Land Ice Working Group Update

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Ice sheets in CESM 1.0

- CESM 1.0 includes the Glimmer Community Ice Sheet Model (Glimmer-CISM)
  - Serial code
  - Uses the shallow-ice approximation; not valid for fast flow
- CESM also includes a surface-mass-balance scheme for ice sheets in the Community Land Model
  - Uses CLM snow physics
  - Multiple elevation classes for improved accuracy
- Support for one-way coupling from CLM to CISM
  - Ice sheet model is forced by mass balance from CLM
  - CLM topography and land units do not evolve (yet)
  - No coupling between ice sheets and ocean (important for marine-based ice)

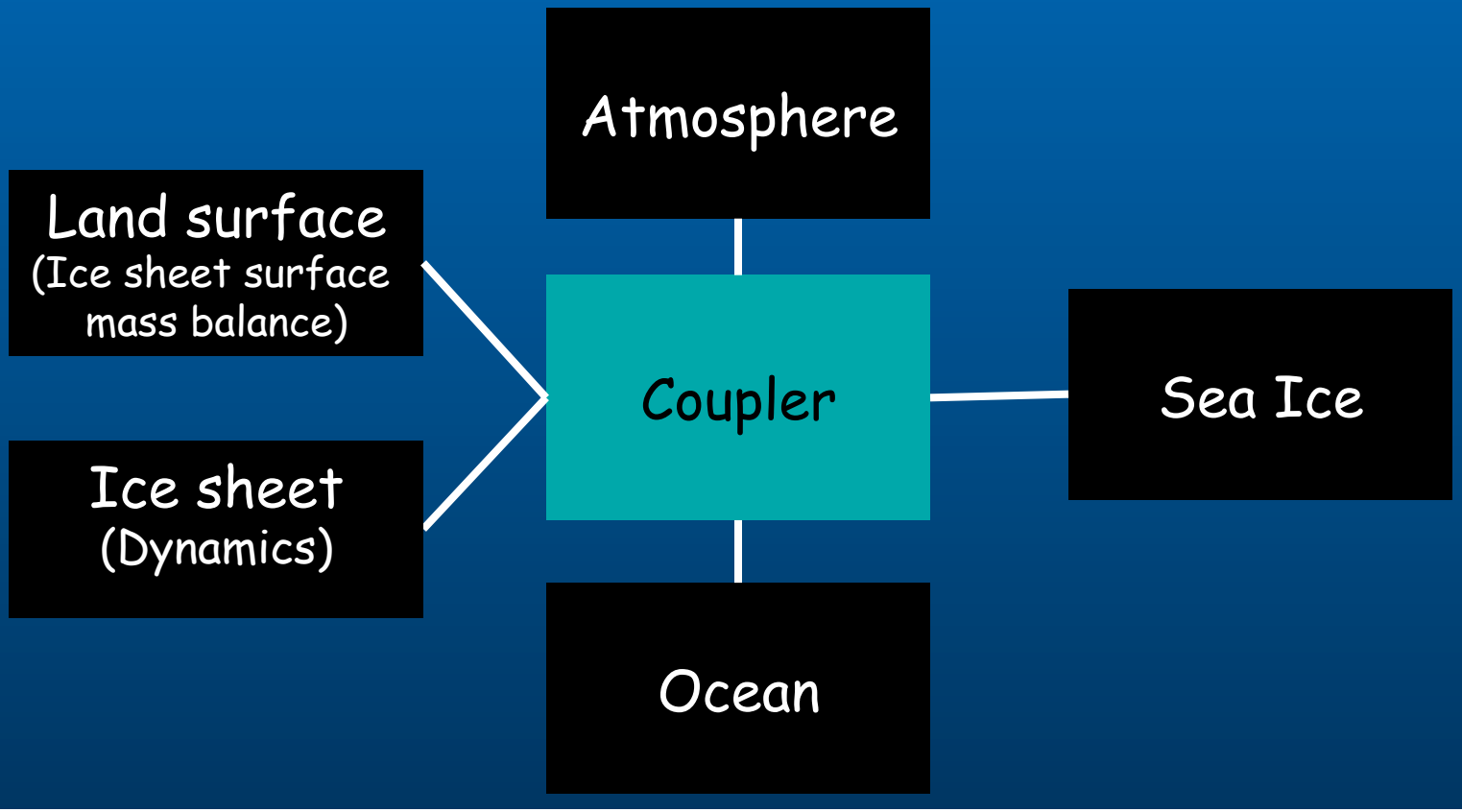
Ice sheets in CESM 1.0

Land -> Ice sheet (10 classes)

- Surface mass balance
- Surface elevation
- Surface temperature

Ice sheet -> Land (10 classes)

- **Ice fraction and elevation**
- **Runoff and calving fluxes**
- **Heat flux to surface**



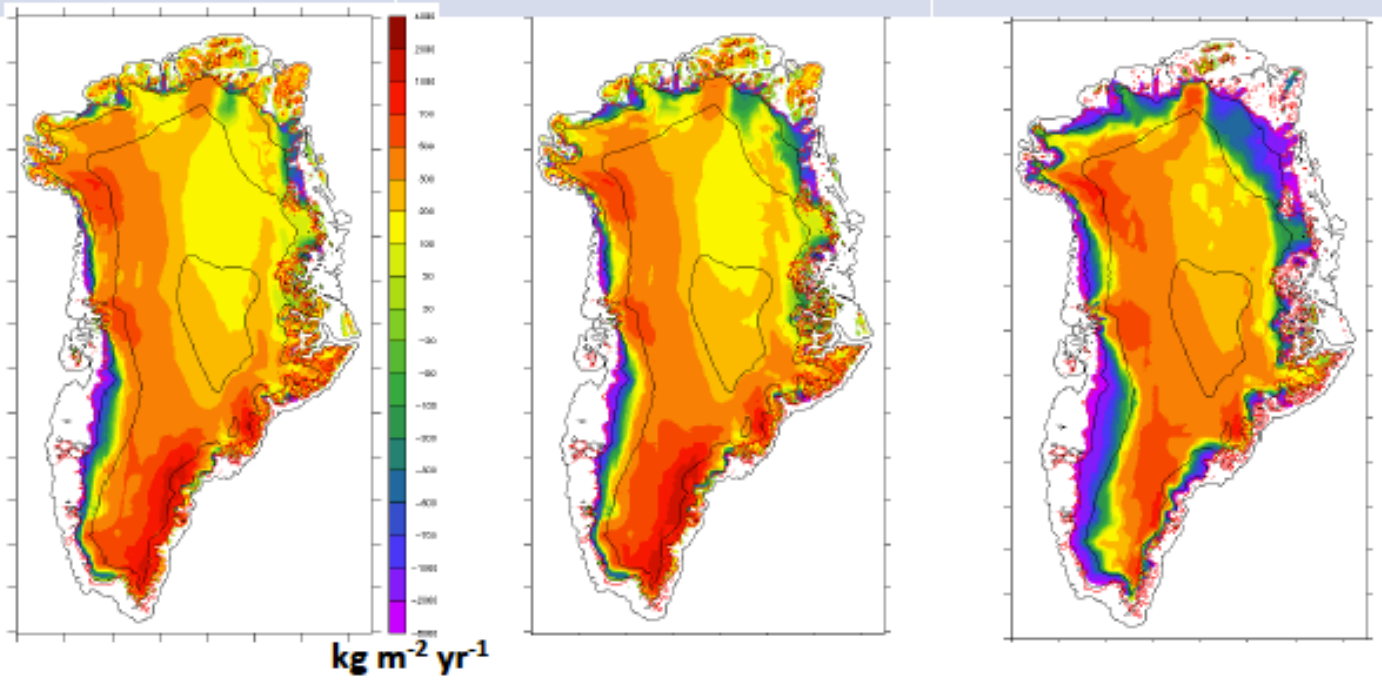
Ice sheets in CESM 1.0

- Work to date has focused on Greenland's surface mass balance
- We have completed a suite of CMIP5 simulations: pre-industrial, 20th century, RCP8.5
  - 20th century SMB and trends in good agreement with RACMO
  - SMB decreases from ~400 Gt/yr to ~0 during 21st century

	Pre-industrial (80-99)	20th-century (1980-1999)	RCP8.5 (2080-2099)
SMB (Gt/yr)	**452** ± 91	**421** ± 107	**61** ± 142

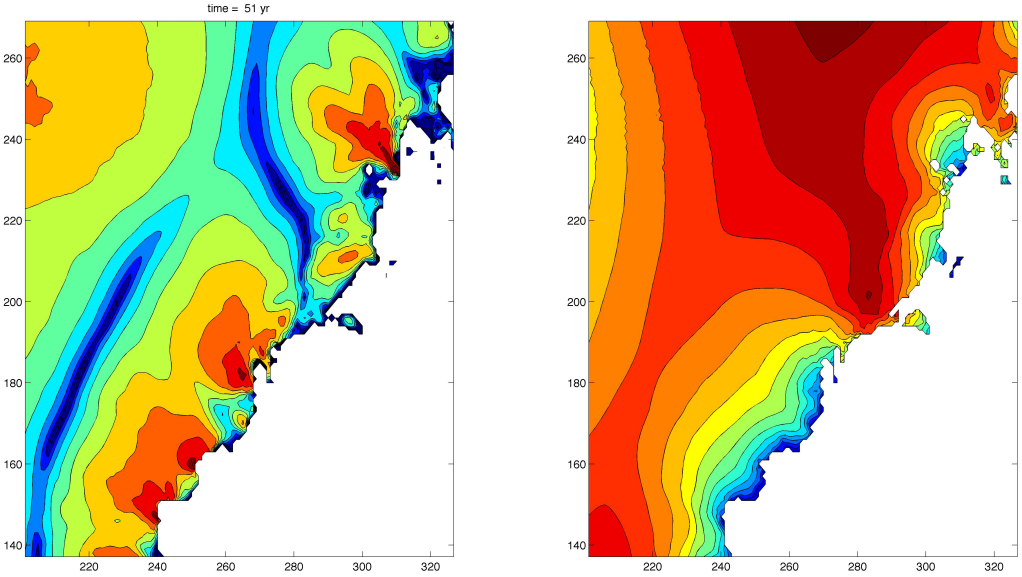
Red = net accumulation

Blue = net melting



CISM 2.0

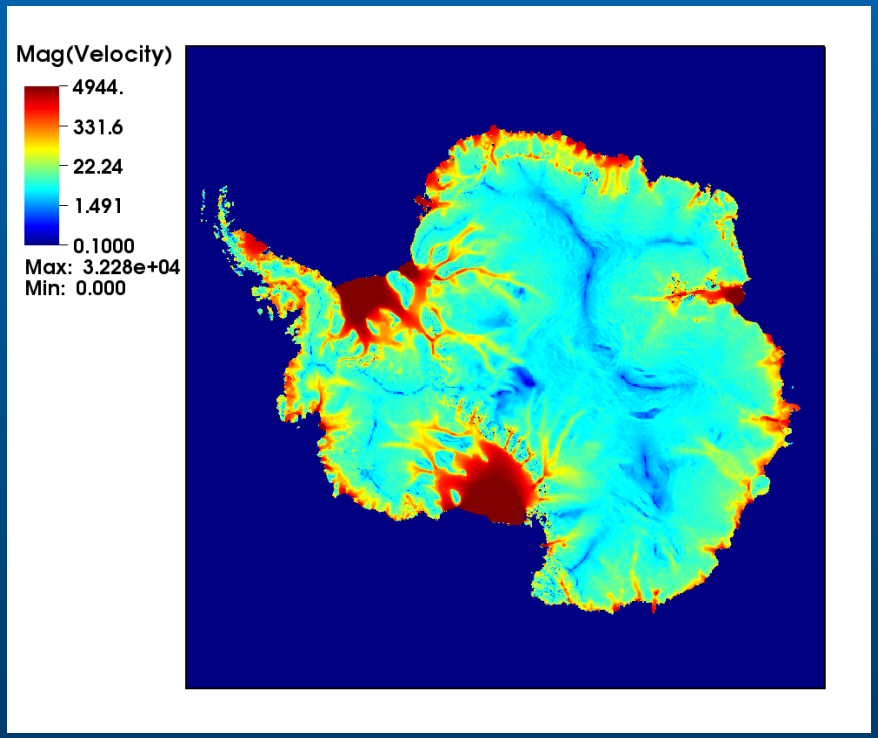
- A top priority is to have one or more **parallel, scalable, higher-order ice-sheet dynamical cores**
  - Beta version includes the Payne-Price velocity solver (3D Blatter-Pattyn) using Trilinos software, JFNK methods (talk by K. Evans)
  - Now parallelizing the mass and energy transport so that the entire code is scalable



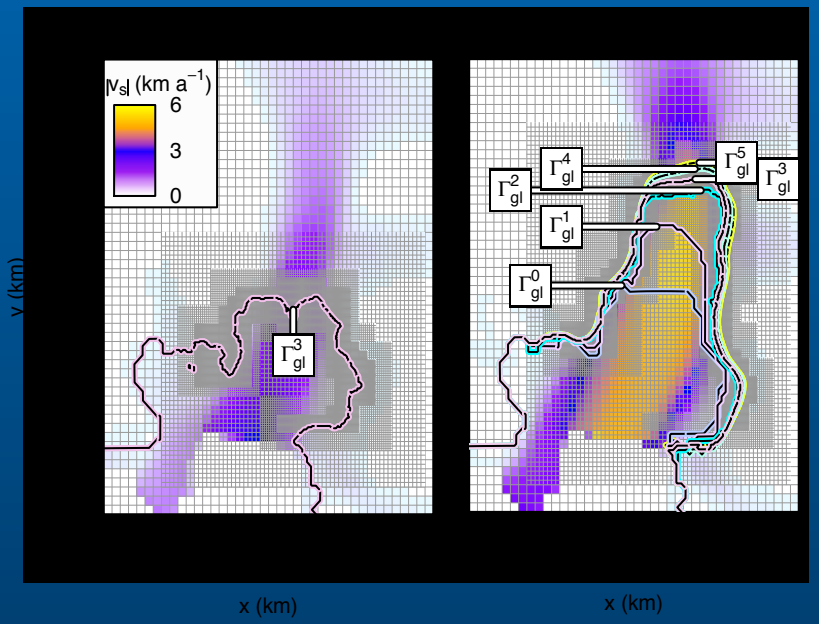
Greenland ice sheet surface velocity (left) and surface elevation (right) from Payne-Price dynamical core (S. Price)

CISM 2.0

- Now adding the BISICLES dycore (vertically integrated “L1L2”), using Chombo adaptive mesh refinement software (talk by D. Martin)
- BISICLES interface (Fortran90 to C++) could be used to link to other model dycores



Antarctic ice sheet velocities from BISICLES



Grounding-line migration simulated for Pine Island Glacier (D. Martin)

CISM 2.0

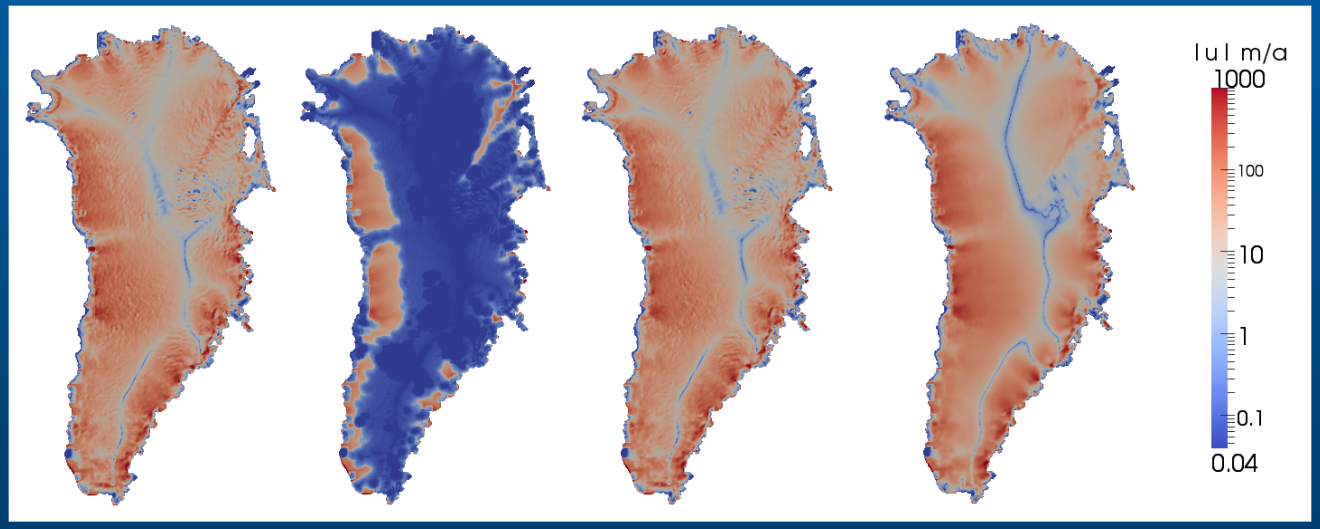
- Next 6 months:
  - Improve dycore robustness (Friday morning discussion)
  - Build with CESM and validate results
- Aiming for June release to coincide with CESM 1.1
  - Details in talk by B. Sacks

Future work

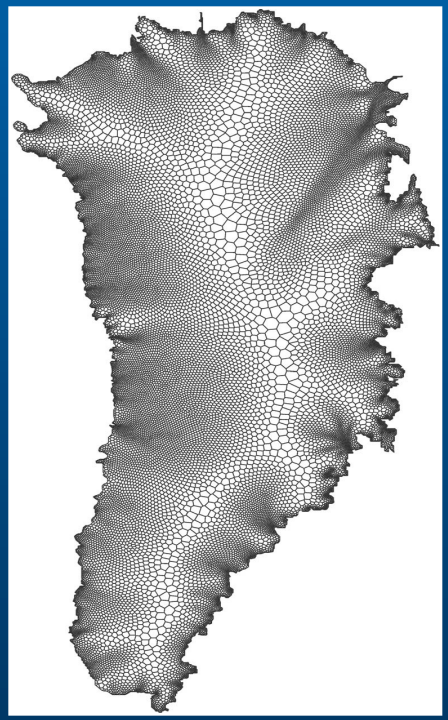
- New dynamical cores on adaptive and unstructured meshes
- Optimal initialization
- Improved physics parameterizations
- Two-way coupling with land and ocean models
- Glacier models
- Work with other ice-sheet and climate models

New dynamical cores

- We will further develop the BISICLES dycore
  - Extend from L1L2 to 3D higher-order and Stokes flow
- We are also developing a dycore in the Model for Prediction Across Scales (MPAS) framework
  - Unstructured variable-resolution grids are well suited for ice sheets
  - Already have prototype L1L2, 3D HO, and Stokes solvers using finite elements (talk by Mauro Perego)



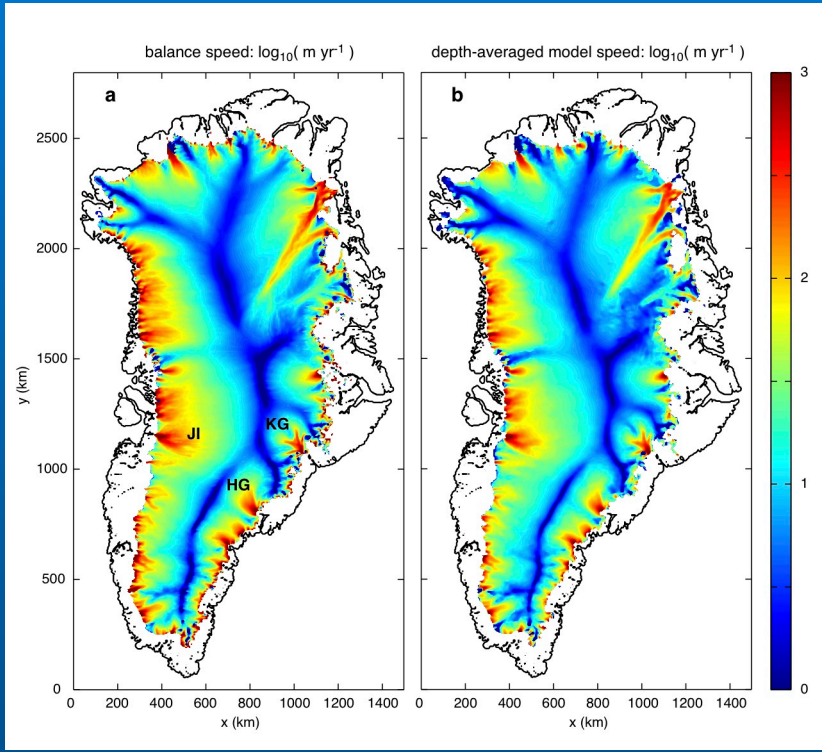
Greenland ice flow from SIA, SSA, L1L2 and 3D HO solvers (M. Perego)



Optimal initialization

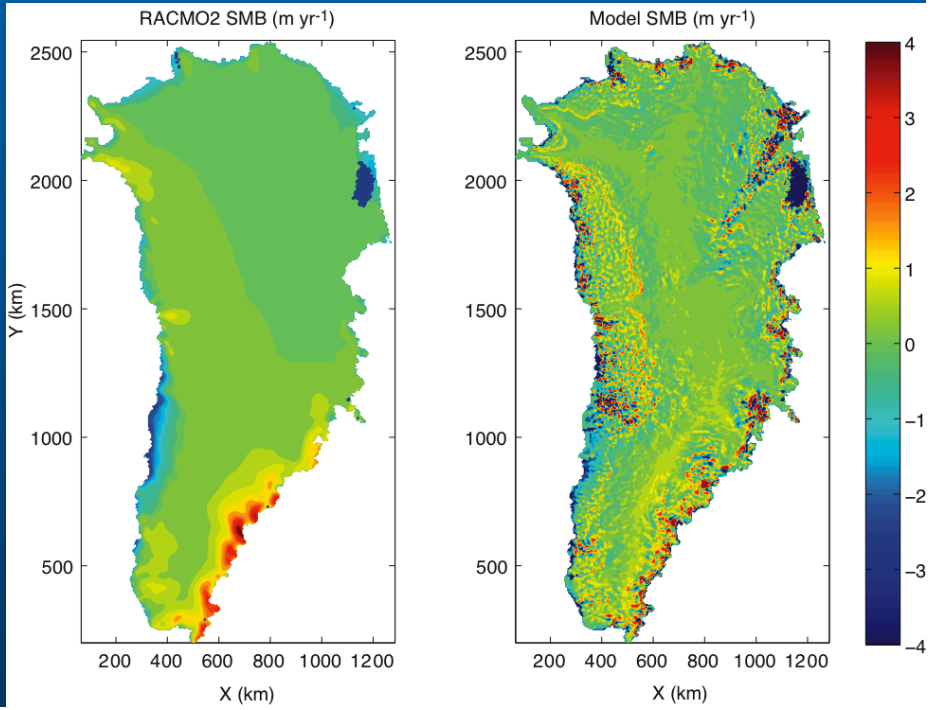
- We want to spin up ice sheets so that
  - The ice sheet thickness, extent, and velocity are in good agreement with observations.
  - The ice sheet is at or near steady state with CESM climate.
- There is no perfect solution, but we can get closer using optimization methods to tune poorly constrained ice-sheet parameters.

Optimal initialization



Basal sliding parameters in each grid cell can be tuned so that model ice speeds (above right) match balance speeds (above left).

But the implied flux divergence is noisy: Compare RACMO velocity divergence (below left) and divergence of the tuned velocity field (below right).



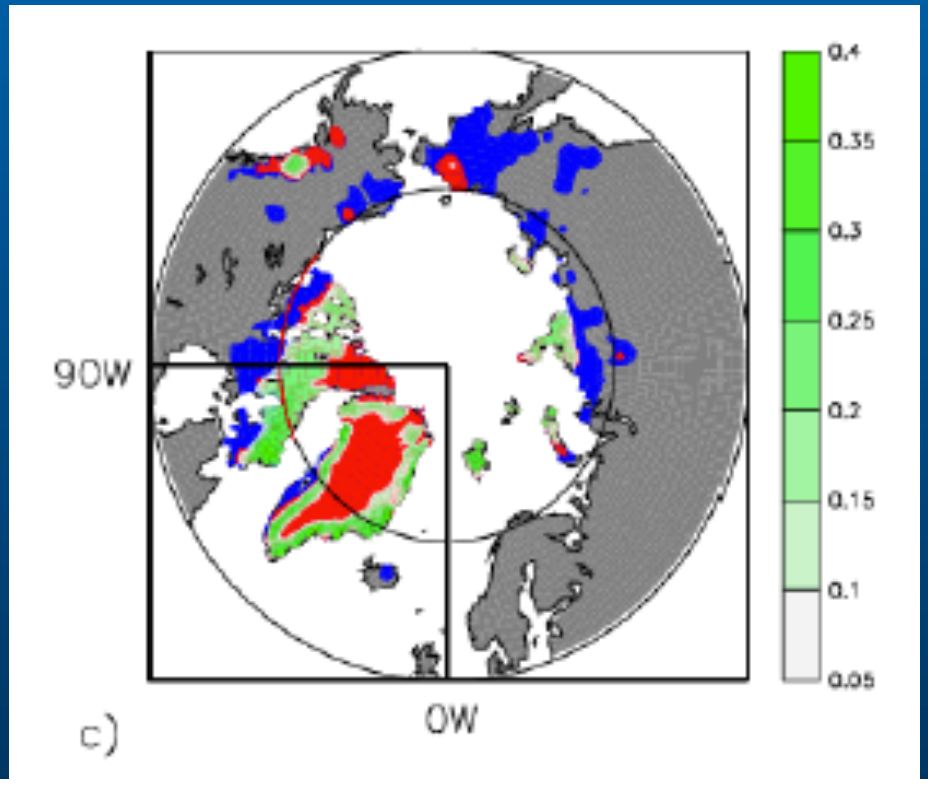
Improved physics in CISM

- Improved calving models
  - Recently funded NSF grant (J. Bassis – Univ. Mich.) will focus on process-scale modeling of calving and incorporation of calving models in CISM
  - Recently submitted NASA proposal focuses on similar issues
- Improved models of basal sliding and ice sheet hydrology
  - Basal sliding: unified treatment of flow over hard and soft beds
  - Collaboration with UBC, SFU, LDEO on basal hydrology model development
  - Talks by M. Werder, T. Creyts, M. Hoffman

Two-way coupling and long-term simulations

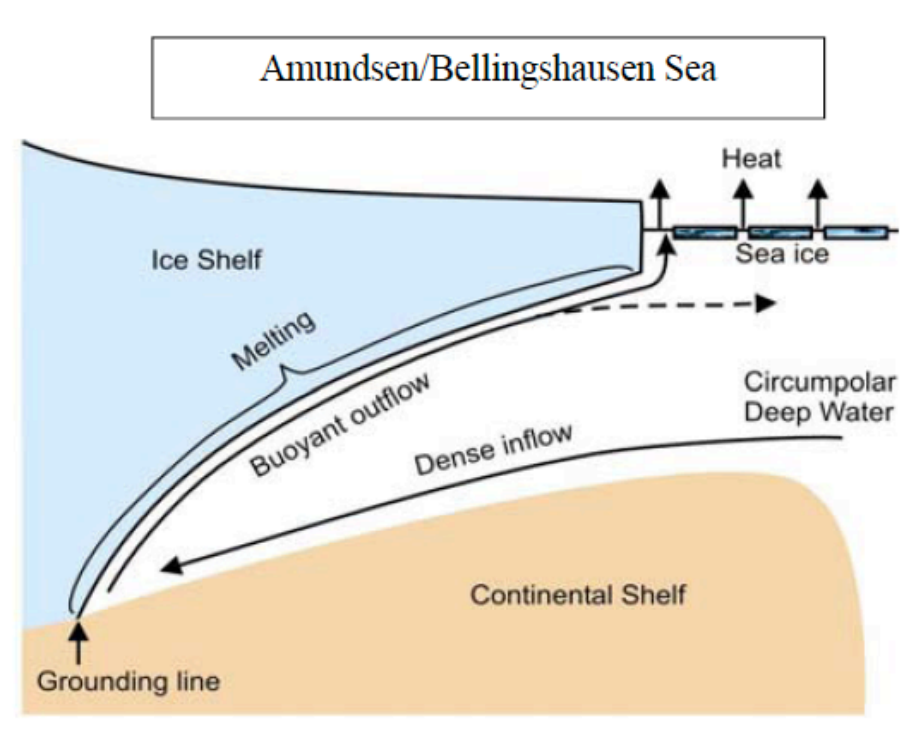
- We would like to simulate ice-sheet inception, advance, and retreat on century-to-millennial time scales.
- We have a good Northern Hemisphere surface mass balance for both modern and paleo climates. Can use this to force CISM.
- Need dynamic landunits: vegetated to glacier and vice versa (work in progress)

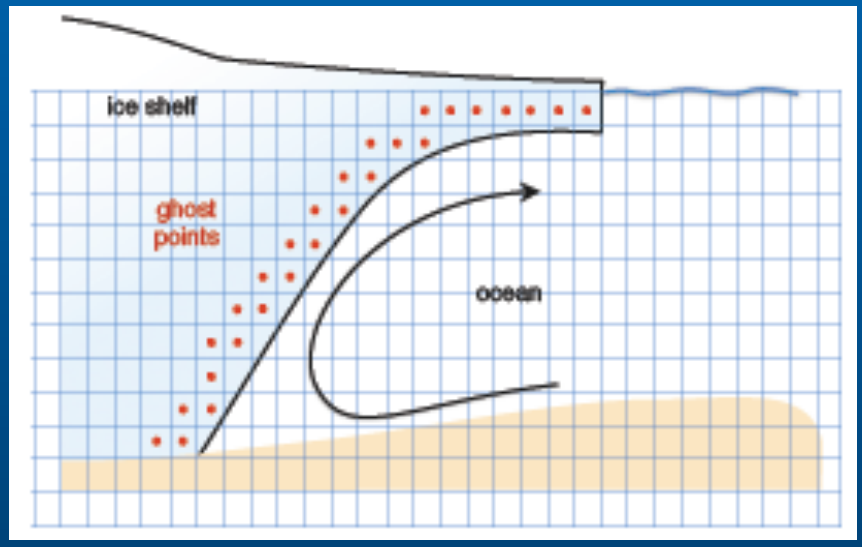
Northern Hemisphere snow cover and accumulation, c. 115 ka (M. Jochum)



Ice-ocean coupling

- We are modifying POP to simulate ocean circulation and heat/ mass exchange beneath floating ice shelves.
  - Using immersed boundary methods at the ice/ocean interface (talk by X. Asay-Davis)
- We plan to couple oceans and ice sheets dynamically in CESM, to study mechanisms of marine ice sheet instability.





Left: Schematic of Circumpolar Deep Water delivering heat to the grounding line

Right: Sub-ice-shelf circulation using immersed boundary method with ghost points

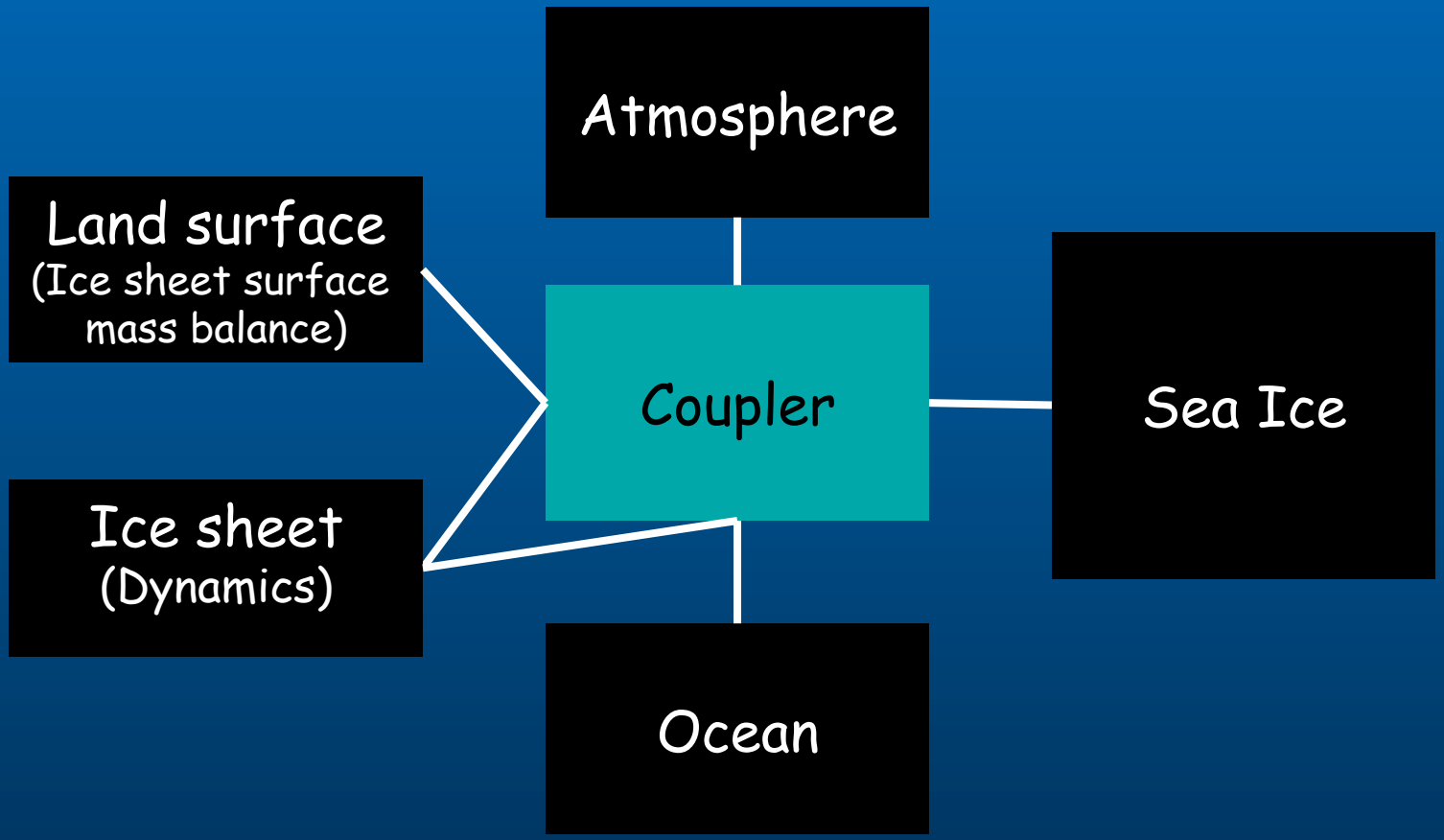
Ice-sheets in CESM 1.x

Ocean -> Ice sheet/shelf

- Basal heat flux
- Basal mass flux
- Ocean density (average over column)

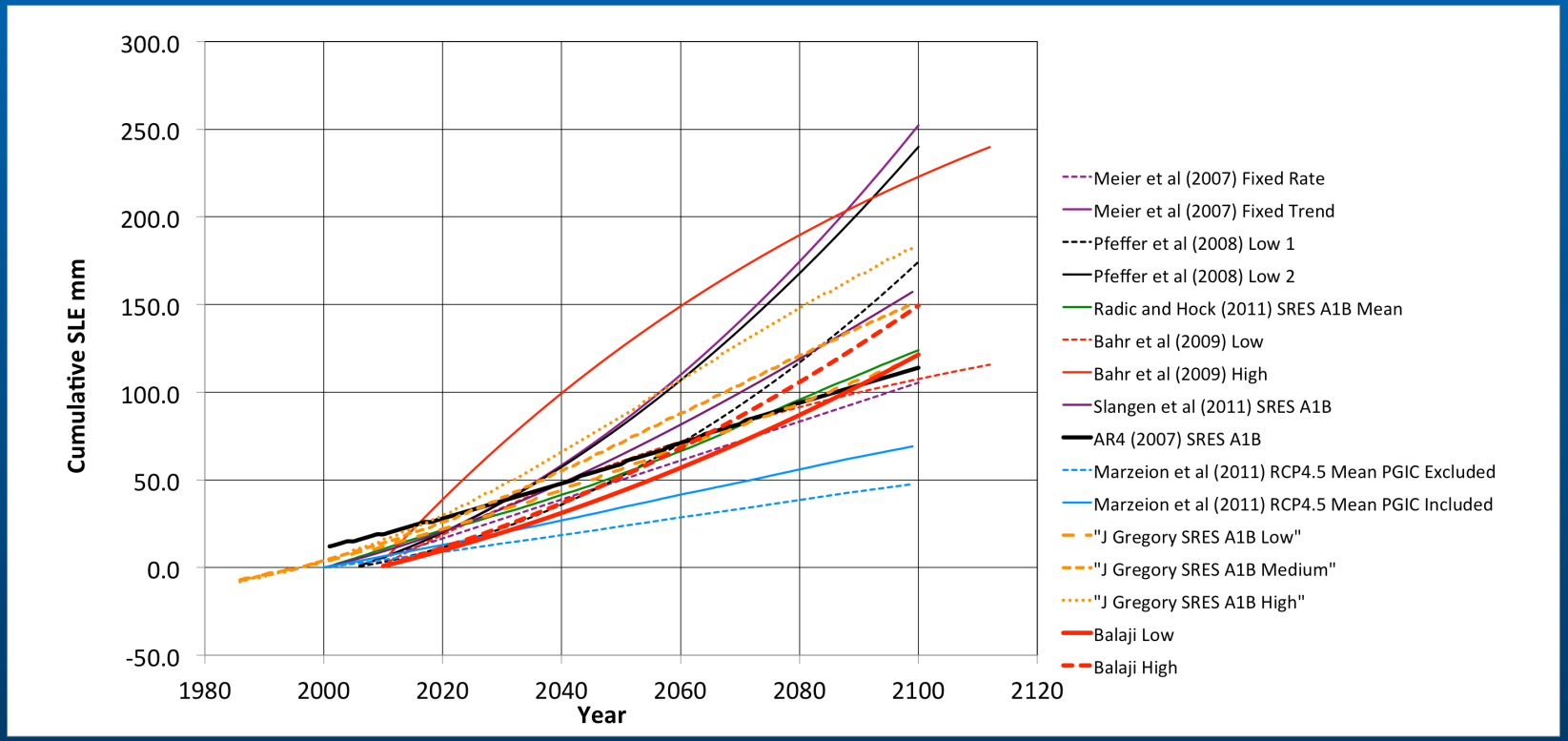
Ice sheet/shelf -> Ocean

- Lower surface elevation
- Grounded/floating ice fraction
- Basal temperature info (for heat flux computation)



Modeling glaciers

- Projections of the glacier contribution to sea-level rise are widely scattered.
- It is not practical to model each individual glacier.
- We plan to develop statistical glacier models (based on area-volume scaling relationships), forced by the surface mass balance from CLM.
- To be implemented in CESM and the Regional Arctic System Model



Range of projected 21st glacier contribution to sea-level rise (T. Pfeffer)

LIWG climate simulations

- We are proposing new CISM/CESM simulations on Yellowstone:
  - Test and validate new ice-sheet dycores and physics parameterizations
  - CMIP5 suite (pre-industrial, 20th century, RCP8.5) with CAM5 atmosphere
  - CMIP5 suite with two-way land/ice-sheet coupling
  - Long-term simulations of Greenland ice sheet stability
  - Last Interglacial transient simulation (130 to 110 ka) with dynamic Greenland ice sheet
  - Northern Hemisphere glacier inception, c. 115 ka
  - Ice-sheet response to uncertainty in climate forcing
- We are also participating in SeaRISE and Ice2sea: international projects aimed at assessing century-scale contributions of ice sheets to sea-level rise.

PISCEES: Predicting Ice Sheet and Climate Evolution at Extreme Scales

PISCEES is a proposed 5-year, multi-institutional DOE SciDAC project focused on computational improvements in ice sheet models and integration within CESM:

- Development of BISICLES and MPAS dynamical cores
- Improved basal boundary conditions
- Performance optimization
- Verification and validation toolkit
- Uncertainty quantification (using Dakota software)
- Standard model interfaces

Working with other models

- Develop standard interfaces between ice sheet models and climate models
- Inter-model comparisons
  - Couple multiple ice sheet models (CISM, ISSM, PISM, PSU…) to CESM and other climate models (HadGEM, NASA, UVic…)
  - Talks by B. Fischer, J. Fyke, C. Khroulev, M. Morlighem, D. Pollard