Land Ice Working Group Highlights

27th Annual CESM Workshop

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and the CESM Land Ice Working Group

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NCAR

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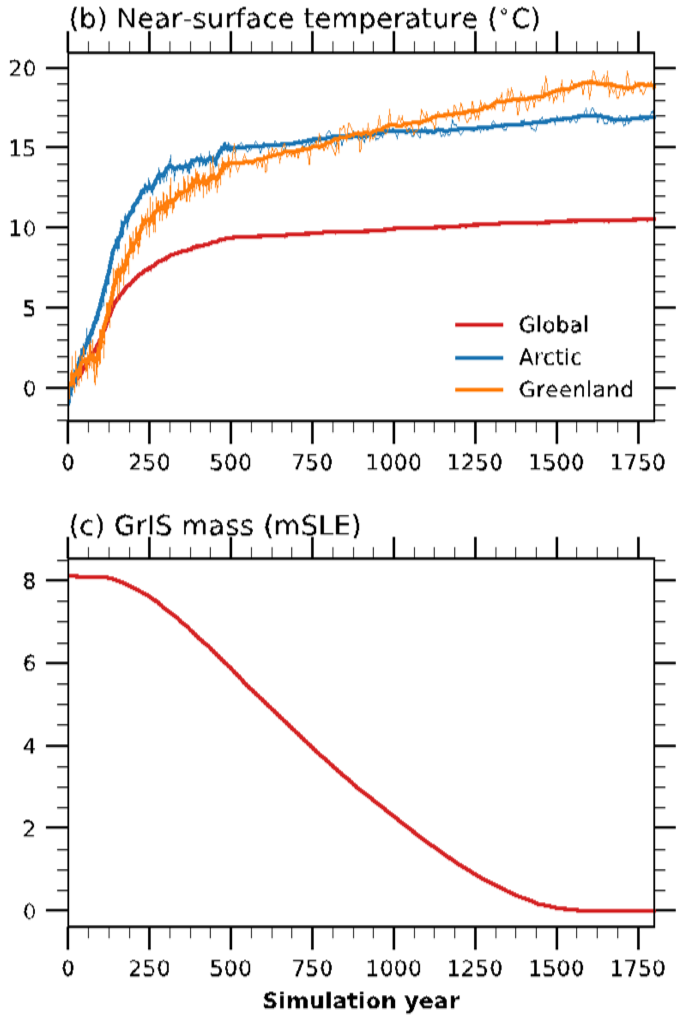
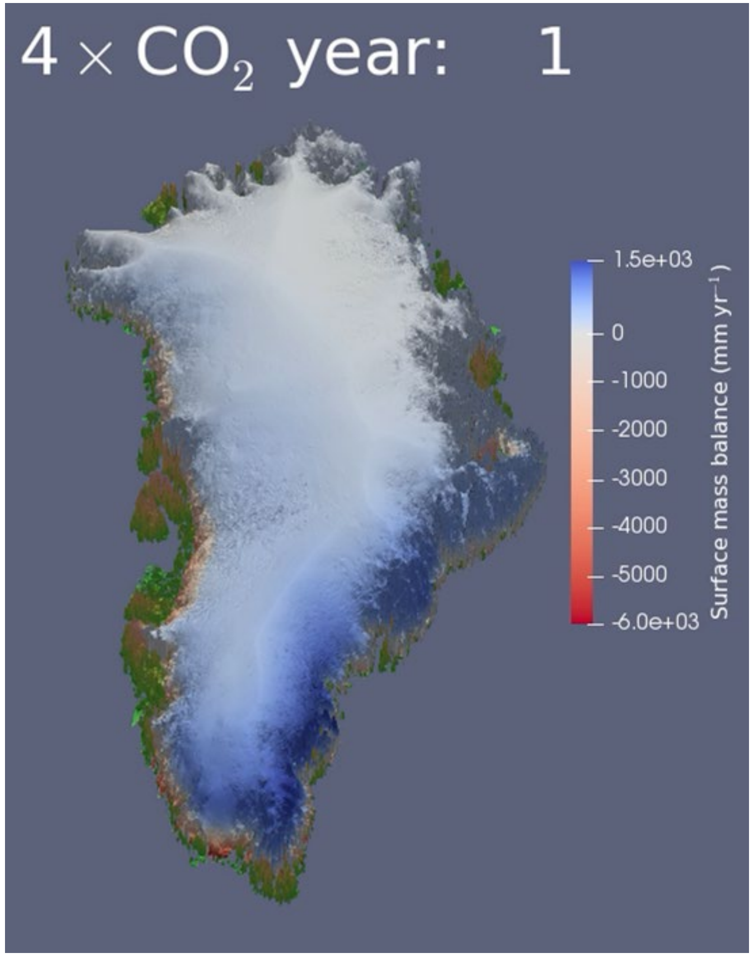
Land Ice Working Group highlights

- CESM-CISM simulations with a **coupled Greenland Ice Sheet**
- Impacts of Antarctic freshwater input to the Southern Ocean
- Simulations of **paleo ice sheets and ocean circulation**
- Extended standalone ice-sheet projections for the **Antarctic Ice Sheet**
- High-resolution simulations of **glacier surface mass balance and dynamics**
- Plans for CESM3

Simulations of complete Greenland Ice Sheet melting with CESM2-CISM2 under high emissions (1% to 4xCO_2)

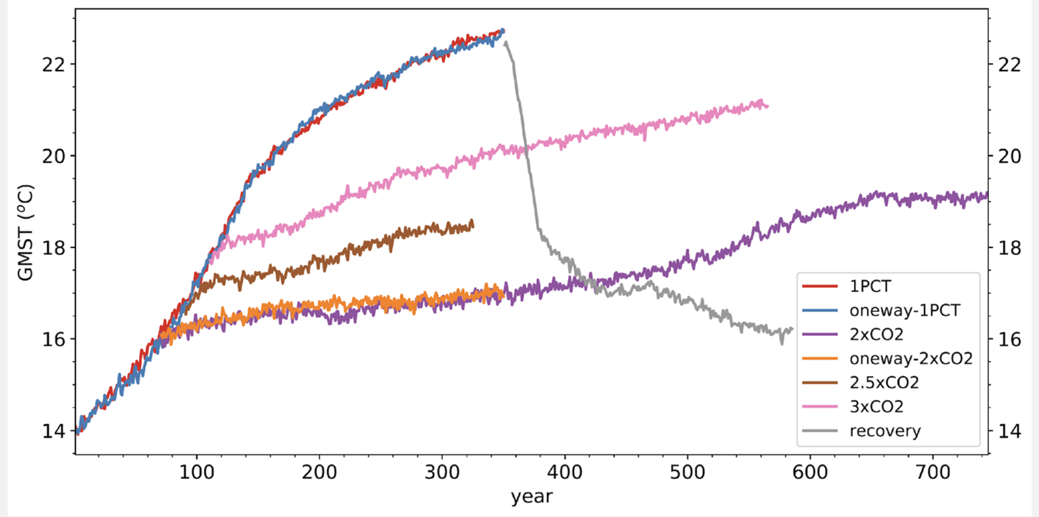




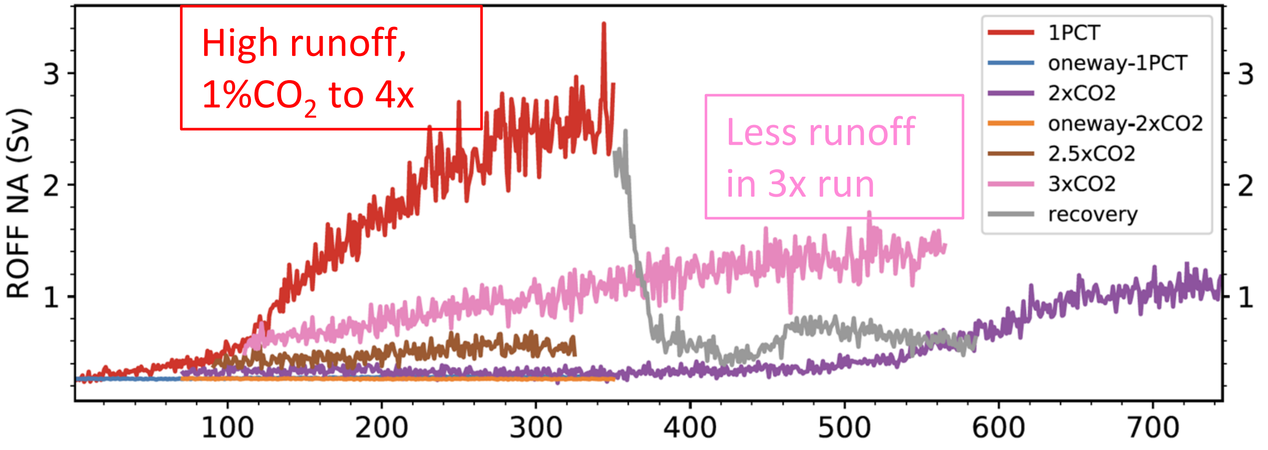
- Total deglaciation in **<1700 years**
- Fastest margin retreat in the Southwest, then the North
- Melt acceleration from albedo feedback and increased sensible and latent heat fluxes
- Feedback from glacial isostatic adjustment is modest because of the fast deglaciation

Greenland runoff and NAMOC for a range of CO_2 scenarios

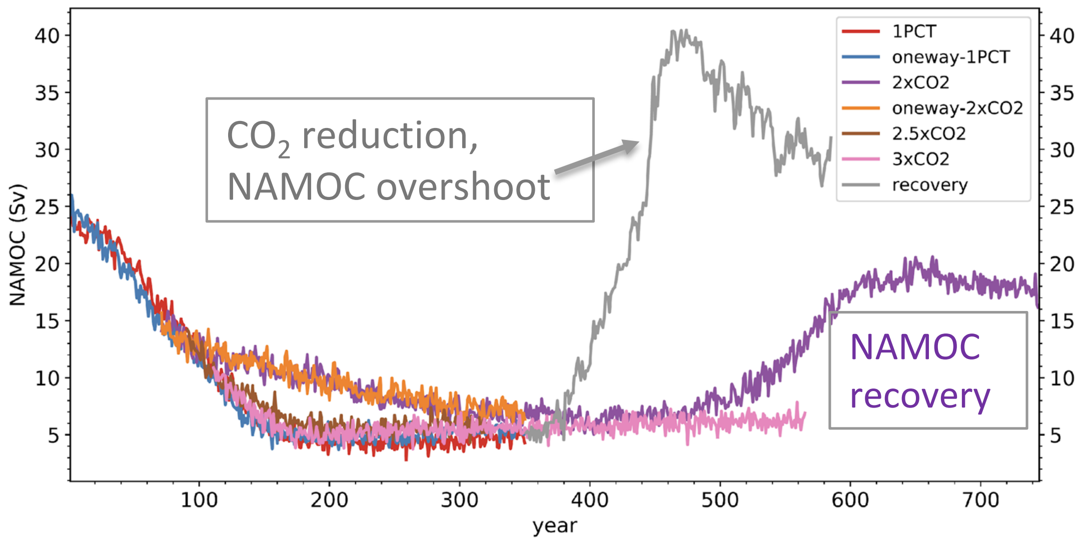
Global mean surface temperature (°C)



N. Atlantic runoff (Sv)



N. Atlantic meridional overturning circulation (Sv)

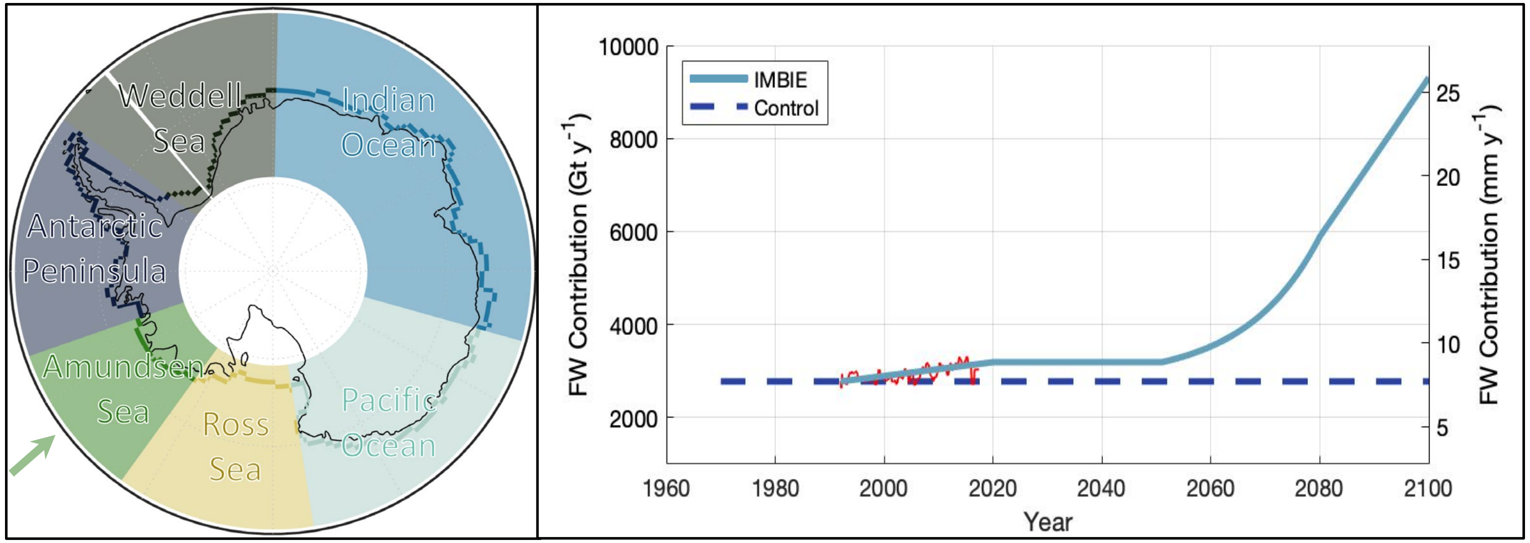


- Multiple 1% CO2 scenarios: **2x**, **2.5x**, **3x**, **4x**
- Much greater runoff for **4x** than **3x**
- The **2x** run allows **NAMOC recovery** (years 500-600), with higher global and GrIS warming and increasing runoff
- **Reduction of CO2** from 4x to 1x in two decades (year 350) results in **NAMOC overshoot**
- One-way **2x** & **4x** runs (GrIS runoff replaced by prescribed preindustrial runoff) have similar NAMOC evolution compared to coupled runs, implying minor GrIS role in NAMOC decline

Impacts of Antarctic freshwater input to the Southern Ocean

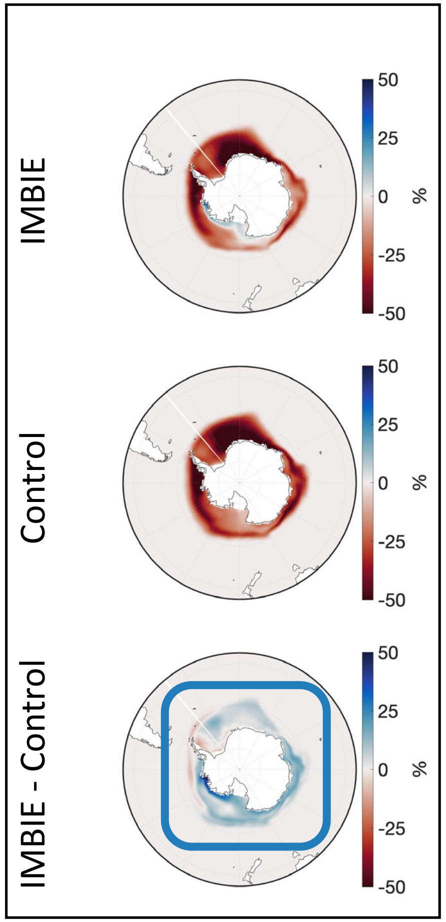
Name	Freshwater Forcing	Notes
Control	Constant	Future forcing: SSP5-8.5
IMBIE	Linearly increasing (1992-2020), constant (2021-2049), exponentially increasing (2050-2100, based on high-end ice sheet retreat scenario)	All extra freshwater is distributed equally to the Amundsen Sea basin coastal grid cells, same SSP forcing

Amundsen Sea Basin



Time series of the freshwater forcings for each simulation as well as the IMBIE mass balance data plotted in red

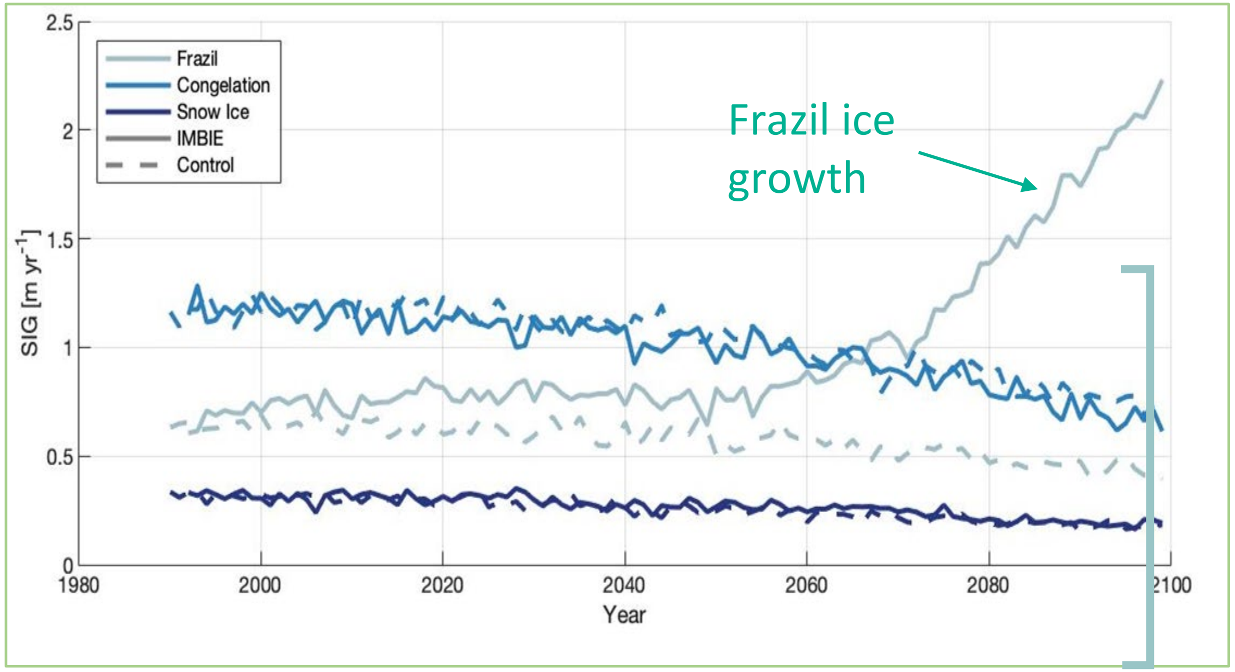
Impacts of Antarctic freshwater input to the Southern Ocean



Sea ice fraction, difference between end and beginning of century

Increased AIS freshwater drives significantly more Southern Ocean sea ice, largely driven by **frazil ice growth**.

Sea ice growth (m/yr)



What is driving the difference in sea ice?

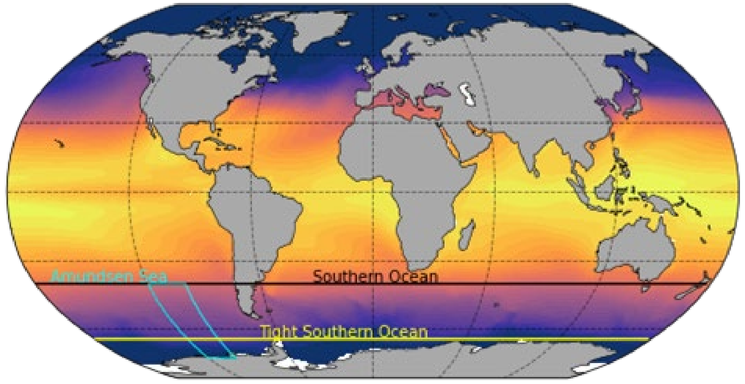
- In addition to being fresher, the surface ocean is also cooler. The cooler, fresher surface ocean is trapping more warm water at depth.
- Also, there is a reduction of the AMOC weakening signal.

CESM2 Southern Ocean response during the Last Interglacial

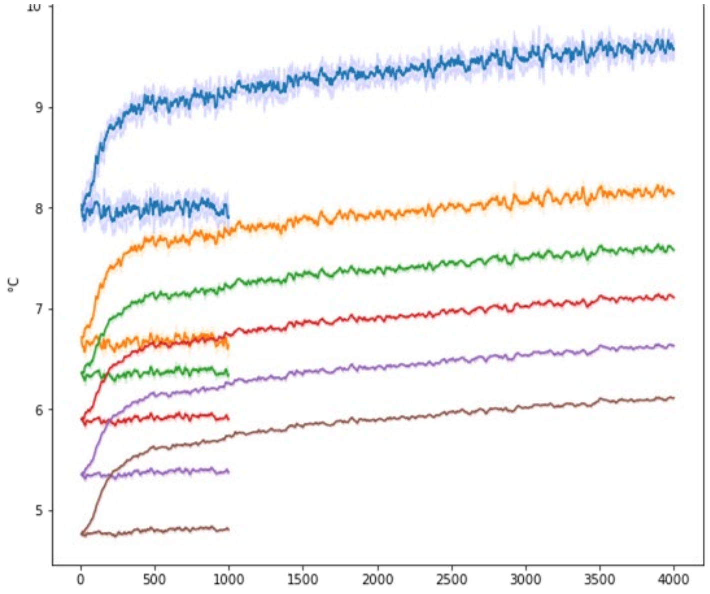
NSF-funded collaboration: U. Washington (Mira Berdahl, Eric Steig), NCAR CGD (Gunter Leguy, Bill Lipscomb, Bette Otto-Bliesner, Esther Brady), Washington Sea Grant (Ian Miller, Harriet Morgan), Brookhaven National Lab (Nathan Urban)

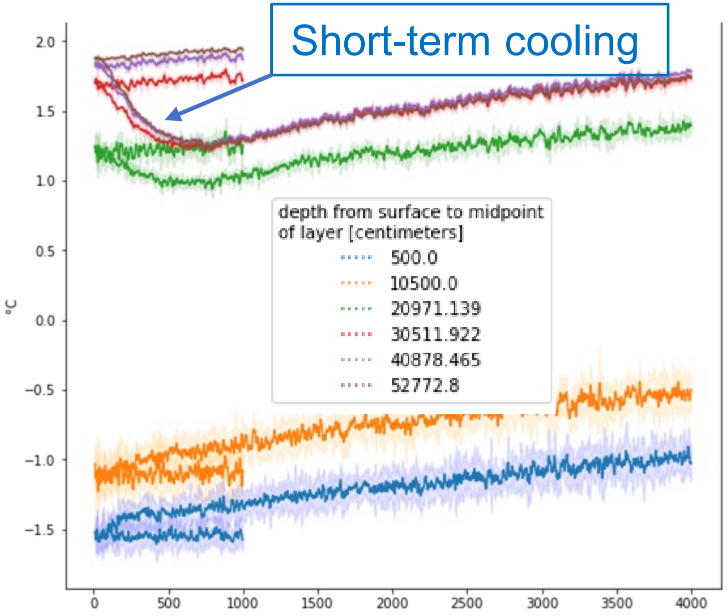
CESM Last Interglacial run (127ka) with Heinrich 11 freshwater forcing

- Orbital parameters, vegetation, GHGs prescribed to LIG levels. Other forcings and boundary conditions as in the *piControl* simulation.
- 0.2 Sv freshwater in North Atlantic between 50-70^{o} North for **4000 years**



Ocean temperature (^{o}C) at various depths.
Left: Southern Ocean. *Right:* `Tight' Southern Ocean (close to Antarctica).



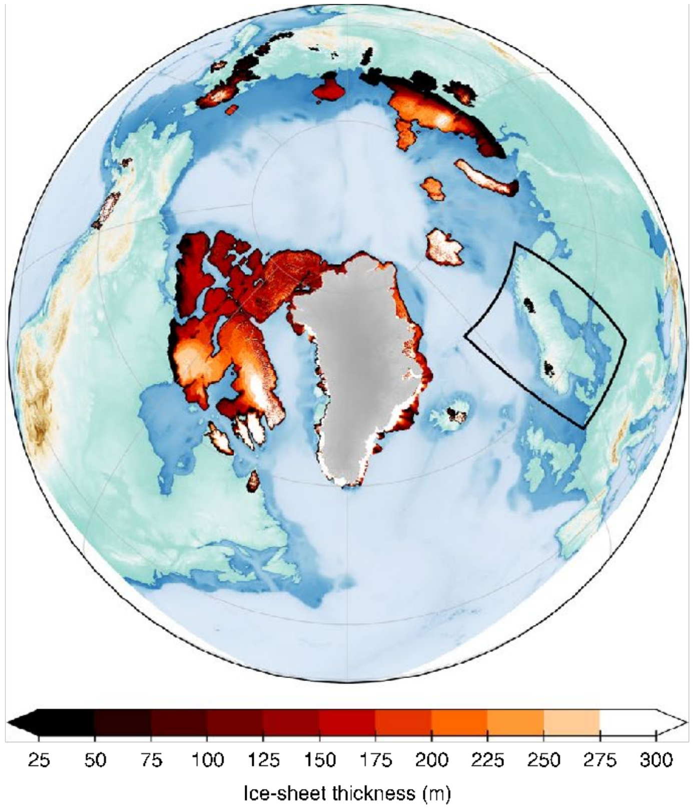


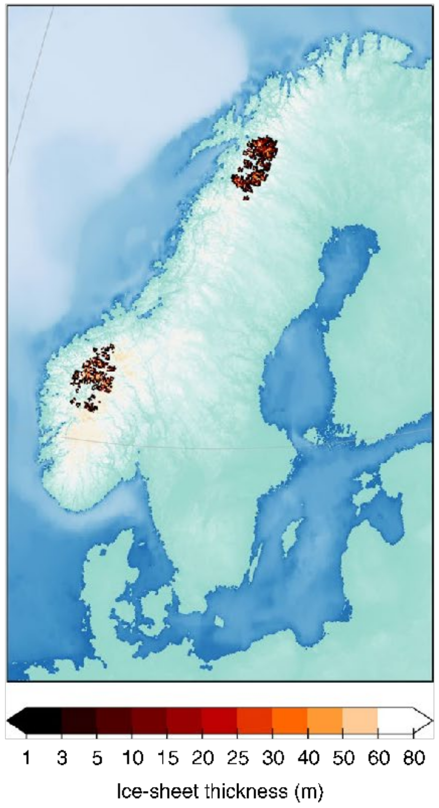
Unexpected short-term cooling at depth close to the Antarctic Ice Sheet. Likely wind-driven.

Slow rebound in ocean temperatures likely facilitated by eddy transport of warmer water accumulated in the northern part of Southern Ocean.

Ocean gateways and ice sheet expansion

Lofverstrom et al. (Nature Geoscience, 2022)

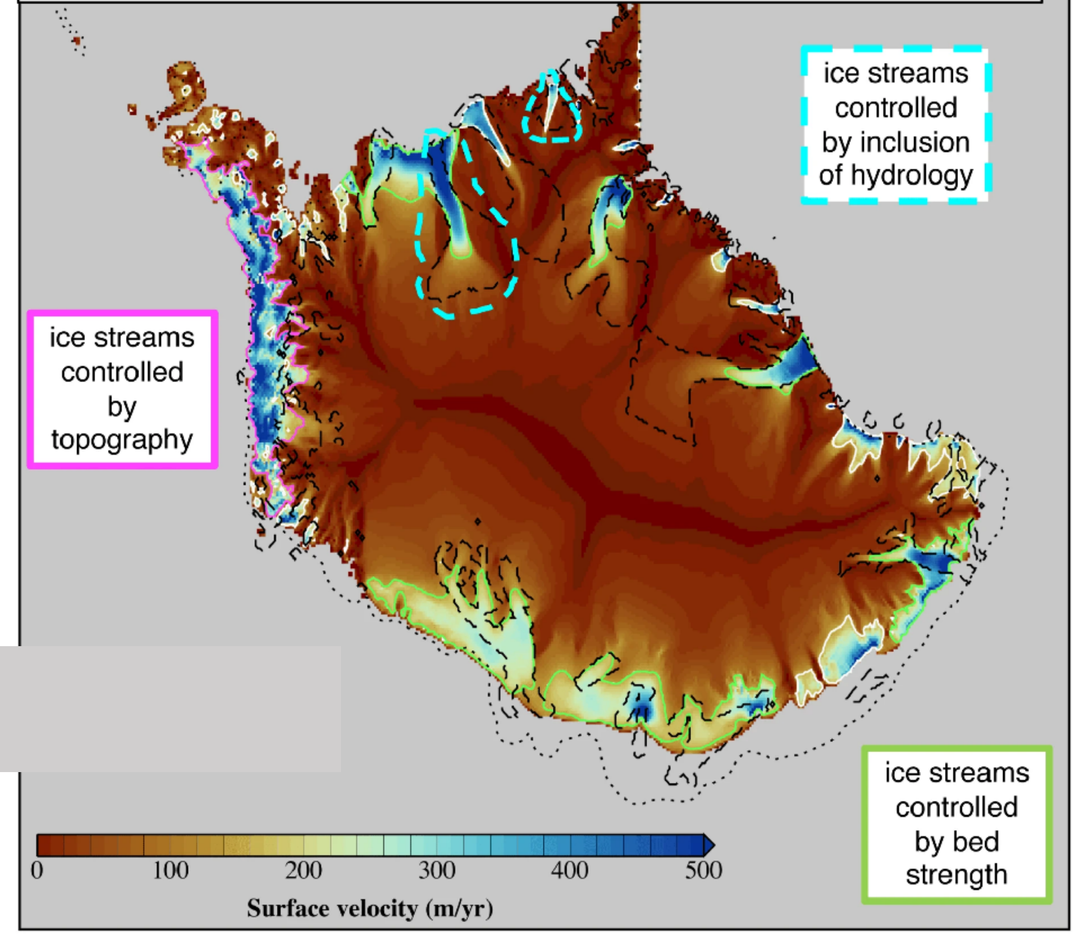




- Simulated **Northern Hemisphere ice sheet inception** at 116 ka using coupled CESM–CISM.
- Proximity to the warm North Atlantic initially precludes ice growth in Scandinavia.
- A growing North American ice sheet **closes ocean gateways** in the Canadian Arctic Archipelago (left).
- **Freshwater is diverted** east of Greenland. North Atlantic freshening leads to sea ice expansion, cooling, and **Scandinavian ice growth** (right).

Paleo ice sheet simulations with CISM

Surface velocity (m/yr) at 21ka BP from a simulation including hydrology and bed properties. Dashed black contour highlights location of known ice streams (*Margold et al., 2018; Eyles et al., 2018*) and the dotted black contour initial ice extent. Regions of fast flow (> 150 m/yr) are marked by the pink and green contours.



- CESM and CISM are being applied to the North American Ice Sheet complex at the time of the **Last Glacial Maximum**, 21 ka.
- CISM generates ice streams in good agreement with the paleoclimate record, as a result of **subglacial hydrology** (Arctic margin), **steep bed topography** (Pacific margin), and **weak basal till** (southern margin).
- These runs use offline coupling, but CESM-CISM is now enabled for **multiple coupled ice sheets**, including Antarctica.

Courtesy of Sarah Bradley

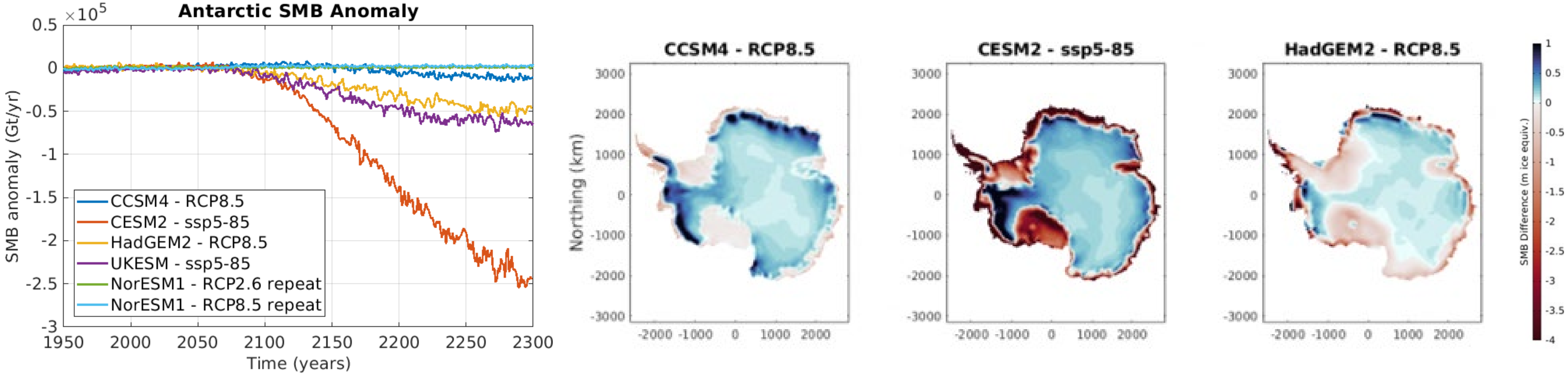
ISMIP6 Antarctica extensions to 2300

ISMIP6: sea-level projections from standalone Greenland and Antarctic ice sheet models

- Projections to 2100 (Seroussi et al. 2020): offsetting sea-level rise from ocean warming, sea-level fall from increased snow

Extended Antarctica experiments: Surface mass balance (SMB) and ocean thermal forcing anomalies based on AOGCMs run to **2300** with high emissions (including CCSM4, CESM2)

- Large variations among AOGCMs. Some models have regions with large negative SMB.
- CISM runs will use new initialization datasets, updated physics and spin-up techniques.

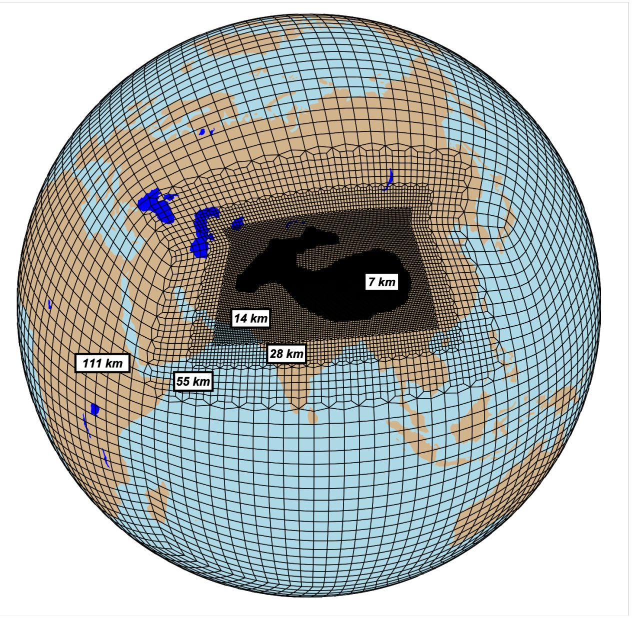


Left: Total Antarctic SMB anomaly (Gt/yr) timeseries. *Right:* Change in SMB between 2015 and 2300 for three AOGCMs. See https://www.climate-cryosphere.org/wiki/index.php?title=ISMIP6-Projections2300-Antarctica.

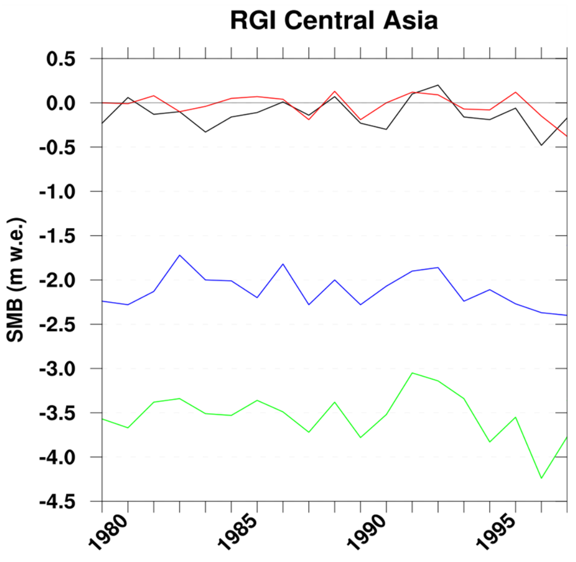
Modeling High Mountain Asia with variable-resolution CESM

AMWG/LIWG collaboration with René Wijngaard (Yonsei University, IRCC, now IMAU, Utrecht U.)

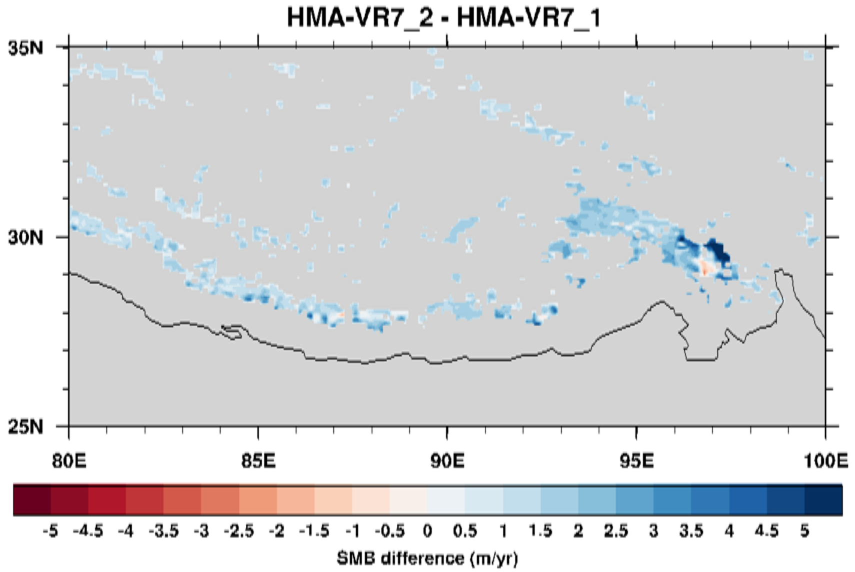
- Variable resolution HMA grid, refined to 7 km, 36 glacier elevation classes, ~90K core hrs per model year
- Two 20-year simulations (1979-1998). Second simulation includes updated glacier cover dataset, new spinup, and modifications/tunings in CAM and CLM.



HMA VR7 grid



Area-averaged annual surface mass balance, Central Asia region, 1980-1998.
Black = observations, Red = WRF-based
Green = HMA-VR7_1, Blue = HMA_VR7_2



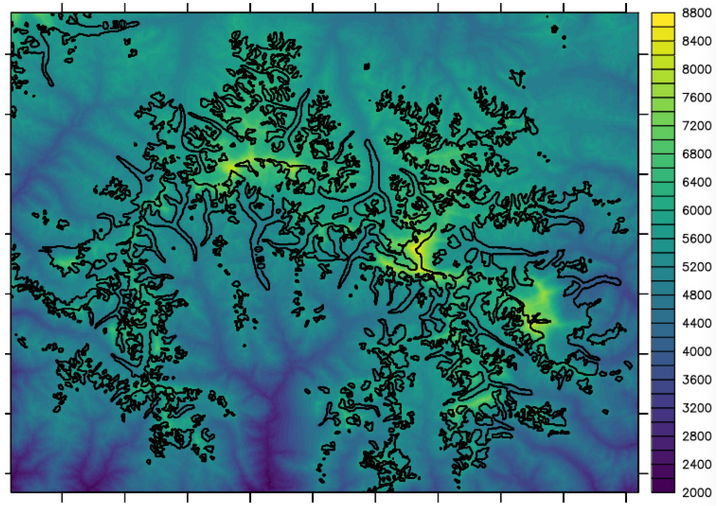
Differences in SMB between the first and second HMA simulations.
Blue = reduced bias, red = increased bias

CISM as a glacier model

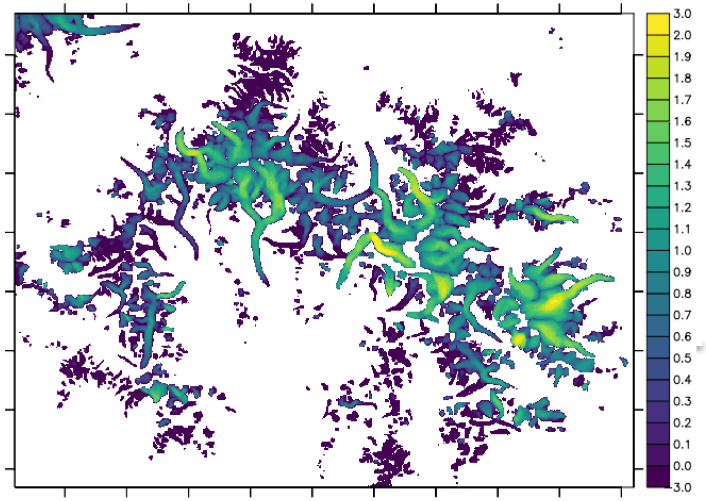
We have created a 100-m CISM grid for **High Mountain Asia** (~100,000 glaciers).

- Initialize with **observed glacier outlines** and **consensus ice thickness estimates.**
- During spin-up, tune SMB and basal friction factors to **match observed extent and volume.**

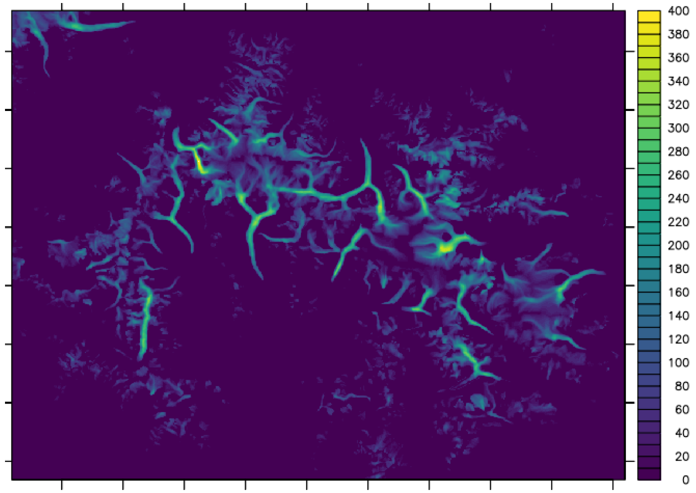
Early results from the Nepal Everest region:



Initial surface elevation, glacier outlines



Surface ice speed (m/yr, log scale)



Simulated ice thickness (m)

We hope to contribute CISM results to GlacierMIP3: https://github.com/GlacierMIP/GlacierMIP3

Plans for CISM3

CESM3 will support fully coupled climate – ice sheet simulations with **Greenland, Antarctica, and/or paleo ice sheets.**

- Until now, CESM-CISM has supported only a single ice sheet. The only out-of-the-box ice sheet has been Greenland.
- We have added support for running **Antarctica** out-of-the-box.
- We have also added support for running **multiple ice sheets** in a single simulation. This is the first out-of-the-box support for a CESM component with multiple grids, each with its own physics parameters. (Thanks to Bill Sacks and Mariana Vertenstein for software development.)

We also plan to use CISM and CESM for studies of mountain glacier retreat and regional water security (e.g., GlacierMIP).

CISM development and coupling

Blue: Implemented and being tested

Green: Development underway

Dynamical core

- C-grid ice velocity solver

Ice sheet physics

- New Coulomb basal sliding law
- Flux-routing basal hydrology scheme
- Damage-based calving law
- Sub-ice-shelf cavity circulation module

Mountain glaciers

- Inversion methods for glacier spin-up

Coupling

- Run with multiple active ice sheets
- Enable water isotopes in CISM
- Runtime atmosphere topography updates

Tools and datasets

- Glacier grid generation and mapping tools
- Support for finer CISM grids: 1^{o} GrIS, 2^{o} AIS
- Land ice diagnostic package

Aiming to release CISM 3.0 by summer 2023

Contact information

Website: https://www.cesm.ucar.edu/working_groups/Land+Ice/

Co-chairs:

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- Miren Vizcaino, M.Vizcaino@tudelft.nl (incoming)
- Bill Lipscomb, Lipscomb@ucar.edu

Liaisons:

- Gunter Leguy, NCAR, gunterl@ucar.edu
- Kate Thayer-Calder, katec@ucar.edu

Please join us for a joint session with the Polar Climate Working Group on **Thursday June 16, 8:30 am – noon MT**.