Ice Sheet Feedbacks on Atmosphere, Land and Ocean Systems in CESM

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JUNE 12, 2023

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Outline

- Land Ice in CESM Overview
- Atmosphere-Ice Sheet Coupling
- Ocean-Ice Sheet Coupling
- Current and Future Work

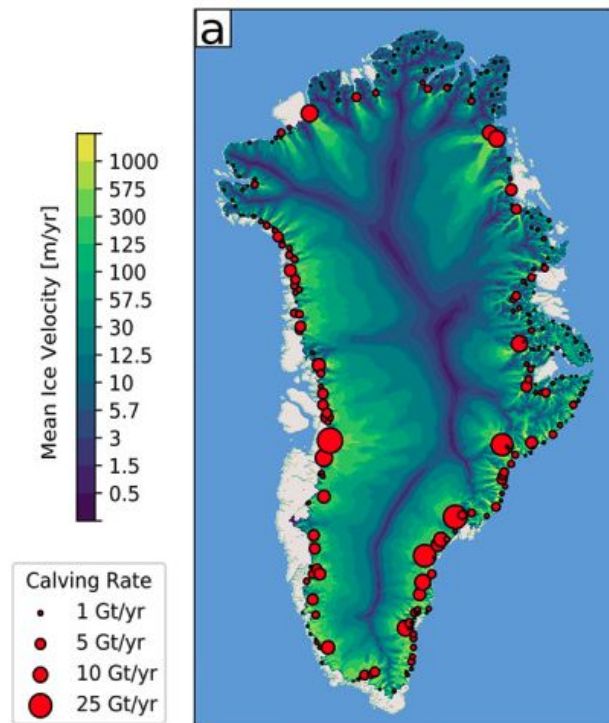Goal: Learn something new about how Land Ice works within the fully coupled CESM system.

Land Ice in CESM: Why?

- Sea level is rising due to melting land ice and thermal expansion of the ocean. Impacting large human populations (8 of the world's 10 largest cities are near a coast).

- Warming and melting of ice sheets is a much slower process than other climate changes. Some sea level increase due to ice sheet disequilibrium is already locked-in, but we aren't sure how much or by when.

- Dynamic ice sheet models in fully coupled climate simulations can produce projections of sea level rise over the next 75-200 years.

- Paleo simulations of ice sheet evolution are helpful for constraining climate sensitivity in the past to help understand the present and future.

(1)

Land Ice in CESM: CISM2

- Greenland and Antarctic Ice Sheets simulated with the **Community Ice Sheet Model v2**
- Relatively new component, smaller community working on it
- 2 CISM Modes: Fully dynamic and interactive "Evolve" mode and fixed size, one-way coupled "No-Evolve" mode
- No-Evolve is the default in most CESM compsets and configurations (including CMIP)
- CISM is one of the highest resolution components of CESM2, generally run at 4km horizontally.

(2) *Muntjewerf et al. 2021*

Mean Ice Velocity [m/yr]

1000
575
300
125
100
57.5
30
12.5
10
5.7
3
1.5
0.5

Calving Rate
· 1 Gt/yr
• 5 Gt/yr
● 10 Gt/yr
⬤ 25 Gt/yr

Land Ice in CESM: Coupling (Evolve)

- Land -> Ice Sheet: Surface mass balance and temp in multiple elevation classes
- Ice Sheet -> Land: Surface elevation, masks for ice cover
- Ice Sheet -> Ocean: Ice (calving) and liquid (basal melt) fluxes
- Ice Sheet -> Atmosphere: Topography update offline

(2) *Muntjewerf et al. 2021*
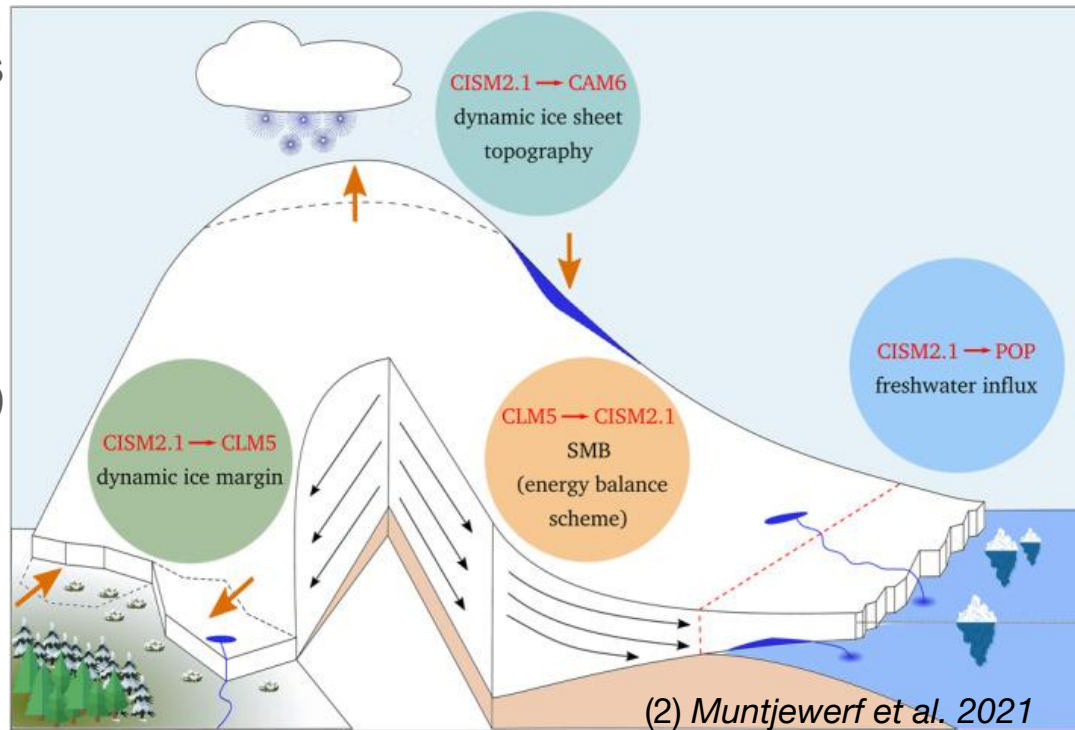
Land Ice in CESM: Surface Mass Balance

- CISM does *not* exchange fluxes directly with the Atmosphere.
- Precipitation, temperature, and snow pack are combined into a surface mass balance (SMB) flux calculated by CLM and downscaled to the ice sheet grid.
- High temporal resolution precipitation and temperature values are accumulated and averaged into a yearly addition or subtraction of ice mass at the ice sheet top.

Surface Mass Balance

(2) *Muntjewerf et al. 2021*
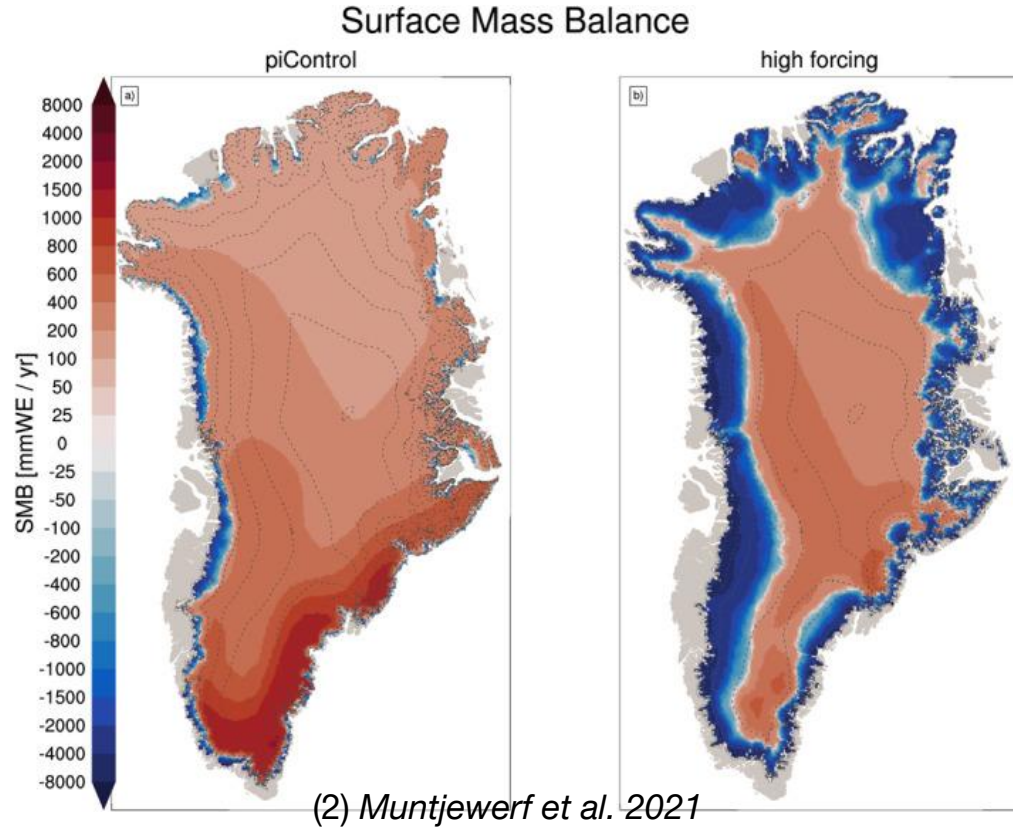
Atmosphere-Ice Sheet Coupling

- On decadal or longer time scales, the topography changes of the ice sheet change orographic drag and atmospheric flows.
- When running fully coupled with Evolve (*not default configuration*), we calculate updates to the CAM topography over the ice sheet offline every 10-ish years.
- The CAM **topo file**, **PHIS** field and **SGS30** fields are updated before the model resumes a restart.
- This workflow is tricky, and we are discussing ways to improve or do this on-line in the future.

(2) *Muntjewerf et al. 2021*
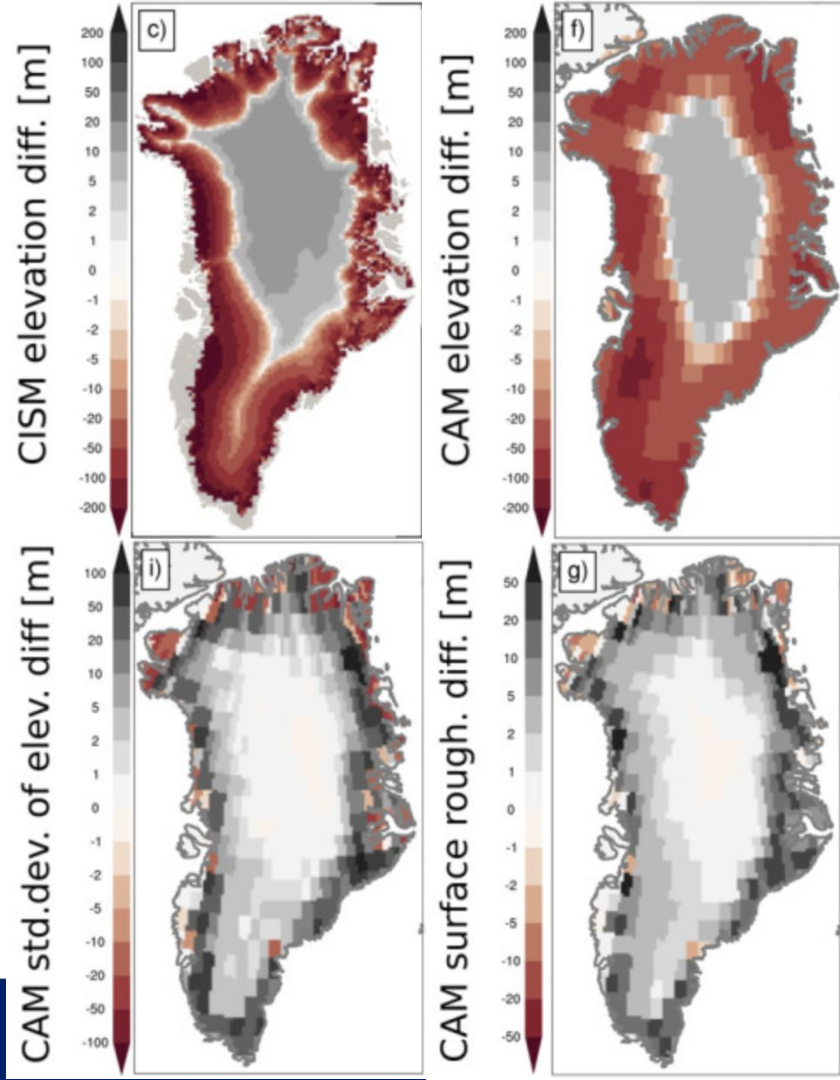
Atmosphere-Ice Sheet Grid Interactions

(3) van Kampenhout et al. 2020

- One reason CISM-Evolve is not used in default coupled CESM cases is due to biases.
- Excess precipitation in the south prevents ablation and grows an excessively large Greenland IS.
- Biases are reduced with high resolution in a CAM VR grid, but exacerbated in standard SE grid that is more uniform than the FV grid (no latitudinal grid refinement).

*VR - Variable Resolution, SE - Spectral Element, FV - Finite Volume*

(4) van Kampenhout et al. 2019
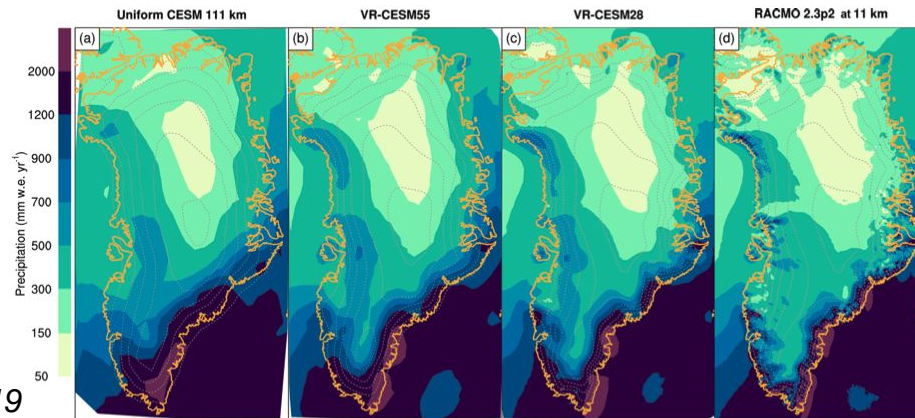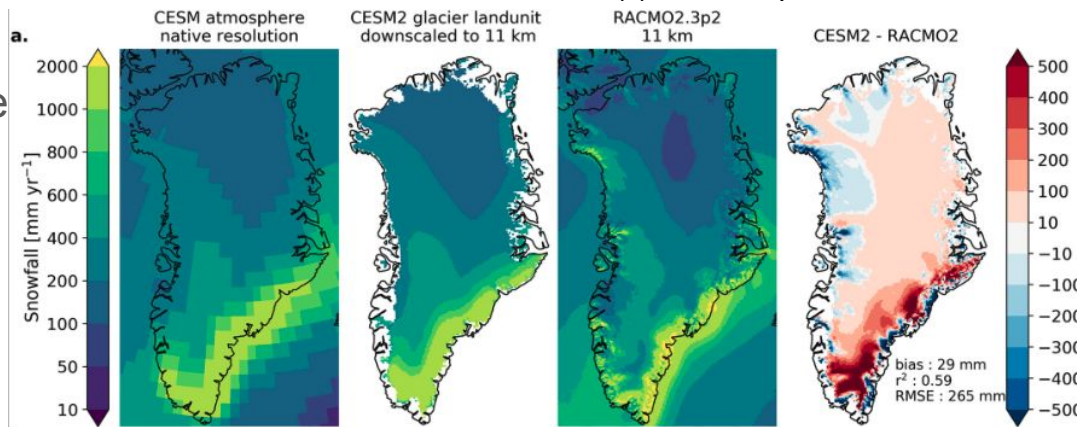
Ocean-Ice Sheet Coupling

- In CESM2-Evolve, ice sheet ocean coupling is only one way. Solid and liquid run-off go directly to the ocean.

- GreenlandIS is mostly grounded, there is not much direct interaction between the ice sheet and ocean.

- Antarctica has floating ice shelves, so CISM needs two-way ocean coupling there.
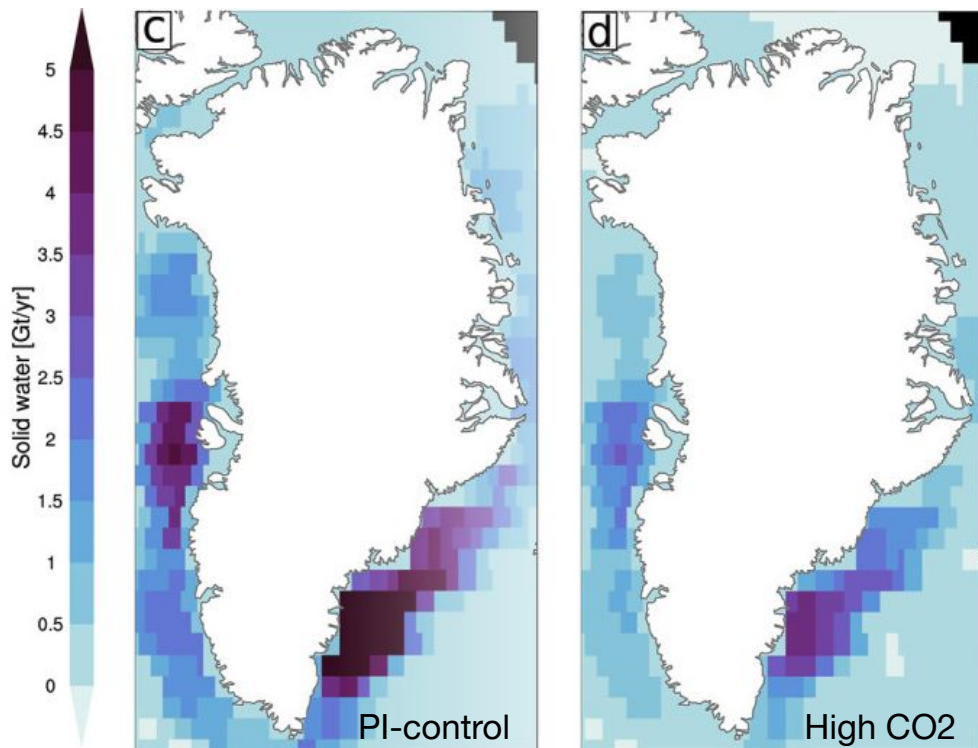

(2) *Muntjewerf et al. 2021*

Ocean-Ice Sheet Coupling

- CESM supports the infrastructure to run a CISM-Evolve Antarctica simulation (or both Greenland and Antarctica).
- Scientifically, there are still a few issues to work out with sub-ice shelf ocean coupling.
- CISM needs temperature and salinity at multiple depths to calculate melt rates below ice shelves.
- In ice shelf regions we need four CESM components working together in the same vertical column!

(f)

SLR = 786 mm

x (km)

CAM

CLM

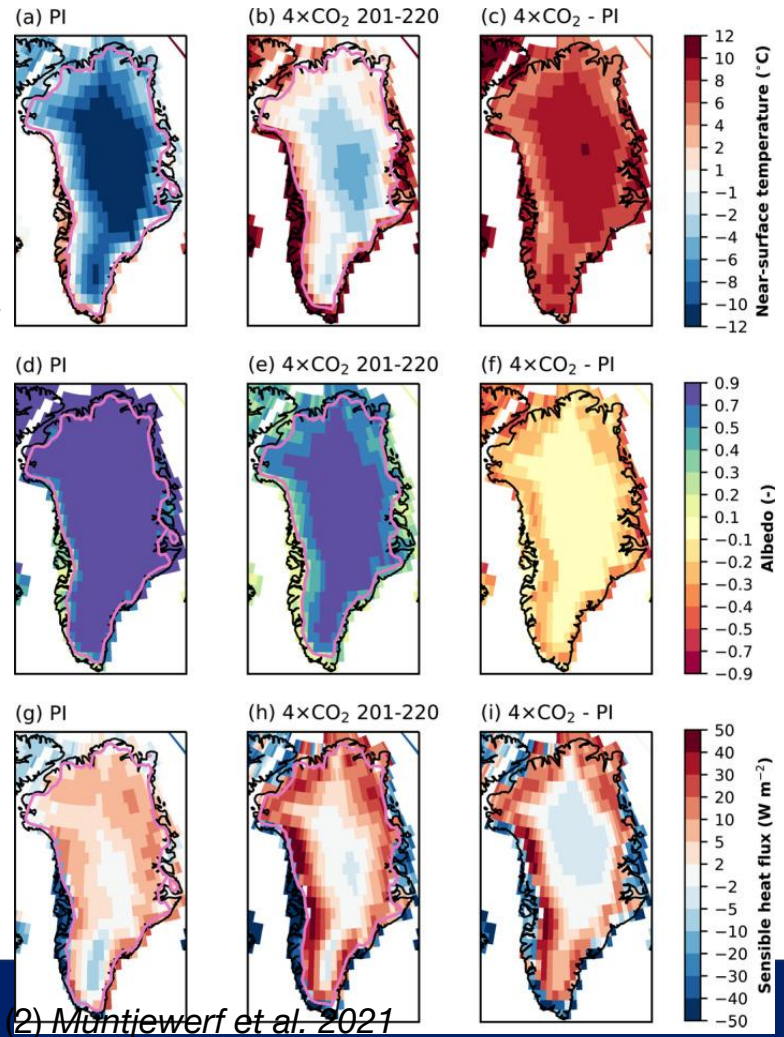CISM

MOM
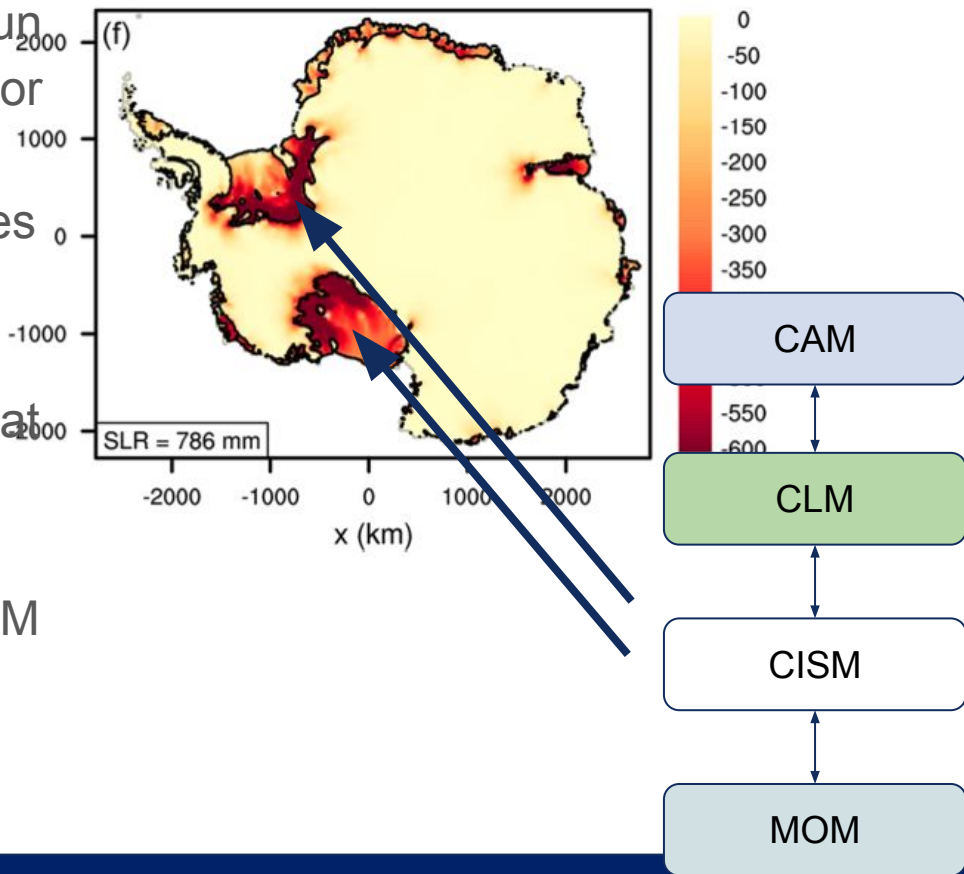
Current and Future Work

- Atmospheric VR simulations
- Mountain Glaciers
- Ocean Coupling and Antarctica
- Topography updating
- Negative Ice fluxes from CISM-NoEvolve
- ISMIP7
- Come to the LIWG meeting on Wednesday morning!

References

1. Nasa Goddard Flickr https://www.flickr.com/photos/gsfc/7163119469/sizes/o/in/photostream/

2. Muntjewerf L, et al. Description and Demonstration of the Coupled Community Earth System Model v2 - Community Ice Sheet Model v2 (CESM2-CISM2). J Adv Model Earth Syst. 2021 Jun;13(6):e2020MS002356. doi: 10.1029/2020MS002356.

3. van Kampenhout, L., Lenaerts, J. T. M., Lipscomb, W. H., Lhermitte, S., Noël, B., Vizcaino, M., et al. (2020). Present-day Greenland Ice Sheet climate and surface mass balance in CESM2. *Journal of Geophysical Research: Earth Surface*, 125, e2019JF005318. https://doi.org/10.1029/2019JF005318

4. van Kampenhout, L., Rhoades, A. M., Herrington, A. R., Zarzycki, C. M., Lenaerts, J. T. M., Sacks, W. J., and van den Broeke, M. R.: Regional grid refinement in an Earth system model: impacts on the simulated Greenland surface mass balance, The Cryosphere, 13, 1547–1564, https://doi.org/10.5194/tc-13-1547-2019, 2019.

5. Lipscomb, W. H., Leguy, G. R., Jourdain, N. C., Asay-Davis, X., Seroussi, H., and Nowicki, S.: ISMIP6-based projections of ocean-forced Antarctic Ice Sheet evolution using the Community Ice Sheet Model, The Cryosphere, 15, 633–661, https://doi.org/10.5194/tc-15-633-2021, 2021.
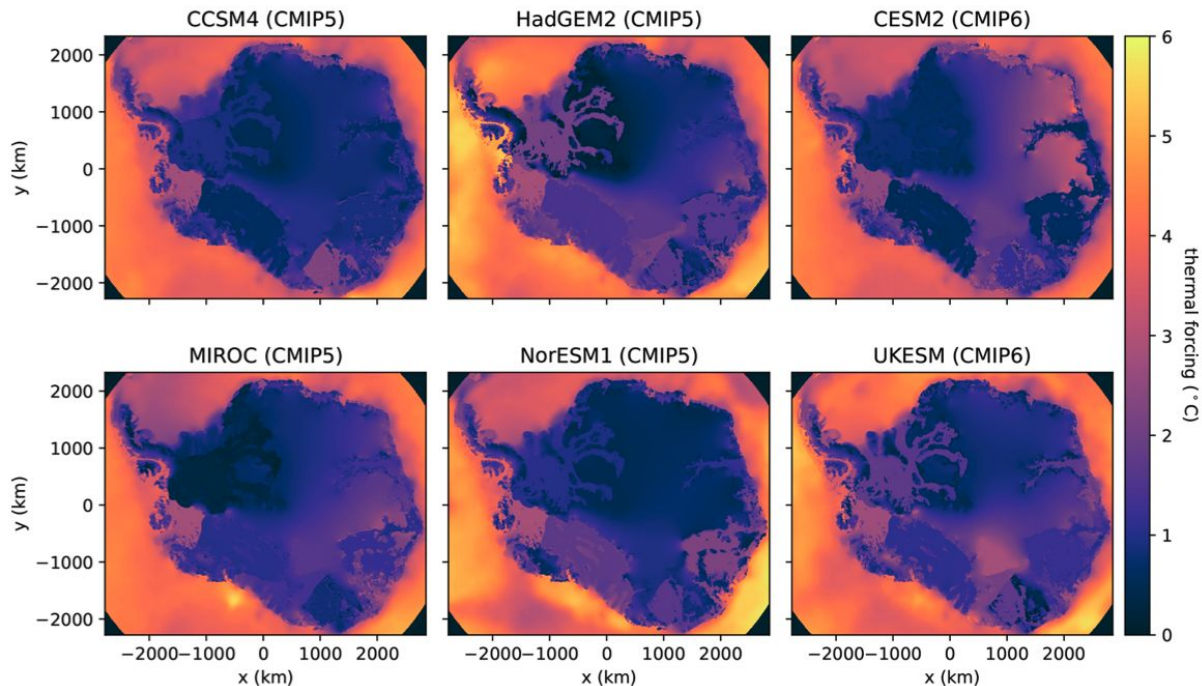
CLM Climate Over Land Ice

- Radiative and energy fluxes to the atmosphere over the ice sheet come from CLM, not CISM.
- Albedo is calculated based on the amount of ice and/or snow in the grid cell vs bare land or vegetation (similar to CLM in other places).
- Dynamic ice sheet boundaries produce a feedback on the atmosphere and climate through CLM's surface fluxes.
- CLM provides these fluxes regardless of what ice sheet model is in use (Evolve, No-Evolve, or stub).

(2) Muntjewerf et al. 2021

Ocean-Ice Sheet Coupling

- Like precip in Greenland, CISM is sensitive to ocean temperature biases around Antarctica.
- We will not be running with Evolve-Antarctica in a default CESM configuration until a satisfactory method of dealing with ocean temp biases is found.

(5) *Lipscomb et al. 2021*