallow-ice approximation:** "higher-order" or full-Stokes models with a unified treatment of vertical shear stresses and horizontal-plane stresses
  - **Improved physical processes:** surface mass balance, subglacial hydrology, grounding line migration, iceberg calving
  - **Ice-ocean coupling:** variable ice shelf geometry, sub-shelf melting, grounding-line migration
  - **High resolution:** ~5 km or less at whole-ice-sheet scale; scalable parallel codes are needed

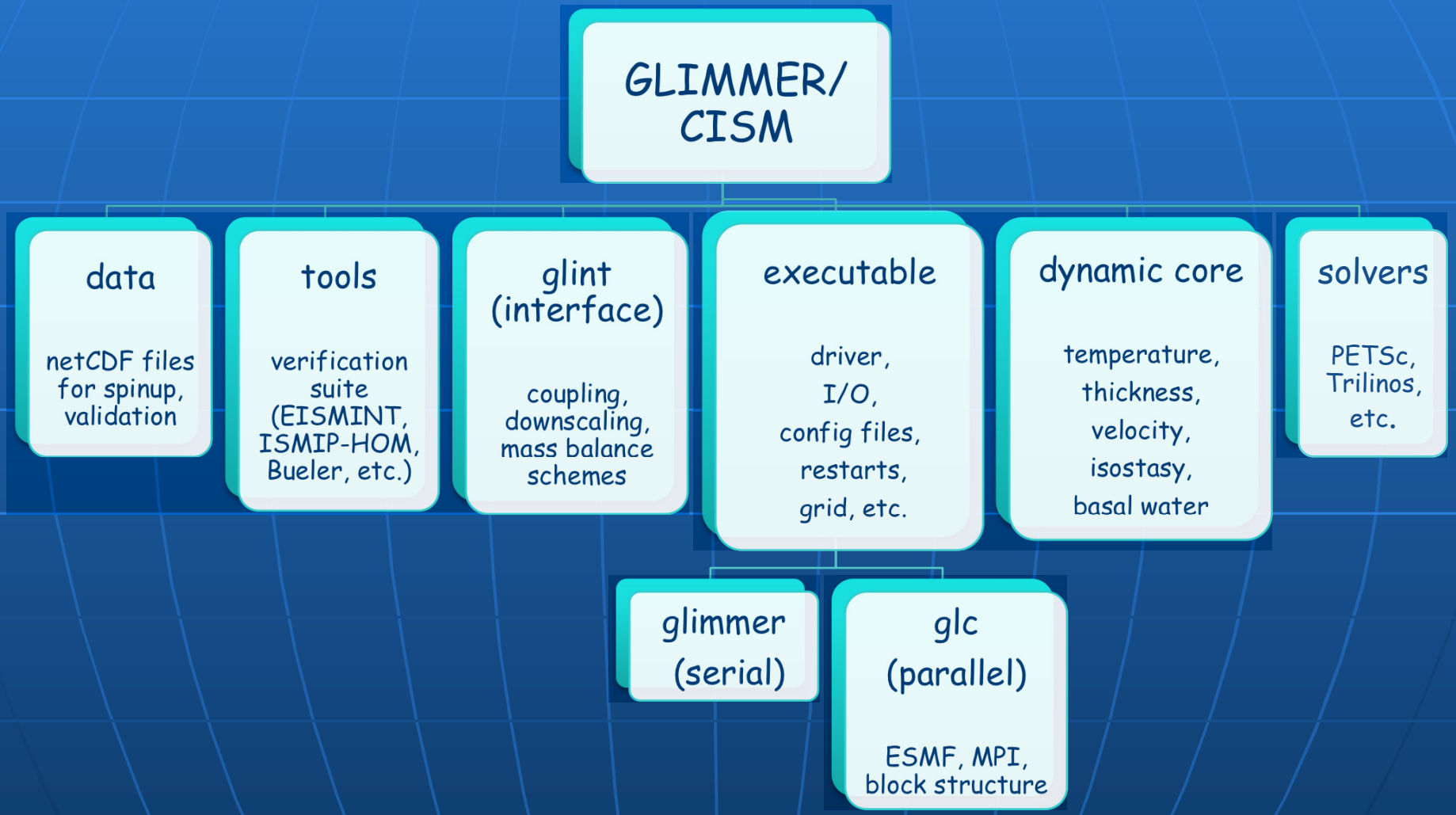
Guidelines for model development

- Scientifically valid
  - Obtain the most accurate and robust results possible, given the available computing resources
- User-friendly
  - Modular (easy to plug and play)
  - Portable (from laptops to petaflop HPCs)
  - Well documented, with uniform coding standards
- Freely available
  - Open-source code on public repository
  - At the same time, respect the authorship and professional needs of code developers

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



Acknowledgments

- Anjuli Bamzai (DOE)
- Jay Fein (NSF)
- Gary Geernaert and Phil Jones (LANL)
- Peter Gent (NCAR)
- Bill Collins (LBL)
- Bob Bindschadler (NASA)

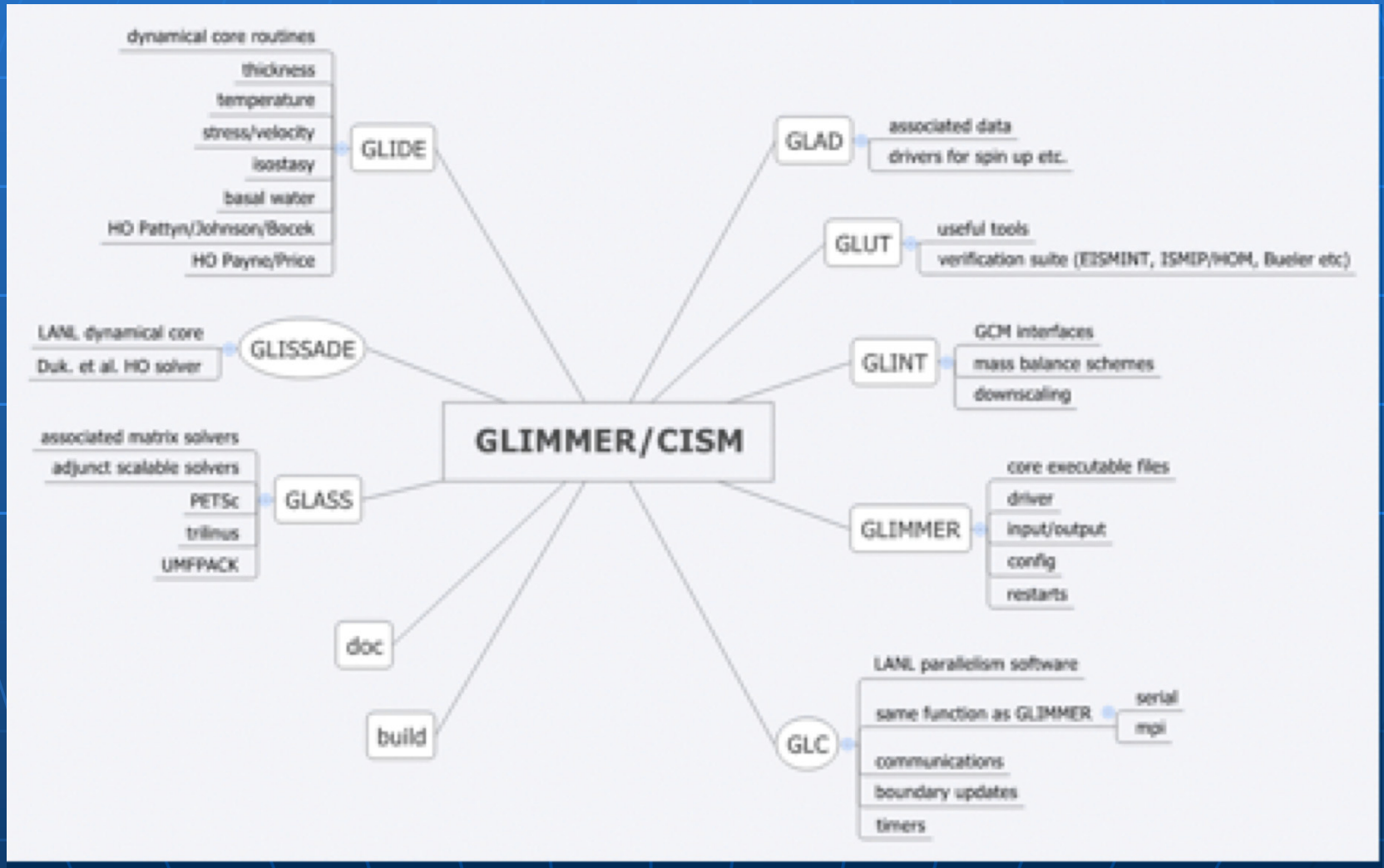
and many others in the CCSM and GLIMMER communities

Extra slides

Summary

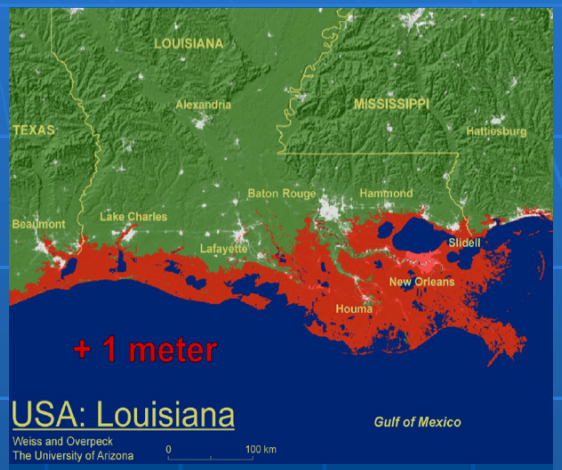
- The GLIMMER/CISM ice sheet model will be ready for CCSM4 climate applications this year, but it is missing physical processes that are critical for predicting decadal-scale sea level rise.
- We aim to have a new and improved Community Ice Sheet Model available by 2010, in time for IPCC AR5.
- CCSM will be one of a small number of GCMs making significant contributions to ice-sheet modeling and prediction during the next few years.

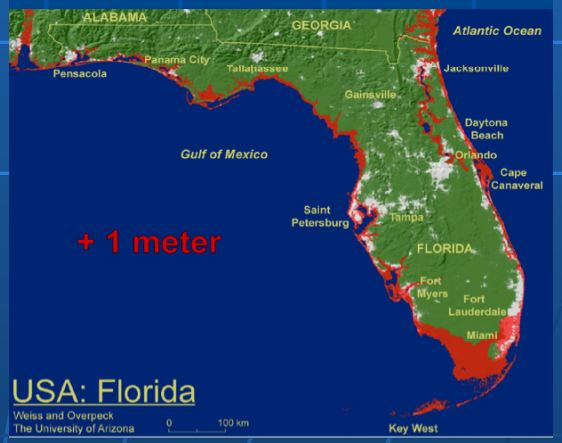
CISM development plan



Ice sheets and sea level rise

- 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.

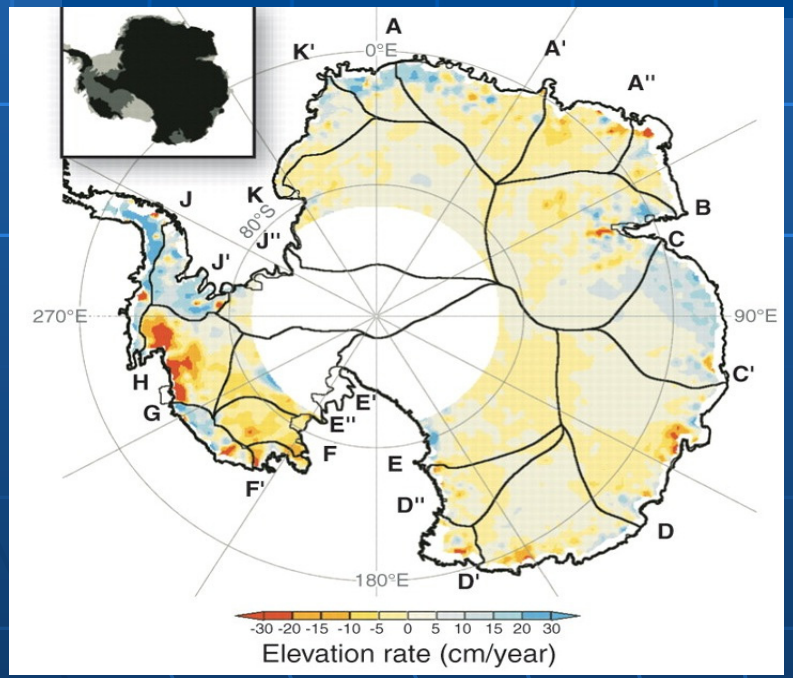




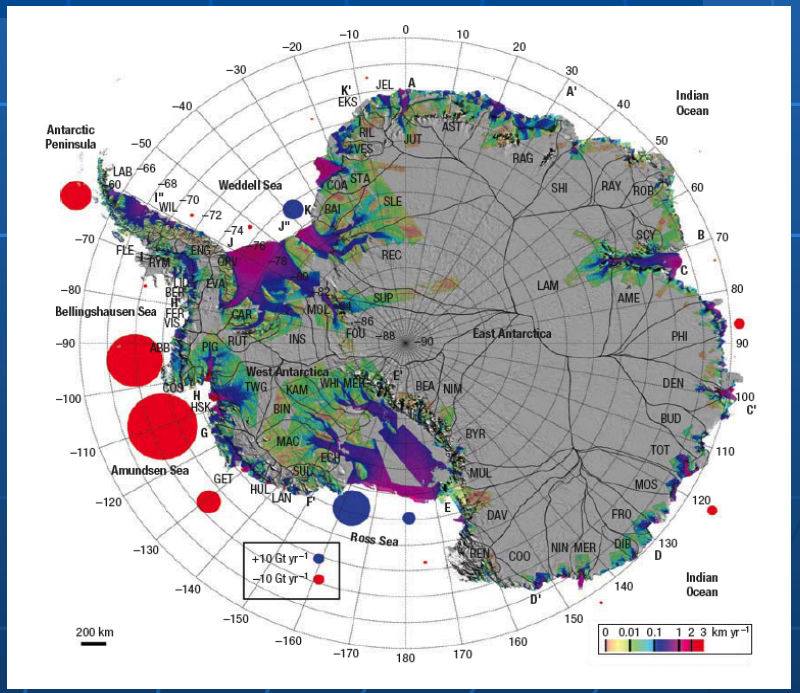
•200 million people in regions <1m
•Raising California Central Valley levees by 0.15 m, will cost over $1 billion

Ice sheet mass balance: Antarctica

- Enough ice to raise sea level by ~60 m, with ~3 m in West Antarctica vulnerable to fast retreat (Bamber et al. 2009)
- Ice discharge estimates suggest a loss of ~200 Gt/yr from West Antarctica and the Antarctic Peninsula, with East Antarctica nearly in balance (for intiution: 500 Gt = 1.4 mm).
- Outlet glaciers in the Amundsen Sea embayment are accelerating and thinning, probably forced by the ocean.



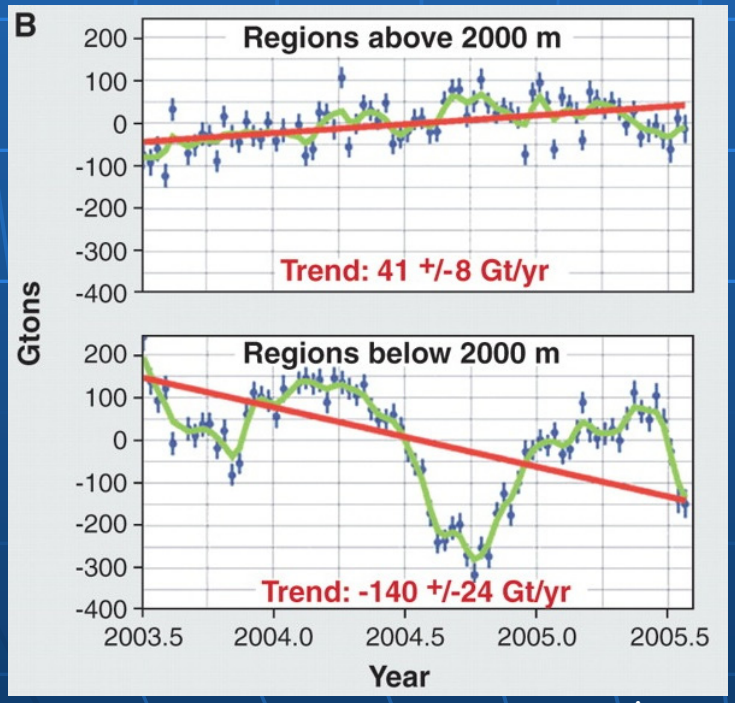
Sheperd and Wingham (2007)

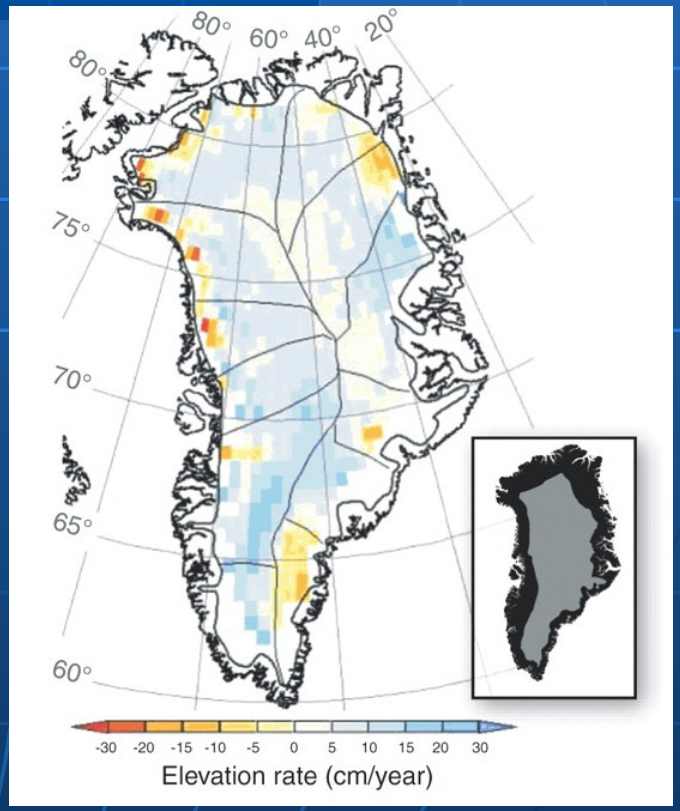


Rignot et al. (2008)

Ice sheet mass balance: Greenland

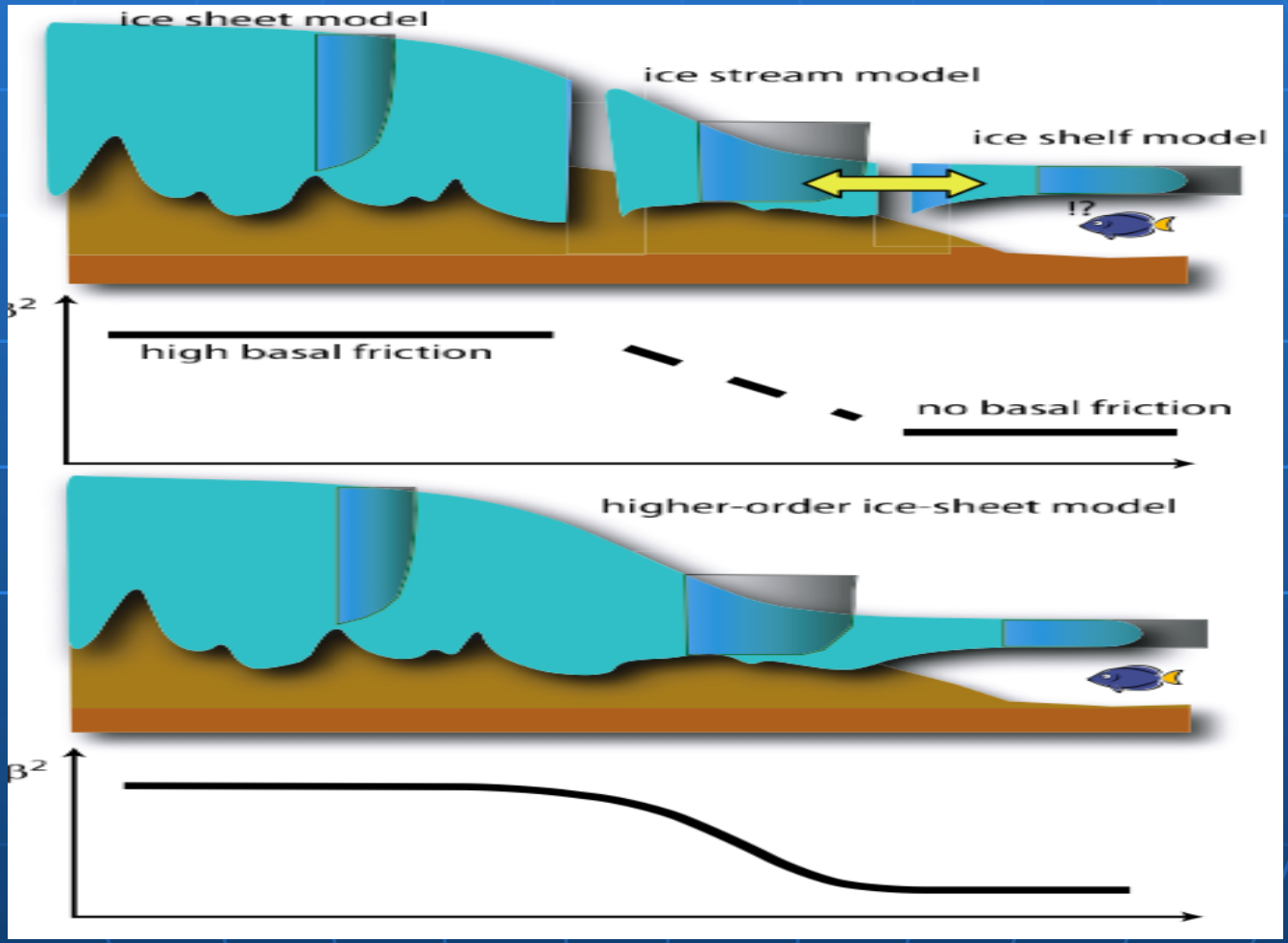
- Enough ice to raise sea level by ~7 m
- Significant and increasing mass loss (~100-200 Gt/yr) since late 1990s
- Attributed to increased surface melting as well as accelerating outflow from large outlet glaciers





Sheperd and Wingham (2007)

Why the Emphasis on "Higher Order" Models?



Pattyn (2006)

Status of HO Modeling in CISM