Progress and Challenges in Coupled Ice-Sheet/Climate Modeling with CESM

Jeremy Fyke, William Sacks, Miren Vizcaíno, William Lipscomb, Stephen Price

Motivation for coupled ice sheet/climate modeling

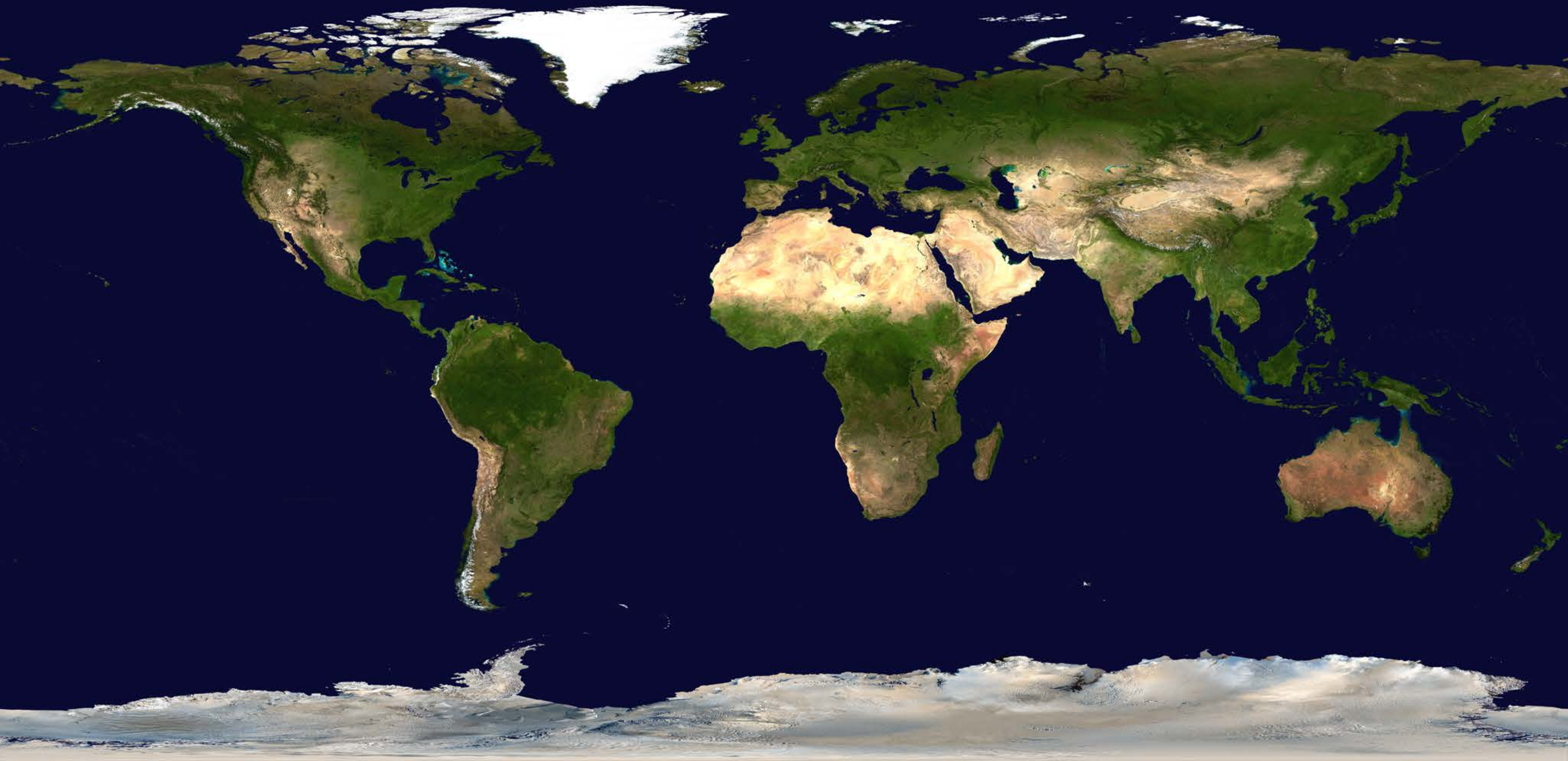
CESM/CISM coupling progress

Future challenges

LA-UR-14-29614

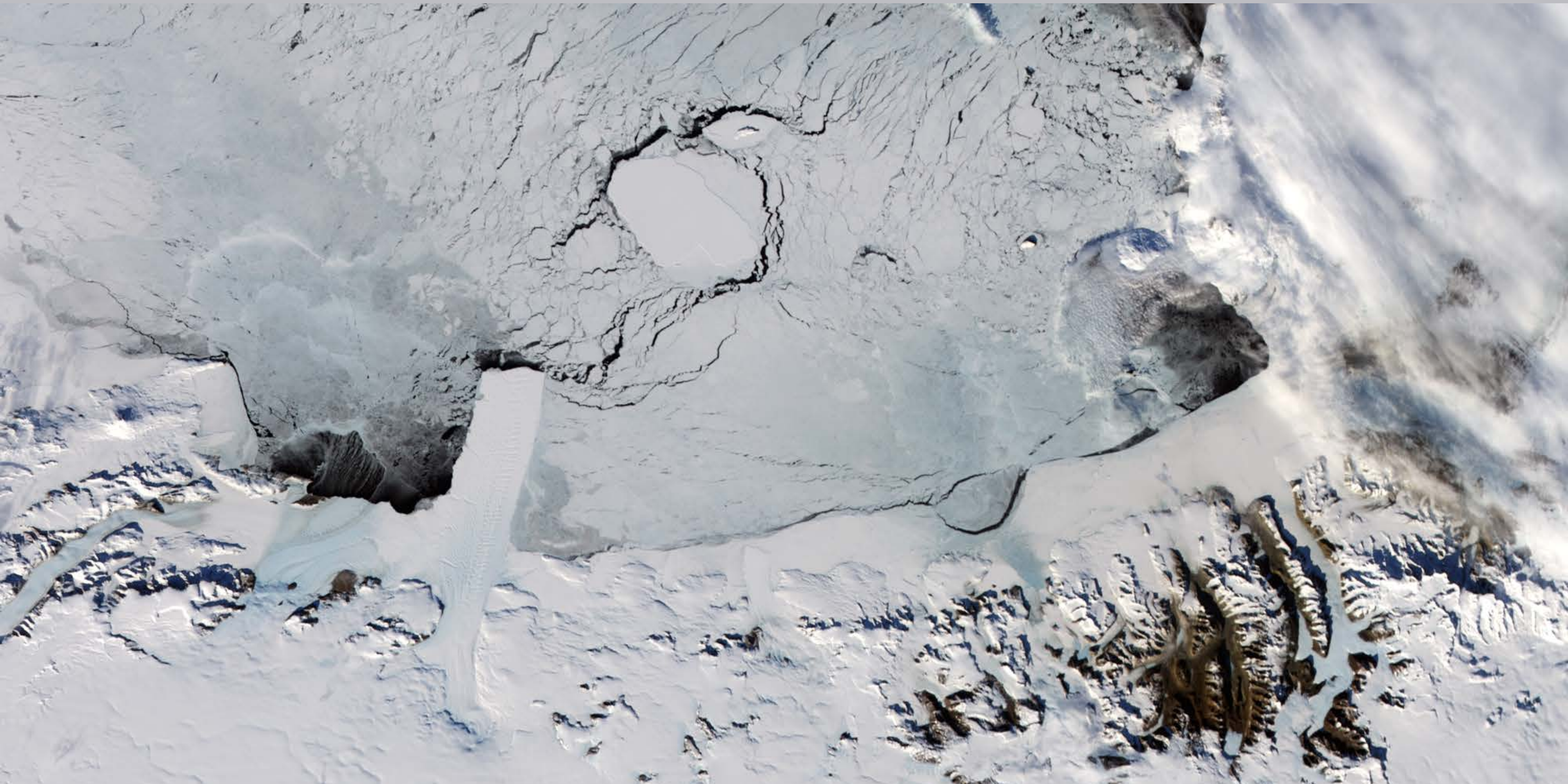
Why simulate ice sheets as part of the coupled climate system?

1. Climate regulates ice sheets.



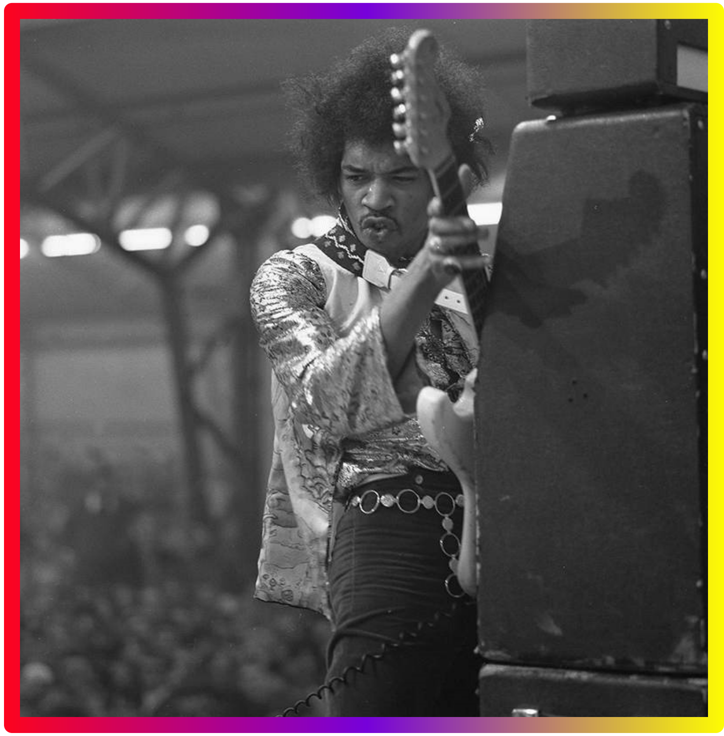
Why simulate ice sheets as part of the coupled climate system?

2. Ice sheets regulate climate.

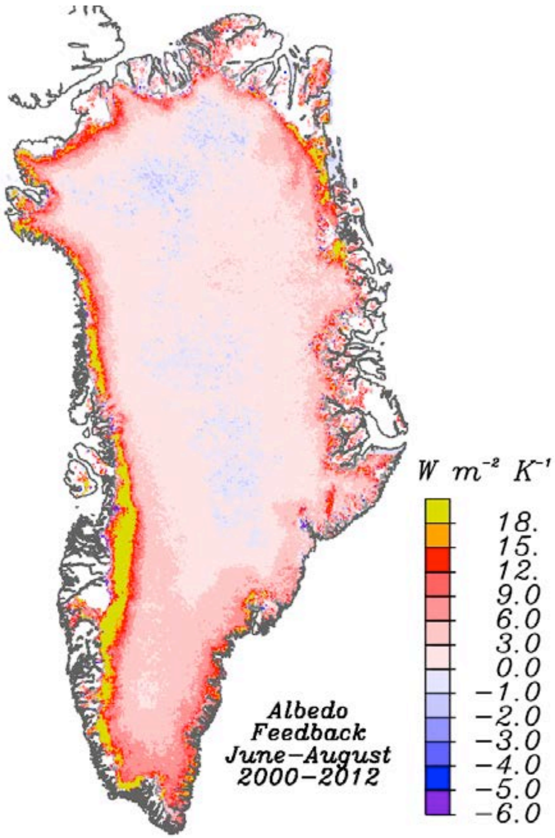


Why simulate ice sheets as part of the coupled climate system?

Ice sheets and climate co-evolve; coupled co-evolution generates *feedbacks*.

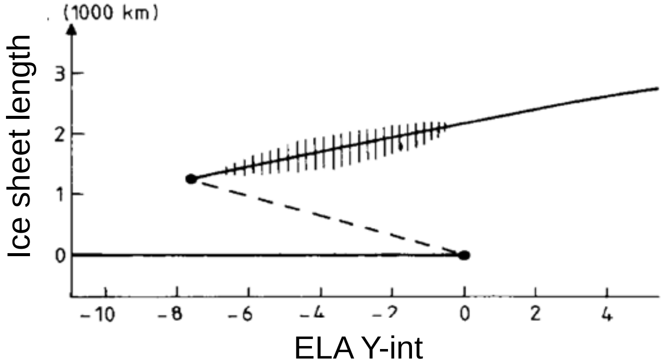


Albedo-melt feedback



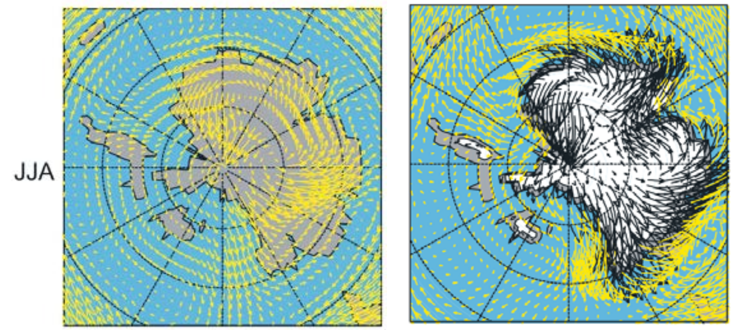
Box et al. (2012 - updated)

Height-SMB feedback



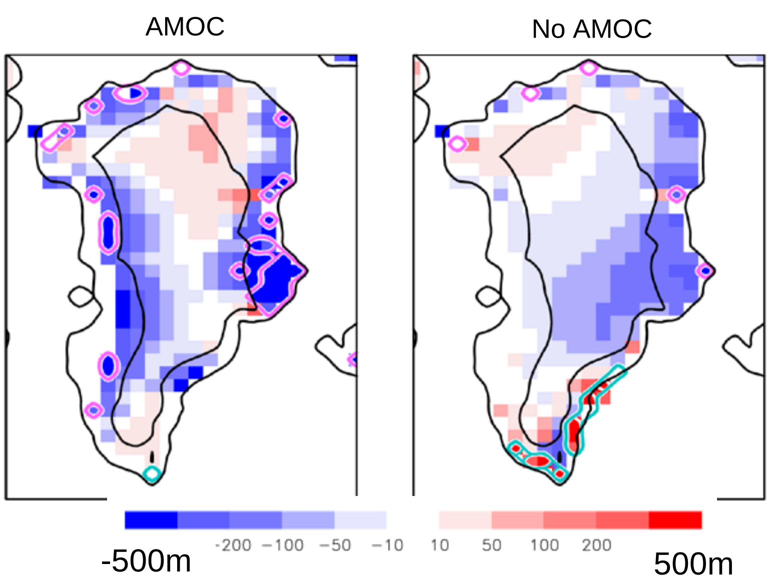
Oerlemans, 1981

Topography-atmosphere feedback



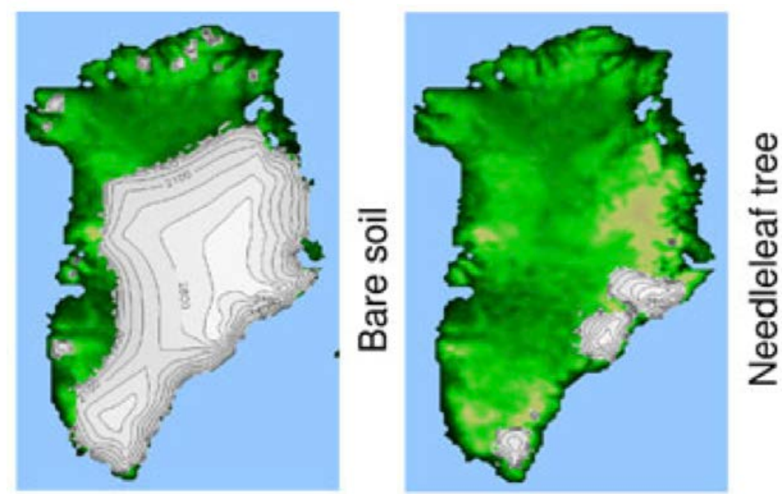
DeConto & Pollard, 2007

Runoff-SMB feedback



Mikolajewicz et al., 2007

Land surface feedback

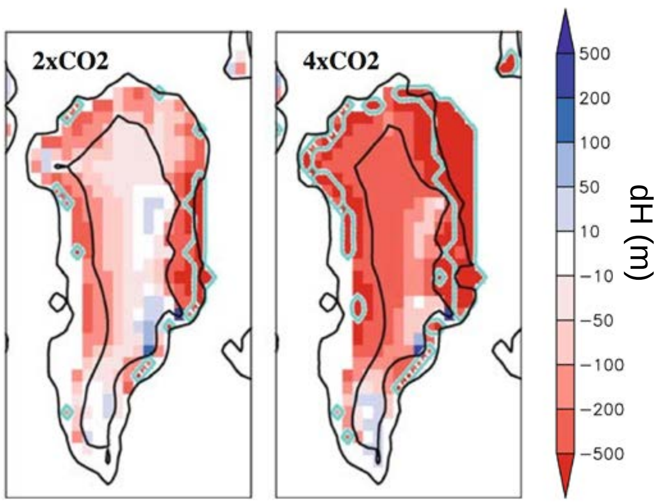


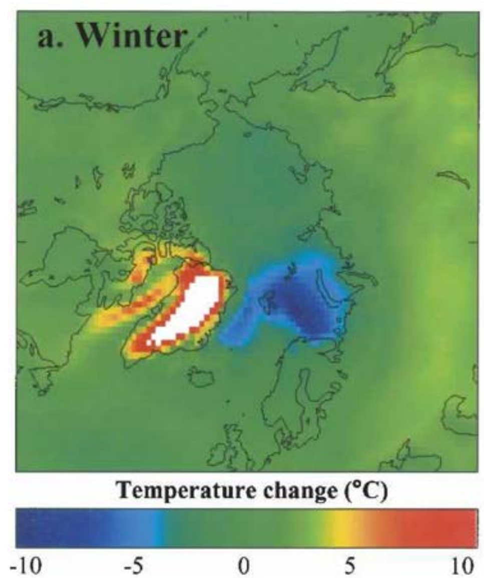
Stone & Lunt, 2013

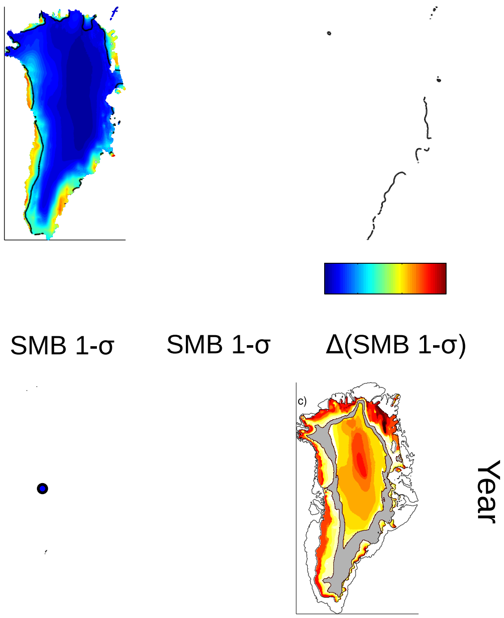
Need to resolve ice-sheet/climate feedbacks? You probably need a coupled ice-sheet/climate model.

What do coupled ice-sheet/climate models succeed at?

- *Internally-consistent:*
  - coupled ice-sheet/climate hind/forecasts (SLR)
  - Regional/global ice-sheet/climate interactions
  - Variability, detection/attribution & emergence







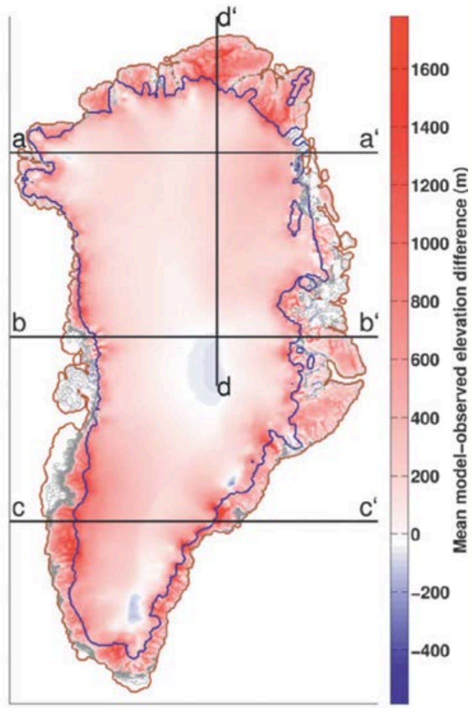
Vizcaino et al., 2010

Ridley et al., 2005

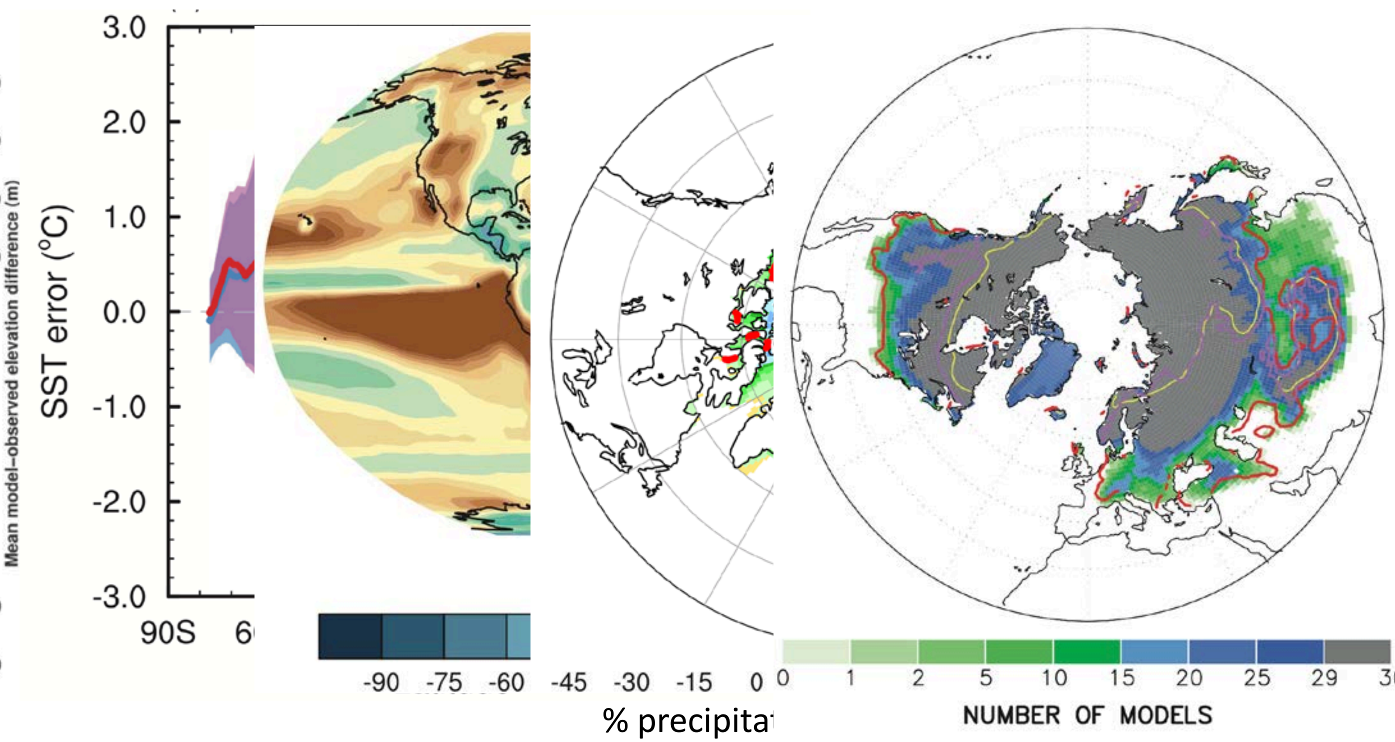
Fyke et al., 2014a/b, GRL

What could coupled ice-sheet/climate models struggle with?

- Exact reproduction of observed ice sheet conditions and trends



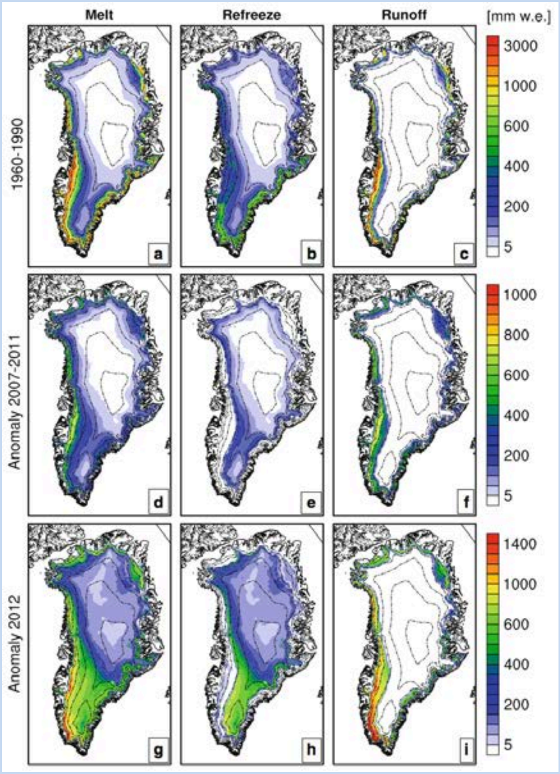
Lipscomb et al., 2013

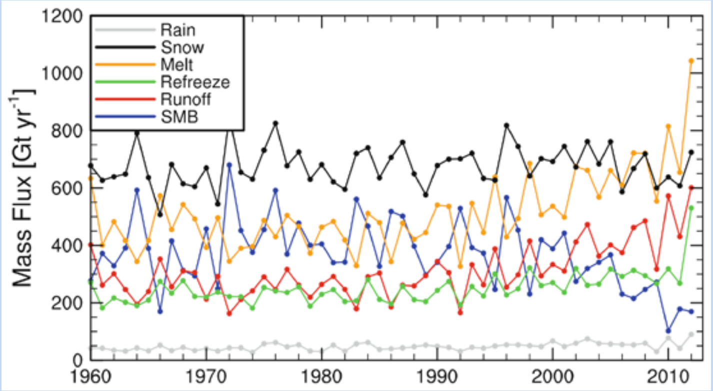


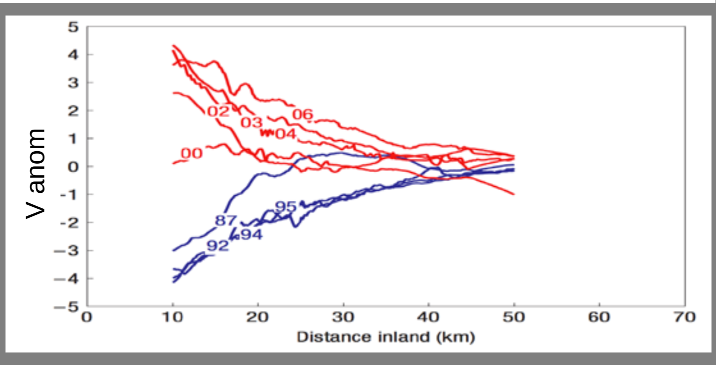
IPCC AR5 Chapter 9: "Evaluation of Climate Models"
Flato et al., 2013

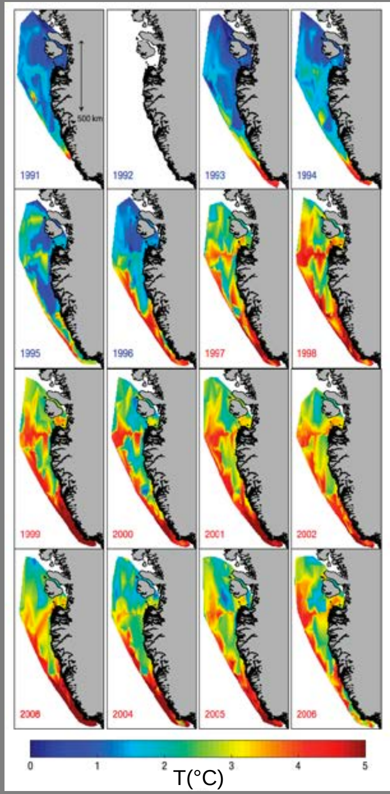
What could coupled ice-sheet/climate models struggle with?

- Matching historical variability
- Short-term ice sheet forecasts







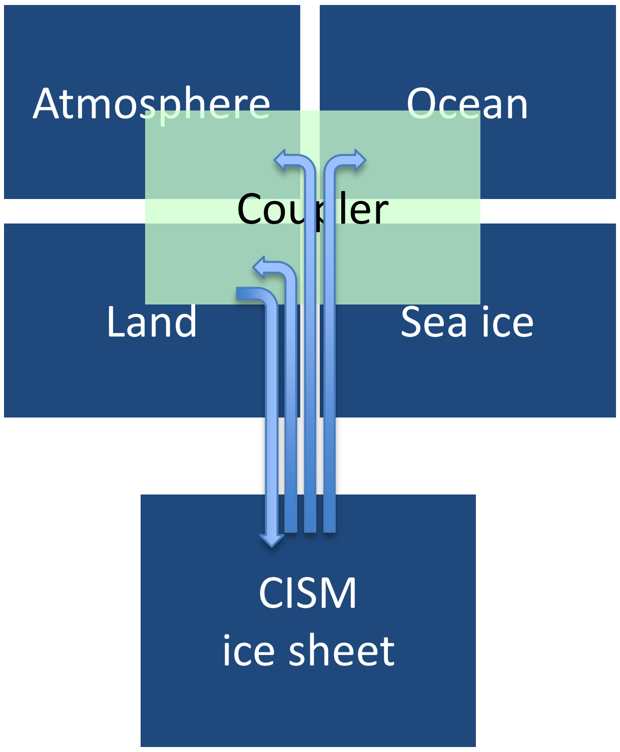


Van Angelen et al., 2013

Holland et al., 2008

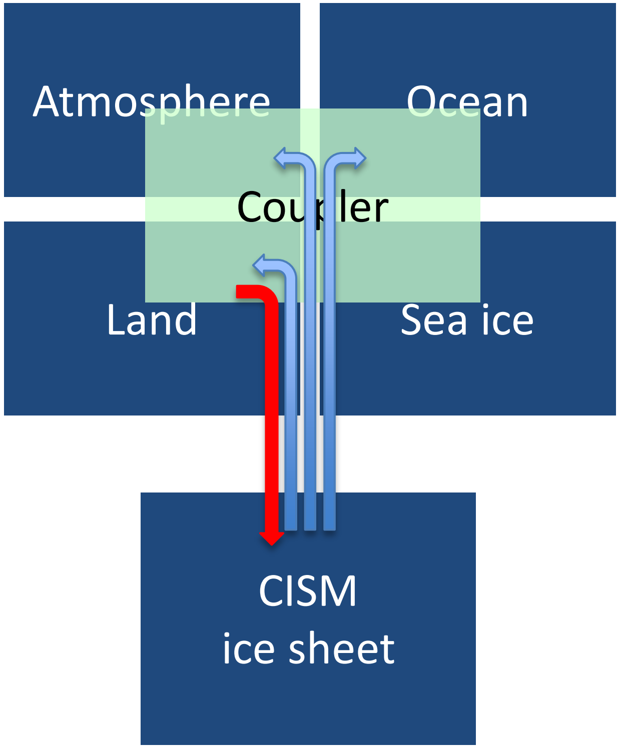
CESM/CISM ice-sheet/climate model

- 1 degree:
  - ocean (POP2)
  - sea ice (CICE4)
  - atmosphere (CAM5-FV)
  - land (CLM4.5)
- coupler (CPL7)

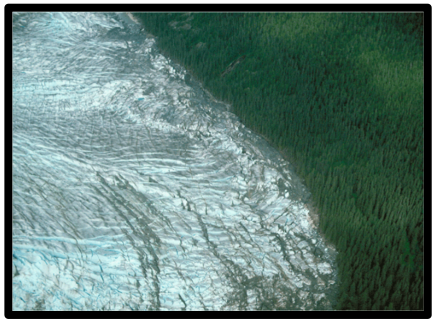


Fyke et al., in prep.

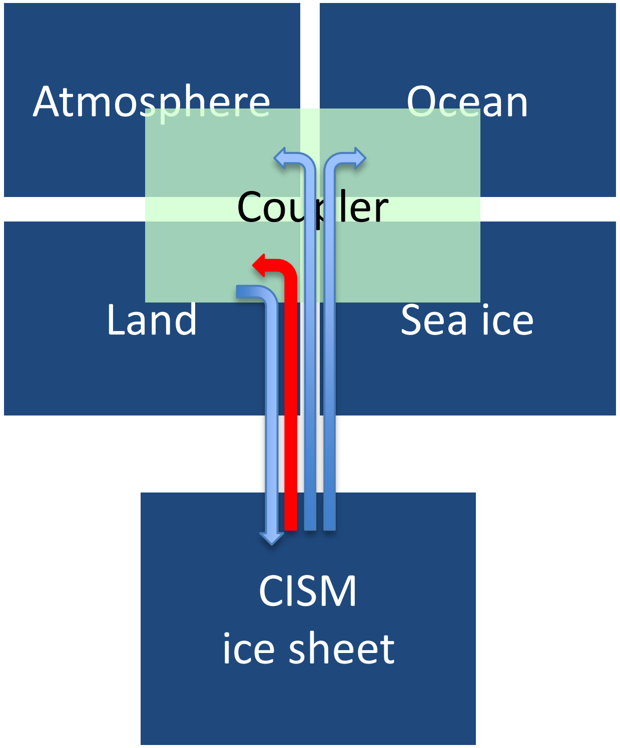
- SMB/surface temperature on multiple elevations in CLM, using EB model, and *no bias corrections*
- SMB/T downscaled to ice grid



S. Price archives
M. Hoffman archives
Fyke et al., in prep.



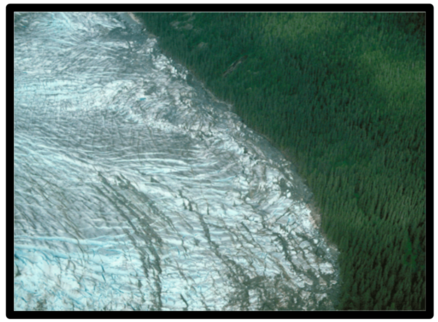
- Dynamic land units implemented in CLM
- Prognostic ice area evolution drives changes to CLM land unit fractions

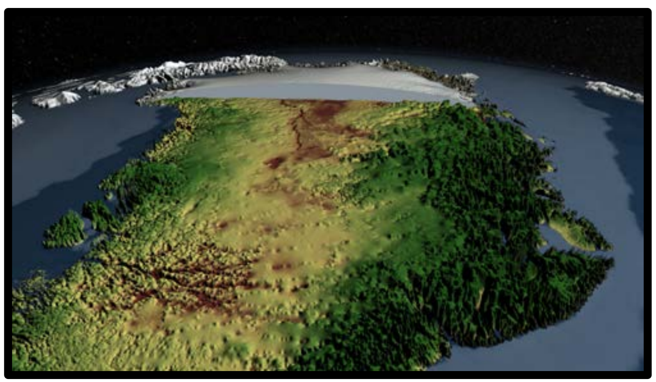


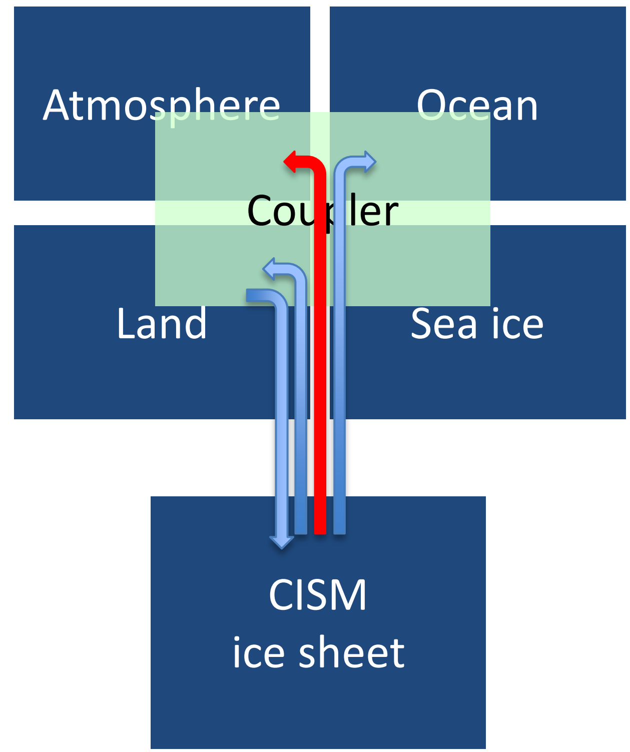
S. Price archives
M. Hoffman archives

Fyke et al., in prep.

- CAM topography updated to reflect evolving CISM geometry
- Shock from updating dissipates quickly below atmospheric noise



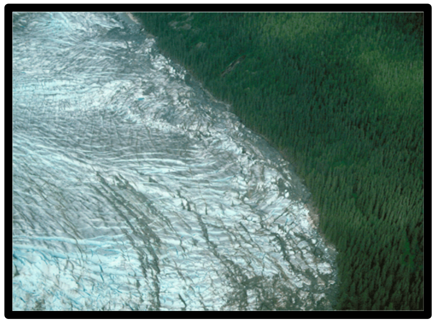


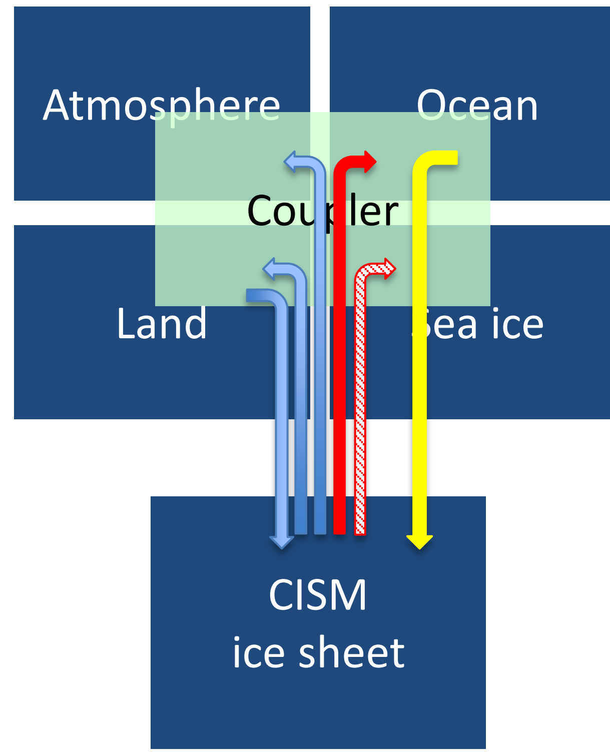


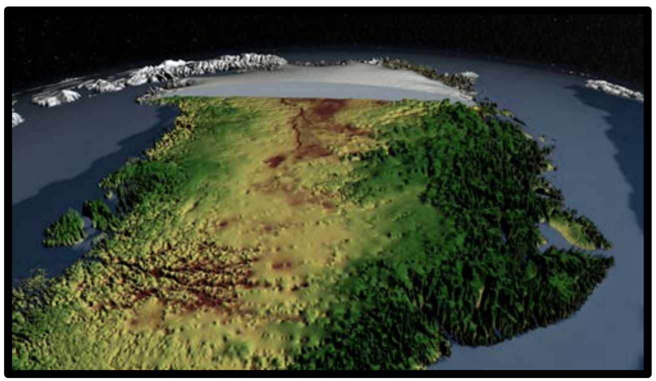
Bamber et al., 2013
Viz: NASA
S. Price archives
M. Hoffman archives

Fyke et al., in prep.

- CISM determines solid ice flux
- Ice discharge (+ negative heat flux) applied in prescribed distribution in POP2



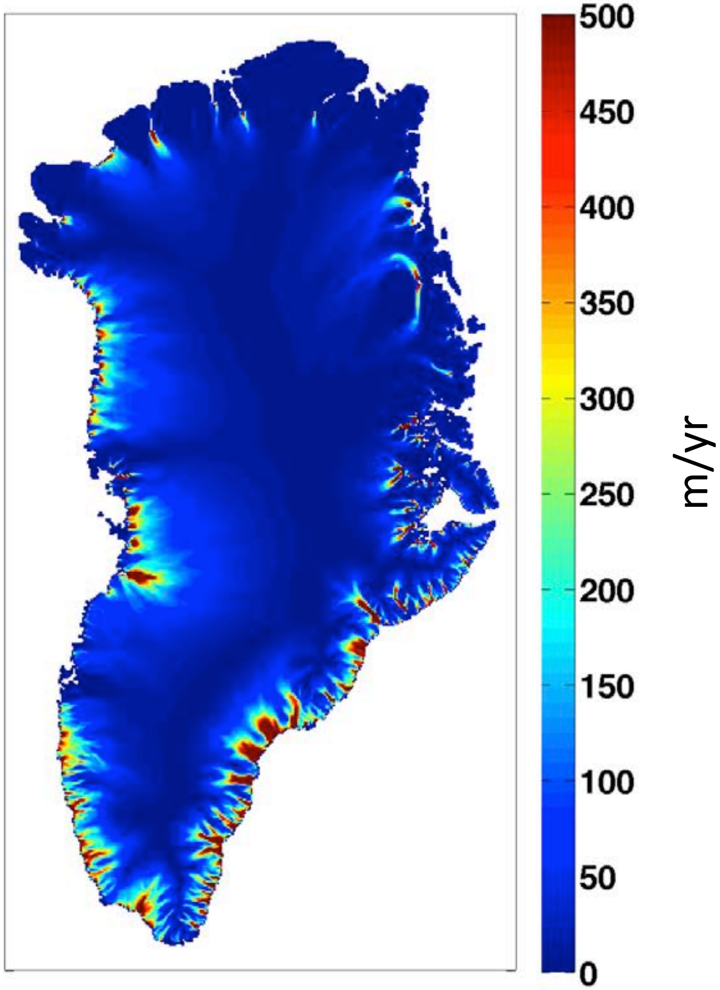


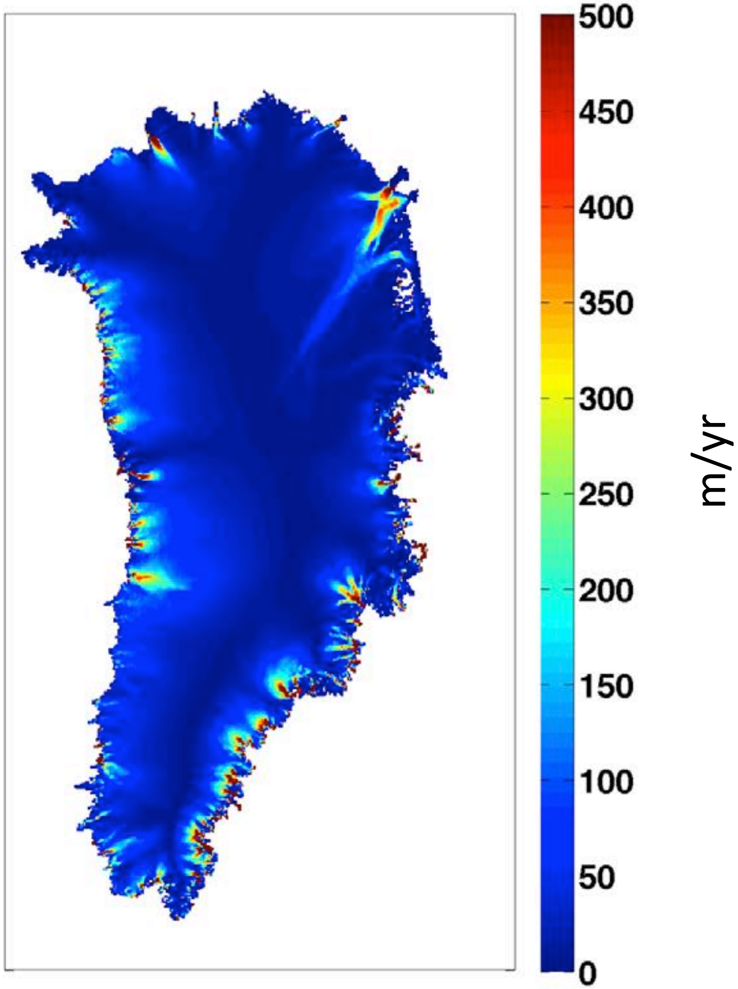


Bamber et al., 2013
Viz: NASA
S. Price archives
M. Hoffman archives

Fyke et al., in prep.

Snapshot of ongoing BG, CISM2, CAM5 (MG1) simulation





Big challenges

- Continued coupled model development
  - Conservative coupling (Sacks, Lipscomb)
  - Improved CLM output (Sacks)
  - Including CISM in default CESM runs (Sacks)
  - Soil/vegetation state conservation (Sacks, Fyke)
  - Iceberg coupling (Fyke)
  - Firn model development (Sacks, Lenaerts, van Kampenhout)
  - Antarctic radiation absorption fix (Fyke)
  - Increased CISM coupling frequency

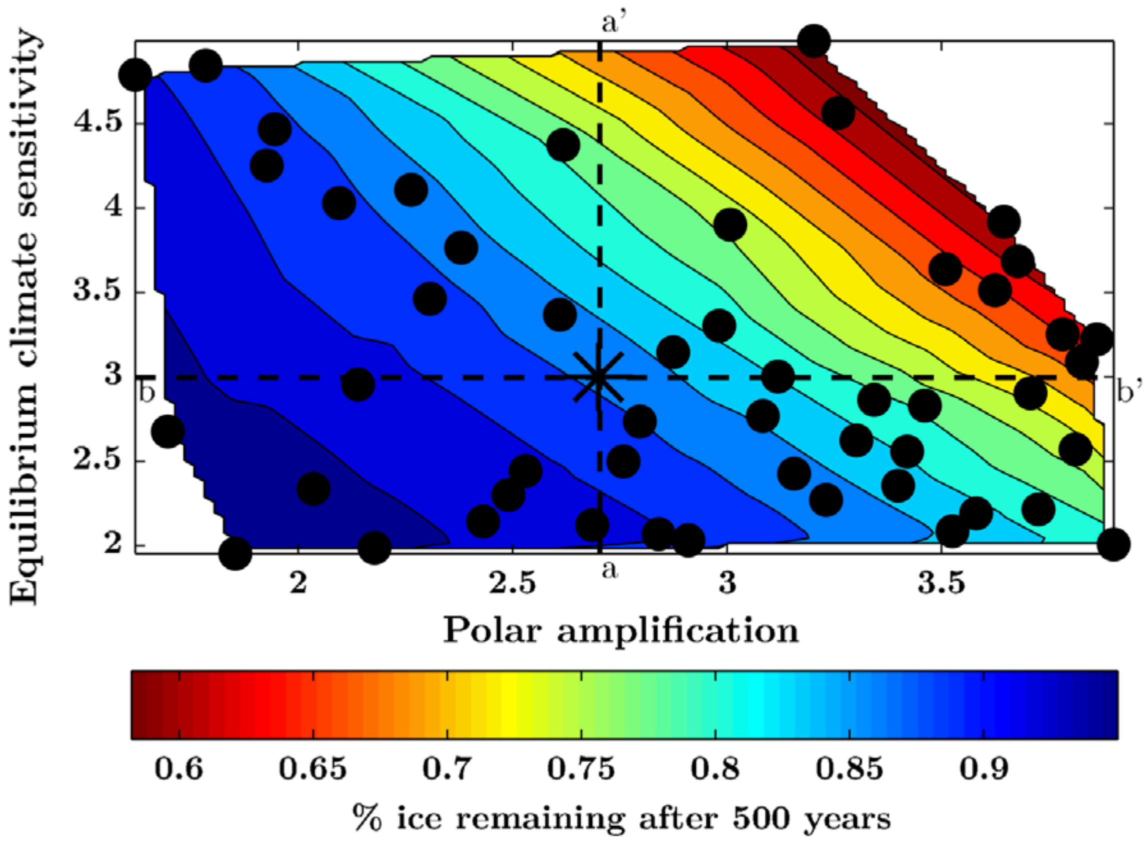
Big challenges

- Tuning a global climate model to acceptably reduce ice sheet biases
  - “In coupled systems, biases in one component propagate to others. Our options are to:
    - Reduce bias (*long term*)
    - Correct bias (*reduced coupling, increased realism*)
    - Accept bias (*increased coupling, reduced realism*).”

Miren Vizcaino

Big challenges

- Quantifying role of climate uncertainty in coupled ice-sheet/climate projections



Fyke et al., 2014c, Clim. Dyn.

Big challenges

A difference in philosophies?

Climate Modelers

Global perspective

Coupled climate system, climate feedbacks

Ice sheets: prescribed BC

Climate looks bad: tune land/ocean/atm. models

Initialization: prioritize coupled system consistency (Fyke et al., 2014d, GMD)

Ice sheet Modelers

Local perspective

Dynamic ice sheet response to perturbations

Climate: prescribed BC

Climate looks bad: change boundary condition file(s)

Initialization: prioritize excellent match to observations

Conclusions

- Ice sheet/climate model has important strengths and weaknesses as a scientific tool
- CESM-CISM2 online in CESM developer repository, undergoing sanity testing
- Challenges remain as the model moves towards production science