The heroic age of ice sheet modeling: CISM, PISM and all that

William Lipscomb

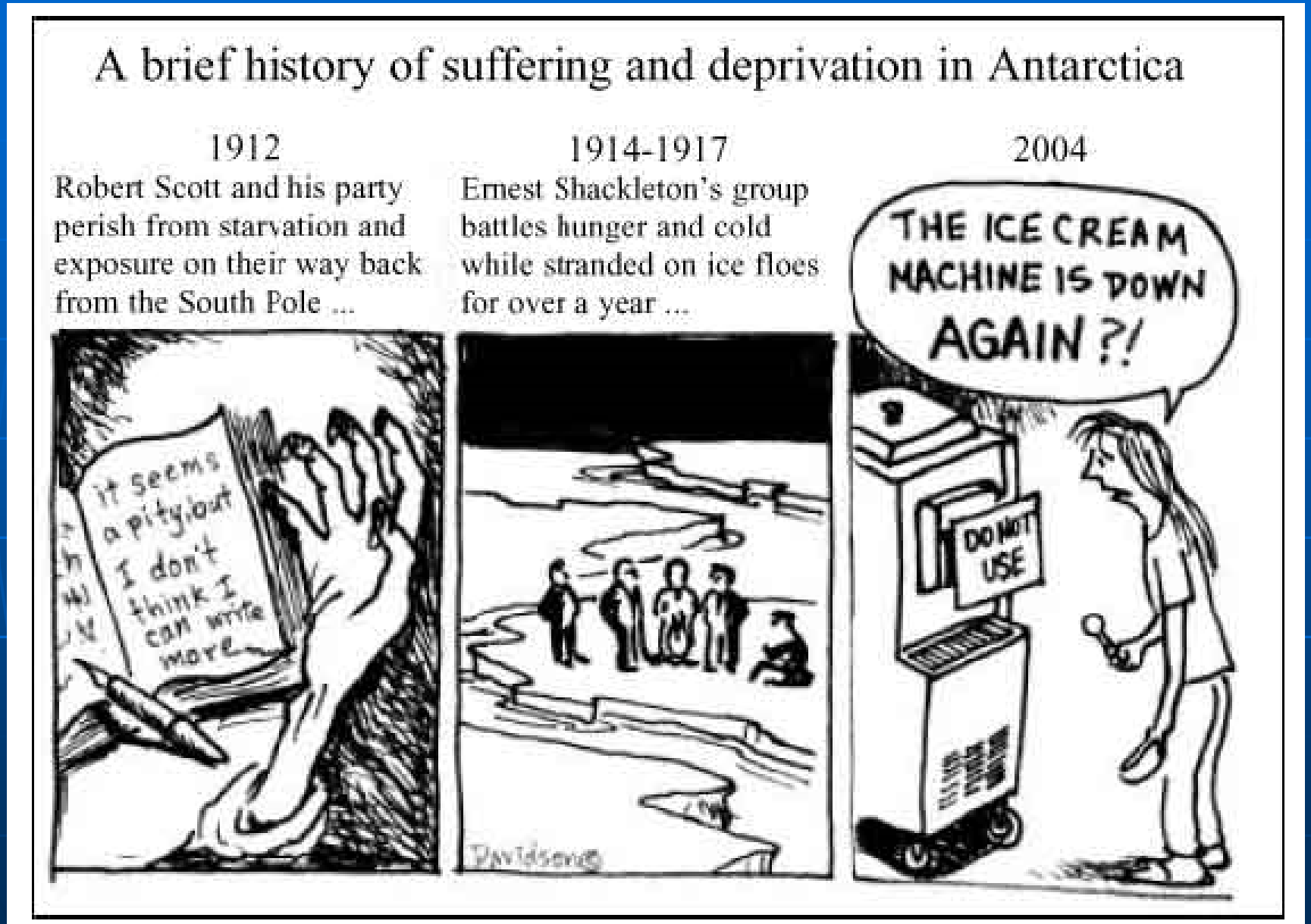
Los Alamos National Laboratory

Outline

- Why this is a heroic age
- Two community models
  - Glimmer-CISM
  - PISM (courtesy of Ed Bueler)
- Related modeling activities
  - Ice sheets in CCSM
  - SeaRISE and Ice2sea
  - DOE IMPACTS
- Challenges for this project

What is a heroic age?

- A time when a small number of bold, ambitious, and/or foolhardy explorers attempt to do something important and unprecedented at considerable risk.
  - It's impossible to predict which activities will succeed and which will not.
  - Future generations will have an easier time; what was impossible will become routine (but not as exciting).



Matt Davidson, The Antarctic Sun, 18 Jan. 2004

A heroic age for ice sheet modeling?

- We have been asked to do many hard things at once:
  - Improved dynamical cores (full-Stokes and/or higher-order stress balance)
  - More realistic physics (surface mass balance, basal sliding, iceberg calving, sub-shelf melting, grounding-line migration, etc.)
  - High grid resolution (~1 km; need scalable solvers)
  - Coupling to global climate models (atmosphere, land, ocean, sea ice)
  - Portable, user-friendly code adapted for emerging architectures

A heroic age for ice sheet modeling?

- And we're expected to produce significantly improved sea-level predictions (with error bars!) for IPCC AR5.
  - AR5 is scheduled for release in 2013.
  - Model results must be analyzed and written up by 2012.
  - Peer-reviewed publications must be accepted by the end of 2011.
  - Model simulations must be well under way by 2010.

Current tools: CISM and PISM

- CISM is the Community Ice Sheet Model (aka Glimmer or Glimmer-CISM), which is being developed in the U.S. and U.K. with support from DOE, NSF, and NERC.
- PISM is the Parallel Ice Sheet Model, developed primarily at the University of Alaska with support from NASA.

A brief history of Glimmer-CISM

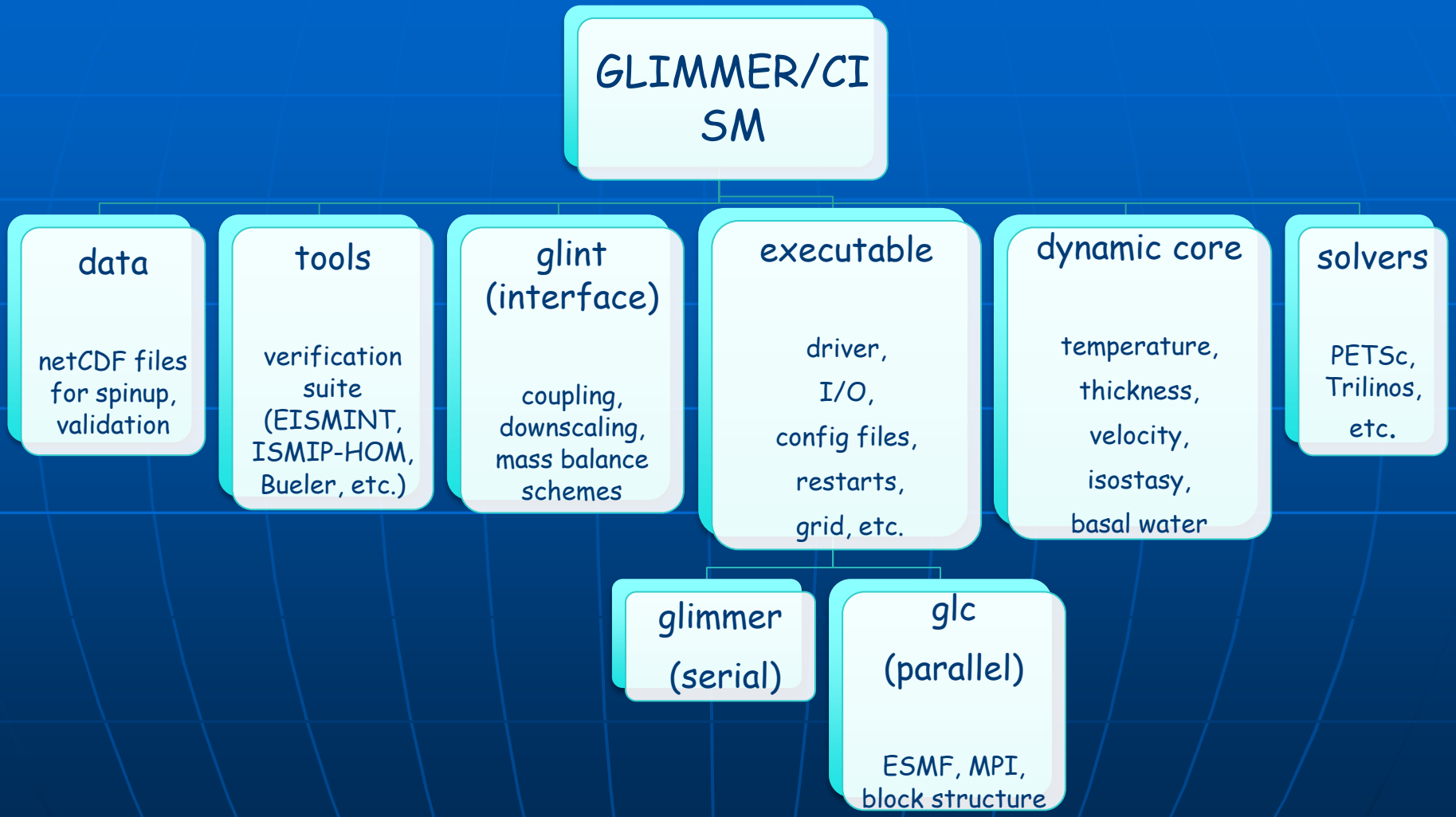
- The **Glimmer** ice sheet model (Rutt et al. 2009) was developed by Tony Payne and colleagues in the U.K. for the purpose of including dynamic ice sheets in global climate models.
  - Object-oriented F95 code; multiple ice-sheet instances
  - Includes an interface (GLINT) for coupling to GCMs
  - Serial code with shallow-ice dynamics
- Two recent U.S. efforts have built on Glimmer:
  - NSF has supported scientists at U. Montana and elsewhere to develop a Community Ice Sheet Model (CISM) based on Glimmer.
  - DOE SciDAC has supported LANL scientists to couple Glimmer to the Community Climate System Model (CCSM) for IPCC simulations and other climate change experiments.

A brief history of Glimmer-CISM

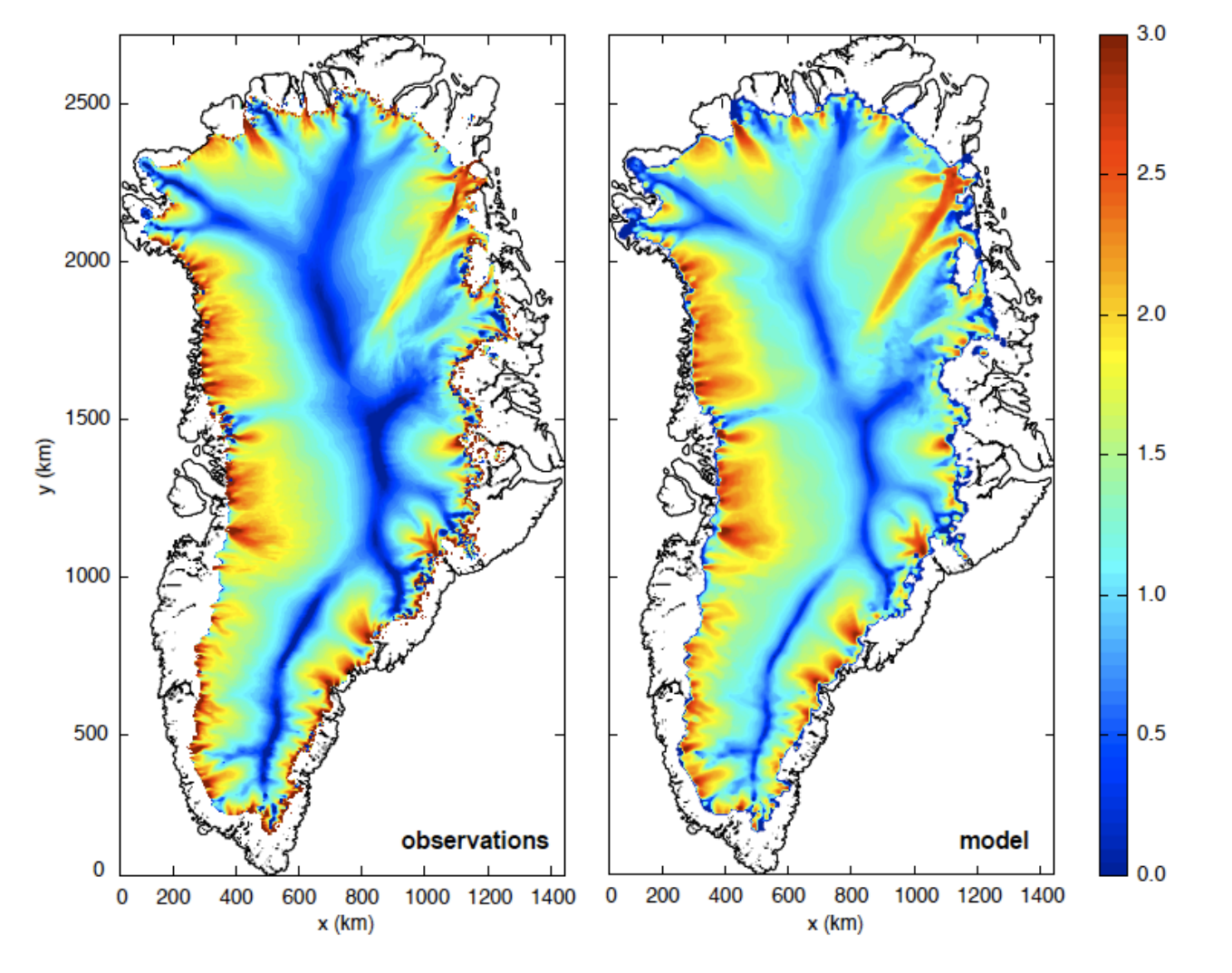
- The U.S. and U.K. groups have recently combined efforts.
  - Glimmer-CISM is being developed in a Subversion repository on BerliOS:

    http://developer.berlios.de/projects/glimmer-cism/
  - Code development is overseen by a 6-member steering committee.
    - M. Hagdorn, A. Payne, I. Rutt (U.K.)
    - J. Johnson, W. Lipscomb, S. Price (U.S.)
- The model now includes two higher-order ice-flow schemes (Payne-Price and Pattyn-Bocek-Johnson).
  - The code is still serial, with inefficient solvers.
  - Need unstructured/adaptive grids and implicit scalable solvers!

Schematic model framework



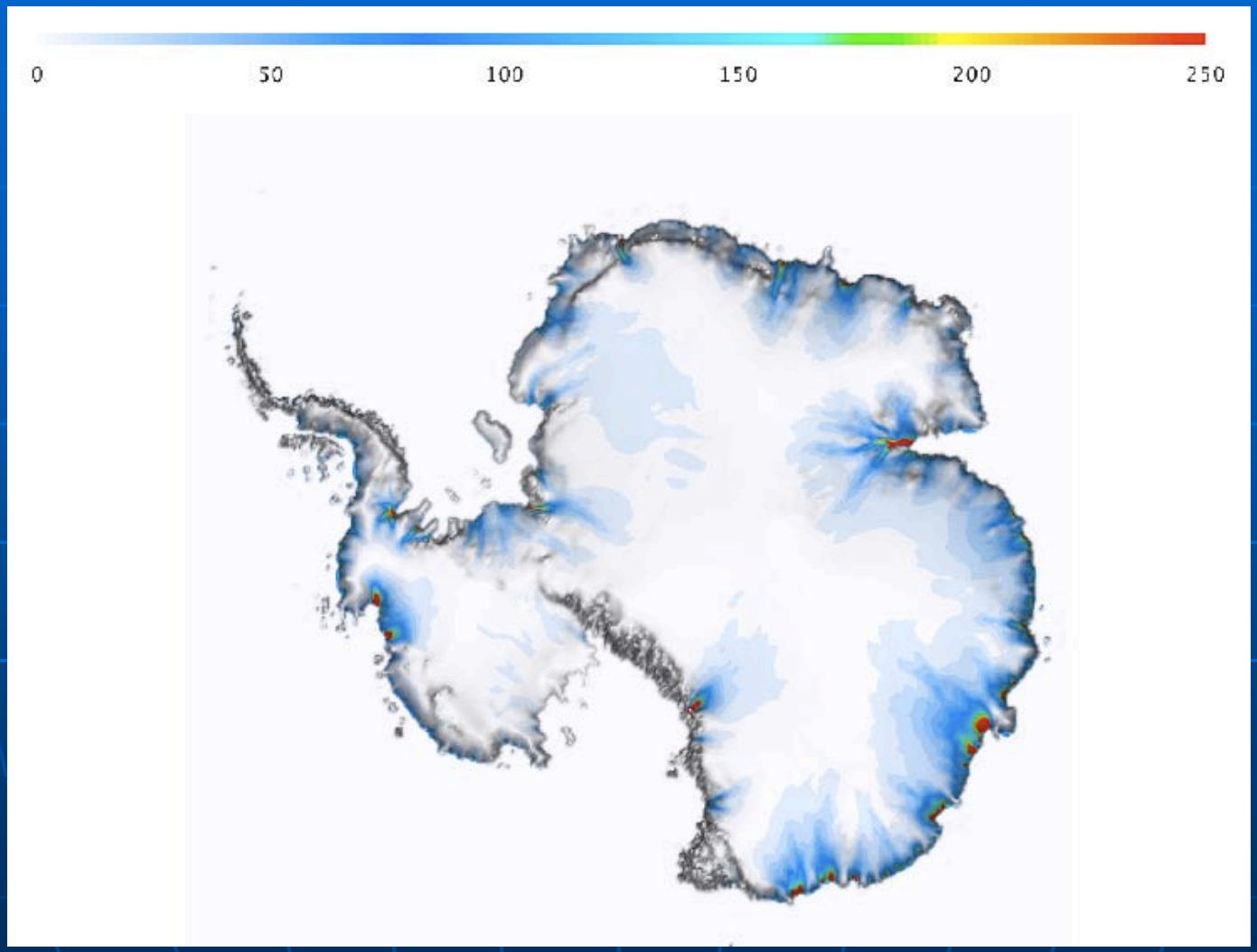
Greenland results



Left panel: Steady-state surface velocity (log of m/yr) based on modern-day observations.

Right panel: Velocity from higher-order (Payne-Price) flow model with tuned basal parameters.

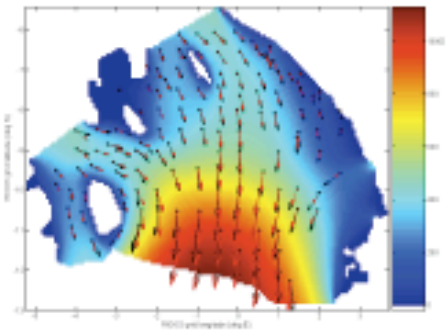
Antarctic results

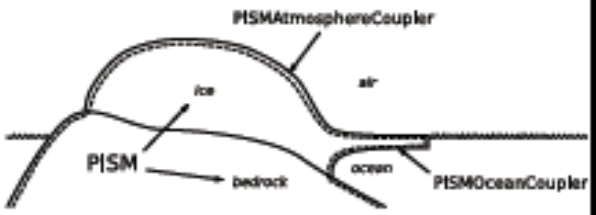


Surface velocity of the Antarctic ice sheet from Glimmer-CISM after a 2000-year spinup at 15 km resolution. (Shallow-ice dynamics with prescribed grounding line location.)

PISM = the Parallel Ice Sheet Model

- `www.pism-docs.org` (open source!)
- supported by NASA Modeling, Analysis, and Prediction
- ice sheet and shelf (upper figure) modeling
- architecture:
  - MPI/PETSc parallelization
  - rectangular horizontal grid
  - arbitrary vertical spacing
  - C++ code; partial object-orientation
  - parallel NetCDF I/O
  - isolation of boundary processes from ice/earth dynamic core (lower figure)
  - well-documented
- shallow hybrid ice flow model (next)
- UAF team: Bueler, Khroulev, Aschwanden, Brown (emeritus)
- collaboration with Potsdam PIK for Antarctica



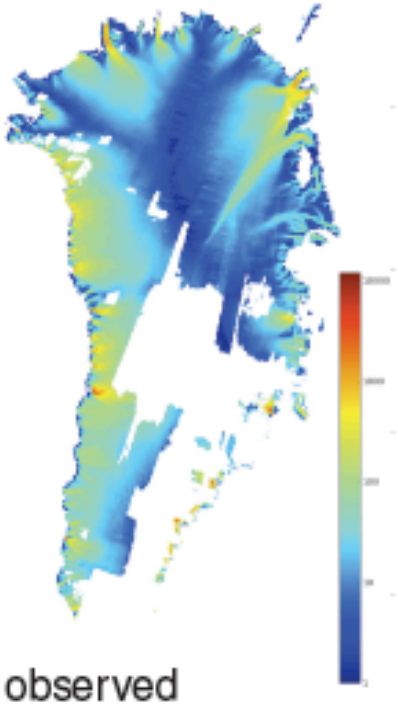


PISM: continuum models

- ice velocity determined by "shallow hybrid" of non-sliding shallow ice approximation (*SIA*) along with shallow shelf approximation (*SSA*), a membrane stress balance, to model sliding (Bueler and Brown 2009)
- Schoof (2006) free boundary concept for ice streams, using SSA and plastic/pseudo-plastic till strength model
- evolving geometry (mass continuity)
- polythermal conservation of energy
- earth deformation
- verification taken seriously (Bueler et al. 2005,2007)
- shallow hybrids can be used *now*
  - at high resolution (5km or finer Greenland grids)
  - for paleoglacial time scales

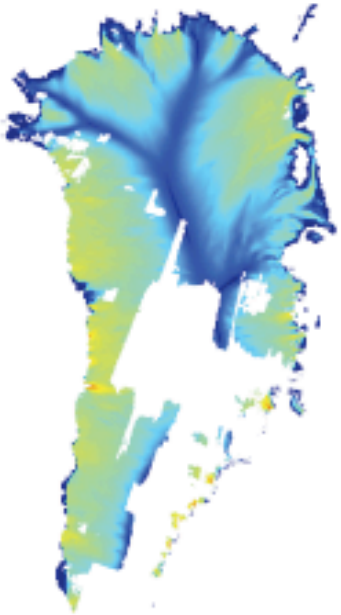
PISM: generic model of fast flow in Greenland

- inverse modeling and data assimilation processes will be essential to century-scale prediction ability, but
- currently PISM has a generic model with a few (< 10) total parameters controlling ice flow and sliding
- assumed marine history for low elevation basal sediments determines till friction angle (in generic case)



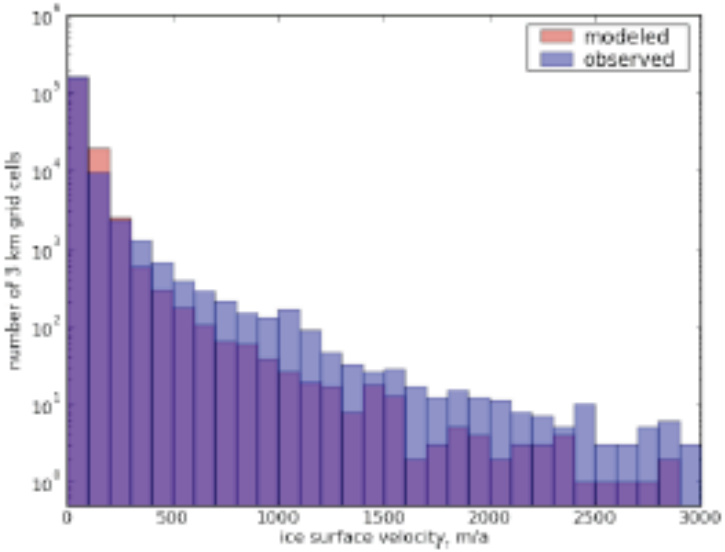
observed

inSAR/speckle surface speed (Ian Joughin)



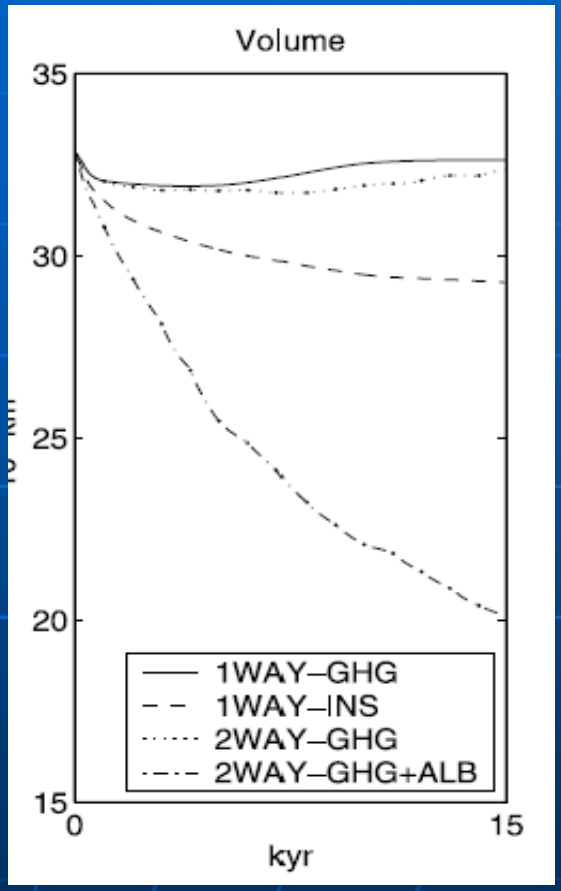
PISM 3km model

medium enhancement, medium pore pressure, very plastic till



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 ocean thermohaline circulation.
  - As ice sheets melt and retreat, the local climate can change, modifying the rate of retreat.

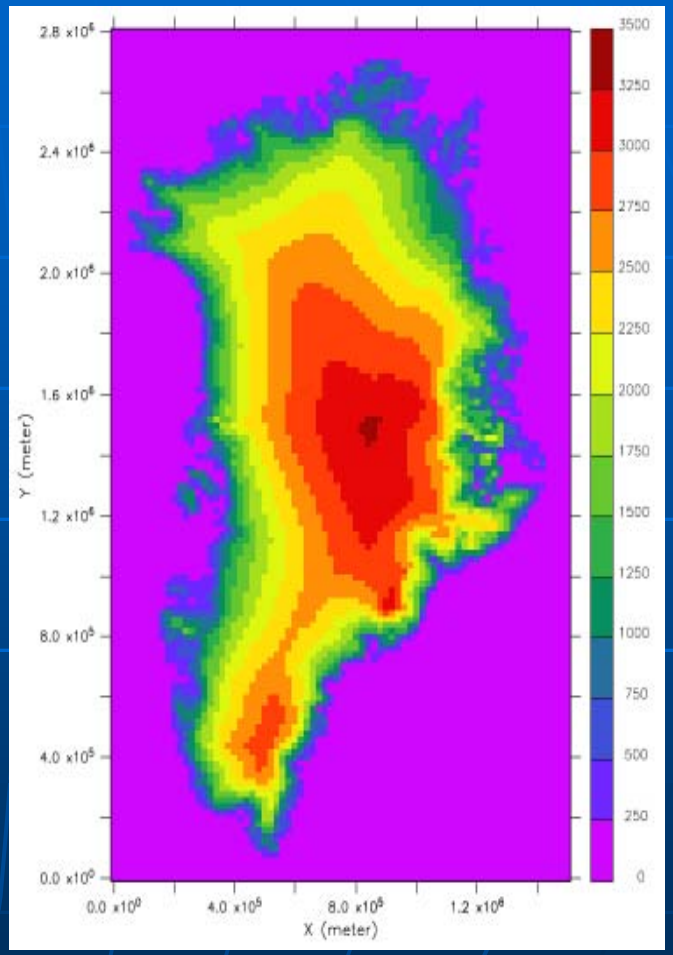


Laurentide volume change

Pritchard et al. (2008)

CCSM ice-sheet model status

- Glimmer has been coupled to CCSM 4.0 (Greenland now; Antarctica and Laurentide later).
- A surface-mass-balance scheme with multiple elevation classes for land ice has been added to the land surface component, 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.
- Glimmer will be replaced soon with the latest version of Glimmer-CISM.



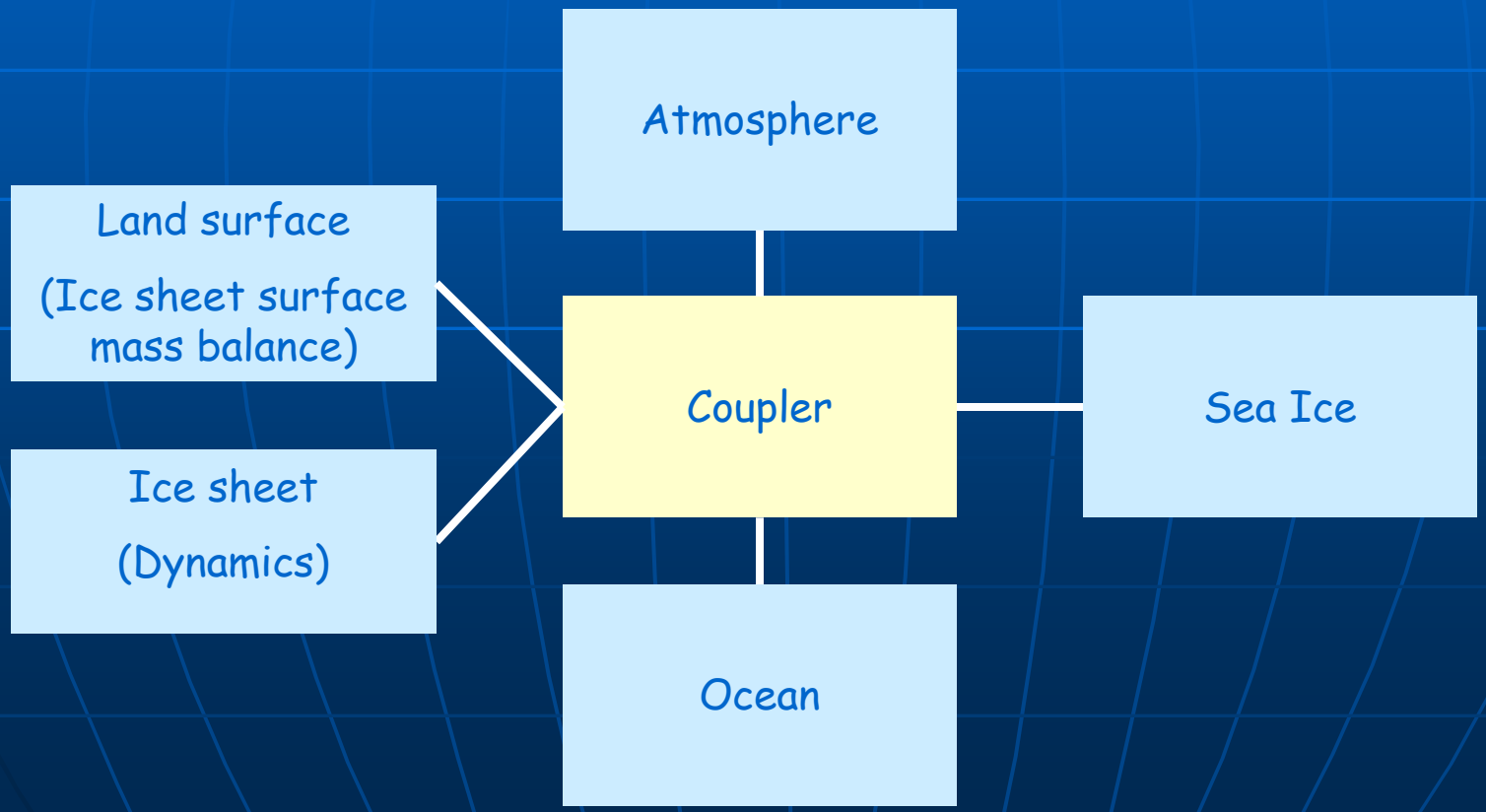
Ice sheet coupling in CCSM

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



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 Feb. 2010)
  - Web site and email list: http://www.ccsm.ucar.edu/working_groups/Land+Ice/

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.

SeaRISE

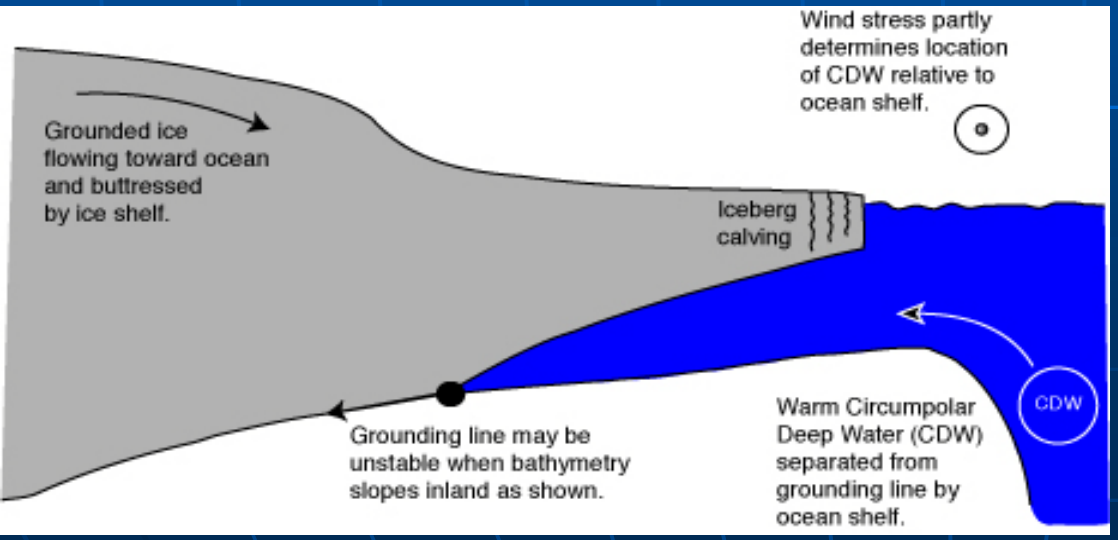
- **SeaRISE** is an international project, led by Robert Bindschadler, with the goal of reducing uncertainties in predictions of sea-level rise associated with ice sheet retreat.
  - Focusing on next one to two centuries
  - Developing standard data sets and experimental protocols
  - Three kinds of experiments: whole ice sheet, regional ice sheet/shelf, and ice-ocean
  - Several models, including Glimmer-CISM and PISM, are participating.
  - Relatively informal with mostly voluntary participation

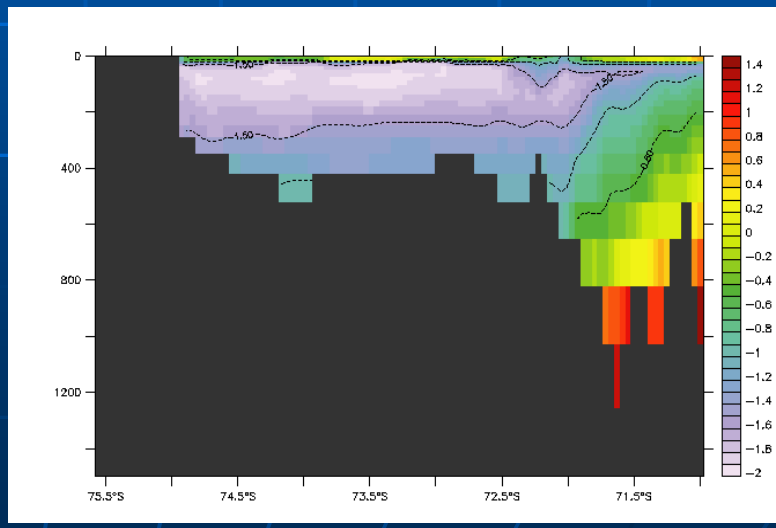
Ice2sea

- **Ice2sea** is a 4-year EU-funded effort, involving 24 institutions, with the goal of improving projections of the ice contribution to sea-level rise over the next 200 years.
  - Broader and more formal than SeaRISE
  - Ice sheet models will be embedded in regional climate models driven by GCM projections.
  - These is interest in forming collaborations between Ice2sea and SeaRISE as the two projects move forward.

DOE IMPACTS

- 5-year multilab project on abrupt climate change
- One subproject is focused on the potential instability of the West Antarctic ice sheet
  - Couple Glimmer-CISM to the HYPOP ocean model
  - Model circulation beneath dynamic ice shelves
  - Partnering with D. Holland and C. Gladish (NYU)





Amundsen sea temperature cross section from POP ocean model

ASCR challenge #1: Sharing code

- We have several teams working toward similar goals using very different approaches.
- Some parts of the model will be developed independently by each group: e.g., the dynamical core and meshing/communication tools. Other parts will be shared: e.g., local physics, GCM coupling mechanisms.
- What is the appropriate version control method? We want to give each team autonomy while facilitating mergers.
  - Currently using Subversion; considering switch to Git or Mercurial.
- What are the protocols for using someone else's code?
- Can we give code users the ability to choose the dynamic core at compile or run time?

ASCR challenge #2: Third-party software

- Obviously, we want to take advantage of state-of-the-art solvers and meshing technology (e.g. SciDAC tools: PETSc, Trilinos, Hypre, Chombo, etc.)
  - Allow ice sheet modelers to focus on ice sheet physics, not math and software
  - Easy to test a wide variety of solvers in a short time
  - Keep up with new numerical methods and emerging architectures
- However, the GCM community has historically resisted the use of third-party software.
  - CCSM developers like to maintain control of source code.
  - We may be required to provide a version of Glimmer-CISM that does not link to external libraries.

ASCR Challenge #3: A cool acronym

- Would be nice to identify this initiative in a pithy way (cf. IMPACTS)
- Any suggestions?

Last words

- Earth system models of the future require scalable implicit methods on unstructured grids.
  - Multiphysics at multiple scales
  - Uncertainty analysis is critical
- These ASCR projects can point the way.

The End