CESM Land Ice Working Group update

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CESM Land Ice Working Group

- **Co-chairs:** Bill Lipscomb (CGD) and Jan Lenaerts (CU Boulder)
- **Science liaison:** Gunter Leguy (CGD)
- **Software liaison:** Kate Thayer-Calder (CGD)
- **Software liaison emeritus:** Bill Sacks (CGD)
- **Web page:**
  [http://www.cesm.ucar.edu/working_groups/Land+Ice/](http://www.cesm.ucar.edu/working_groups/Land+Ice/)
Outline

• Brief overview of land ice in CESM2
• Recent and ongoing simulations
  • CMIP6 DECK experiments
  • New paleo ice sheet configurations
  • ISMIP6 coupled and standalone
• Future directions

Thanks to Sarah Bradley, Gunter Leguy, Jan Lenaerts, Marcus Löfverström, Gustavo Marques, Laura Muntjewerf, Bette Otto-Bliesner, Michele Petrini, Bill Sacks, Raymond Sellevold, Aleah Sommers, Kate Thayer-Calder, Leo van Kampenhout, Miren Vizcaíno, and others in the LIWG
2018 model releases

CISM2.1, https://github.com/cism/cism:
• Parallel, higher-order ice sheet dynamics
• Improved physics: Basal sliding, iceberg calving, grounding lines
• Model description and evaluation: Lipscomb et al. (2019, GMD)

CESM2:
• Improved glacier surface physics in CLM (van Kampenhout et al. 2017)
• Support for two-way coupling between the Greenland ice sheet and the land and atmosphere (with dynamic landunits)
Ice sheets in CESM2

- For most standard configurations, CISM is set to **no-evolve**
  - Ice sheets are fixed
  - The surface mass balance (SMB) is computed in CLM for all glaciated grid cells (in multiple elevation classes, if desired)

- CISM can evolve with **one-way coupling**
  - SMB and surface temperature are passed from CLM to CISM
  - Fixed elevation and land surface types in CLM

- CISM and CLM can co-evolve with **two-way coupling**
  - Ice sheet extent and elevation are passed from CISM to CLM
  - Dynamic landunits in CLM (glacier ⇔ vegetated)

Coupling is supported out of the box for Greenland only.
Greenland SMB is generally realistic, but there are biases associated with coarse (FV1) topography and missing physics (talk by Jan Lenaerts).
Greenland SMB response to increased \( CO_2 \)

Surface mass balance (mm/yr): red = accumulation, blue = ablation

Average of last 30 years of simulation

piCTRL
1pctCO2
4xCO2

Courtesy of R. Sellevold

TU Delft
Glacier elevation classes

Elevation classes give a more realistic SMB, but biases in individual components (incoming radiation and precip) need more attention (Sellevold et al., 2019, TCD).

- Elevation classes produced melt energy and SMB agrees well with regional modeling
- Need more work to improve simulation of individual components
- Lowering the temperature lapse rate leads to higher ablation area, and lowers SMB
**Goal:** Conduct a transient, fully coupled simulation of the Greenland Ice Sheet from 127,000 – 121,000 years ago

- Warmer than present climate due to differences in solar insolation, GHG concentration, and albedo (vegetation distribution)

1. **Preparatory “B-then-T” simulations**

   Run CESM with static ice sheet to generate 50 years of climate data, then force an ice-sheet-only run using those atmosphere data
   - Ice sheet collapse after 6 kyr

2. **BG run with constant orbitals**

   Run CESM with dynamic ice sheet, orbital parameters held at 127ka state
   - Ice sheet retreats, but slower than in T runs

3. **Transient BG run (coming soon!)**

   - See Aleah Sommers’s talk for details (Cross-WG session on long transient simulations)
Simulating inception of ice sheets in the Northern Hemisphere at 116 ka (work by Marcus Löfverström)

- Inception seen in N. Canada as desired
- Closing straits in Canadian Archipelago reduces AMOC, expands sea ice, and supports Scandinavian inception
POP – CISM coupling

Simulate last deglaciation of the Northern Hemisphere with ice–ocean interaction (work by Sarah Bradley and Michele Petrini)

• See Michele’s talk for details (PaleoWG)

\[ B_m(z_b) = \frac{\rho_s c p \gamma_t F_m \cdot (T_o(z_b) - T_f(z_b))^2}{L_i \rho_i} \]

\[ T_f(z_b) = 0.0939 - 0.057 \cdot S(z_b) + 7.64 \cdot 10^{-4} \cdot z_b \]
We have established a protocol for data exchange and run sequencing.

Initial simulations follow idealized community experiments (MISOMIP).

Next step: Test in a global domain with ice shelf cavities.

Courtesy of G. Marques
Ice Sheet Model Intercomparison Project for CMIP6 (ISMIP6)

• ISMIP6 is the first CMIP project focused on ice sheets.
  • **Primary goal**: To estimate past and future sea level contributions from the Greenland and Antarctic ice sheets, along with associated uncertainty
  • **Secondary goal**: To investigate feedbacks due to dynamic coupling between ice sheet and climate models, and impacts of ice sheets on the Earth system

• Includes both standalone ice sheet experiments and coupled ice sheet–climate experiments (Nowicki et al. 2016)
ISMIP6 simulations with CISM and CESM

1. Analysis of CMIP6 global model results that are relevant for ice sheets (Lenaerts et al.)

2. Standalone ice sheet experiments based on CMIP6 model output to estimate past and future sea level rise, explore uncertainty (Lipscomb and Leguy)

3. Coupled climate – ice sheet experiments to explore ice sheet impacts and feedbacks (Vizcaíno et al.)

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<th>CMIP6 experiments used by ISMIP6 (AOGCM)</th>
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<td>- ISM for last few decades (AMIP)</td>
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<td>- ISM for 21\textsuperscript{st} / 23\textsuperscript{rd} century (SSP5-8.5)</td>
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<td>- ISM specific experiments to explore uncertainty</td>
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Spinning up coupled CESM2-CISM2

JG/BG spinup:
- ~300 fully coupled years, 900 ocean years, 9000 ice sheet years
- Ice volume is ~8% larger than observed
- Starting point for coupled historical and future simulations

Greenland ice sheet thickness (m)

Sea-level equivalent volume [mm]

Courtesy of M. Löfverström and the LIWG
CISM Antarctic simulations: Spin-up

- **Goal:** Spin up Antarctica to a steady state consistent with modern observations, given a prescribed SMB. More challenging than Greenland.

- **Method:** Nudge **basal friction parameters** (for grounded ice) and **sub-shelf melt rates** (for floating ice) to match the observed surface elevation.

Antarctic surface ice speed (m/yr, log scale).  
Red = fast, blue = slow
Future land ice development

- **Subglacial hydrology model**
  - Water is conserved and flows down the hydropotential gradient; basal friction evolves over time

- **Improved calving law**
  - Match observed calving fronts given stress and melt rates (talk by Ravindra Duddu)

- **Sub-shelf plume model**
  - Simple steady-state model of ocean circulation beneath ice shelves (based on Jenkins 2018)

- Comprehensive land ice diagnostic package

- **Reduce SMB biases** for Greenland

- Support a dynamic **Antarctic ice sheet** and **paleo ice sheets** in coupled simulations (including ice sheet – ocean coupling)
Summary

- CISM2 and CESM2 include major physical, numerical, and software advances relative to CISM1/CESM1.

- The Land Ice Working Group is using these models for leading-edge science, including standalone ice sheet and coupled ice sheet – climate simulations for ISMIP6.

- Coupling of ice sheets to the land and atmosphere is fairly mature, but ice sheet–ocean coupling is still in its early stages.

- Sea level rise remains a wide-open problem, largely because of uncertainties about Antarctica.