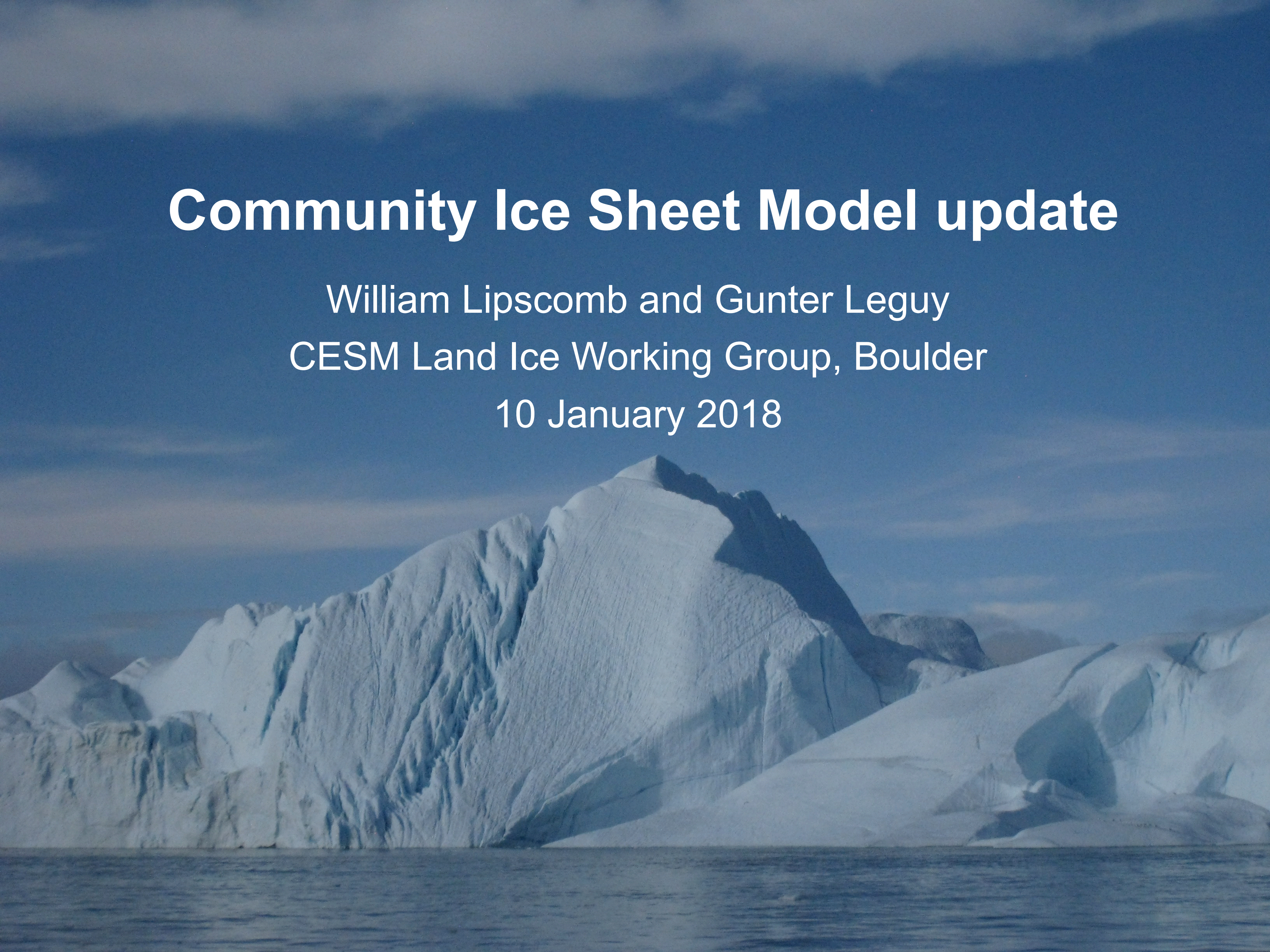


Community Ice Sheet Model update

William Lipscomb and Gunter Leguy

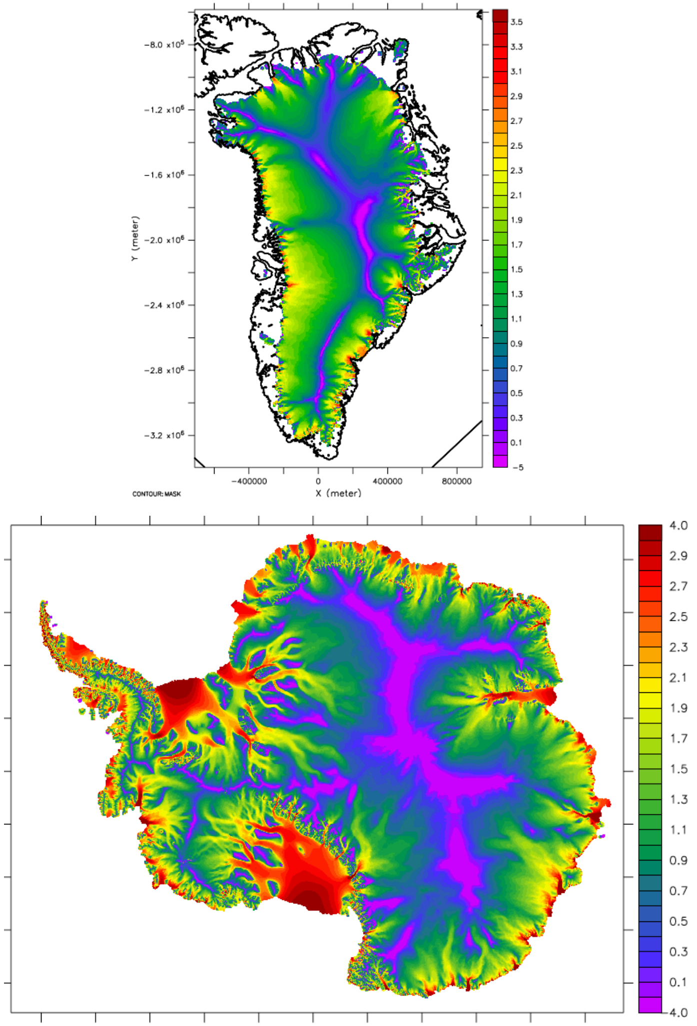
CESM Land Ice Working Group, Boulder

10 January 2018

Community Ice Sheet Model

CISM2

- Parallel dynamical core (Glissade) with suite of velocity solvers (SIA, SSA, depth-integrated higher-order, 3D Blatter-Pattyn higher-order)
- Various physics options for basal sliding, iceberg calving, and isostasy
- Incorporated in CESM2 with support for one-way and two-way coupling
- Now developed and supported by NCAR/NSF (W. Lipscomb, G. Leguy, W. Sacks)
    - Robust and validated for Greenland (participated in initMIP-Greenland)
    - Under development for Antarctica



CISM2: Simulated surface speeds (m/yr, log scale) for the Greenland and Antarctic ice sheets

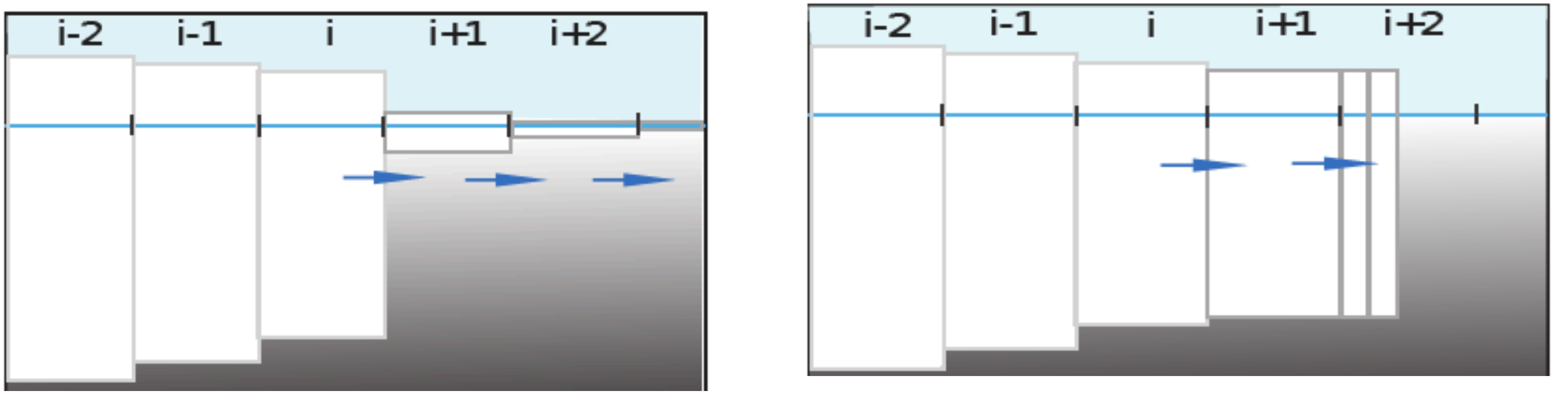
Recent CISM developments

- **Local basal till model**
  - Combined with pseudo-plastic basal sliding scheme for Greenland simulations (similar to PISM; based on Bueler and van Pelt 2015)
  - Improves the simulation of Greenland's basal state
- **Subgrid calving-front scheme**
  - Gives better accuracy and robustness at floating ice margins
  - Supports new thickness-based calving and eigencalving options
- **Height-limiting option for marine cliffs**
  - Based on Bassis & Walker (2012); similar to DeConto & Pollard (2016)
  - Prevents excessively tall cliffs at ice margin
- **Isostasy improvements**
  - Nonlocal elastic lithosphere now supported for parallel runs
  - Exact restart with active isostasy
- **Adaptive time step**
  - Can subcycle transport as needed based on advective CFL condition

- Many minor changes (mass conservation diagnostics, user-friendly restart, …)

Subgrid calving front parameterization

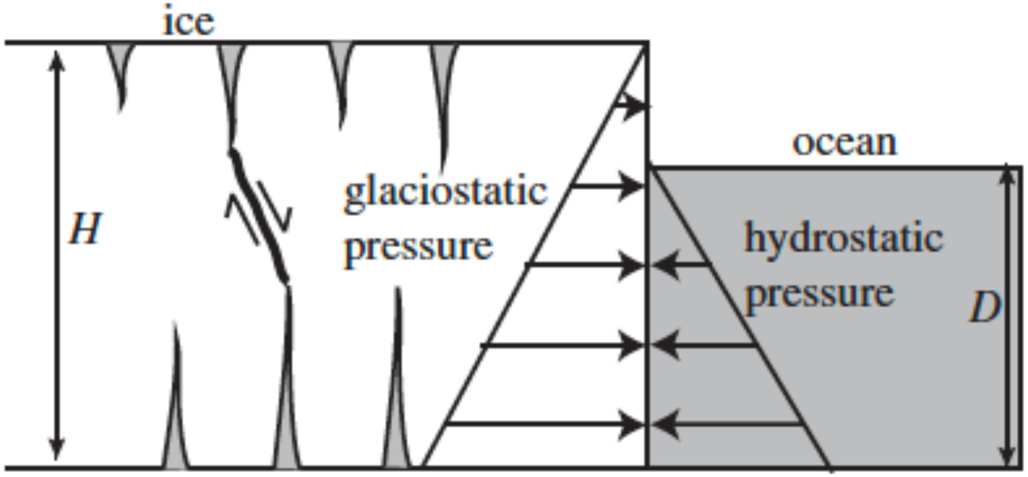
- The calving front is typically a vertical cliff face with small surface elevation gradients.
- Problem: Advection at the calving front leads to thin ice in adjacent grid cells, giving large and unrealistic driving stresses.
- Solution (similar to Albrecht et al. 2011):
  - For calving-front cells, define an effective thickness based on upstream cells.
  - These cells become dynamically active only when sufficiently thick.



Calving front schematics from Albrecht et al. (2011).
Left: Unrealistic diffusion of calving front by advection
Right: Effective thickness at calving front given by upstream cell

Marine ice cliff instability

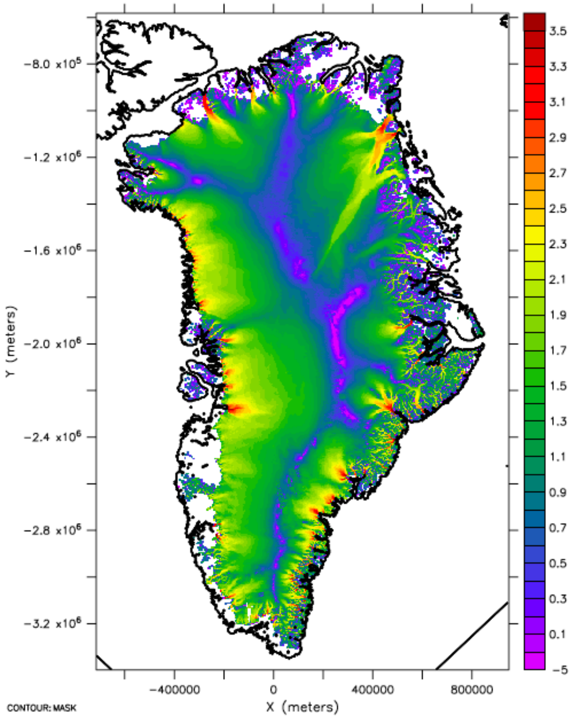
- Bassis and Walker (2012) proposed that marine ice cliffs cannot have a height more than ~100 m above sea surface
  - This is close to the observed limit for Greenland outlet glaciers.
- With higher surface elevation, the longitudinal stresses in the ice exceed the yield strength.
- This mechanism (together with hydrofracture) is critical for rapid Antarctic ice retreat simulated by DeConto and Pollard (2016).
- Recently coded in CISM; next step is to look at effects on ice stability



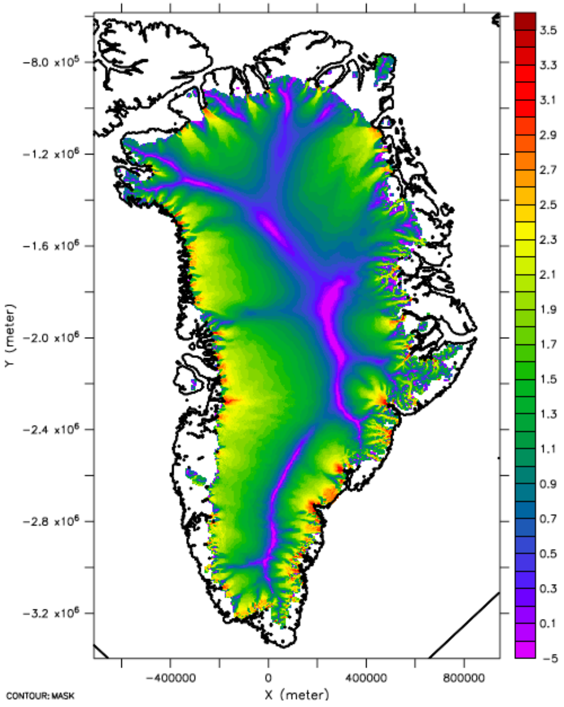
Force balance at a marine ice cliff from Bassis & Walker (2012)

Standalone Greenland simulations

- Using a depth-integrated HO solver (DIVA) and pseudo-plastic sliding law on a 4-km grid with RACMO SMB, surface ice speeds in CISM are (mostly) in good agreement with observations.
    - ~6 tunable sliding parameters; 2D basal traction field is *not* tuned



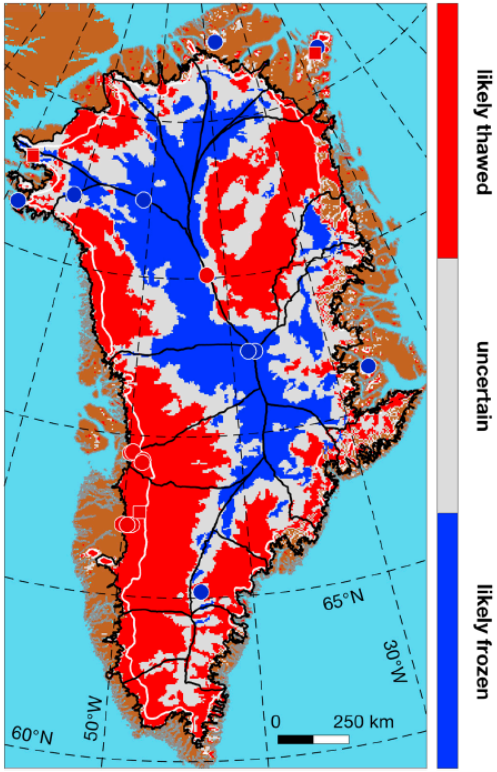
Observed surface speed (m/yr, log scale)



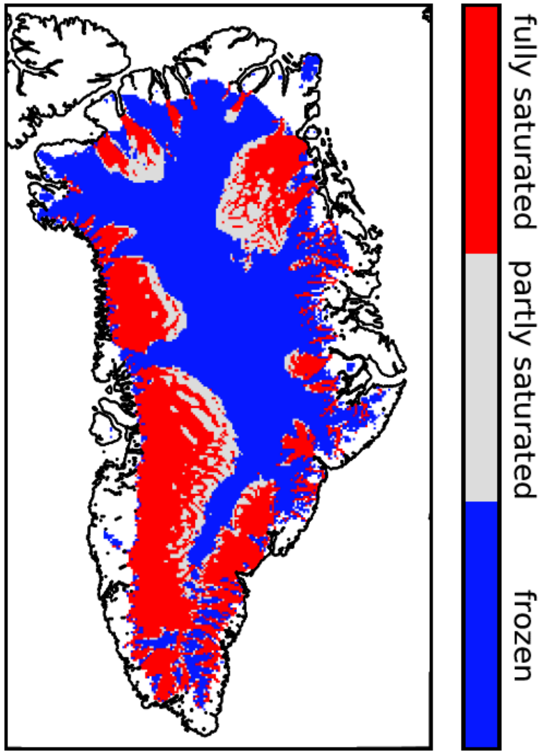
Modeled surface speed in CISM from 50 ka spin-up (m/yr, log scale)

Greenland basal state

- With pseudo-plastic sliding and a local till model, CISM's distribution of frozen and thawed regions agrees well with published estimates.



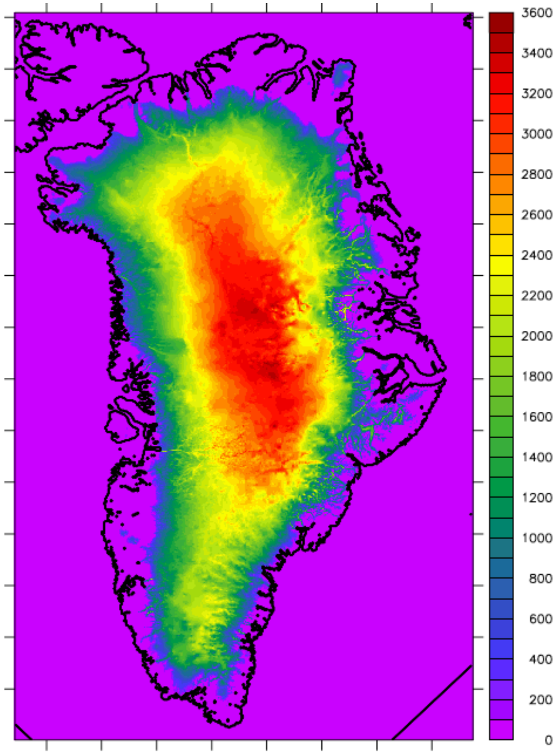
Synthesis of Greenland's basal thermal state from MacGregor et al. (2016)



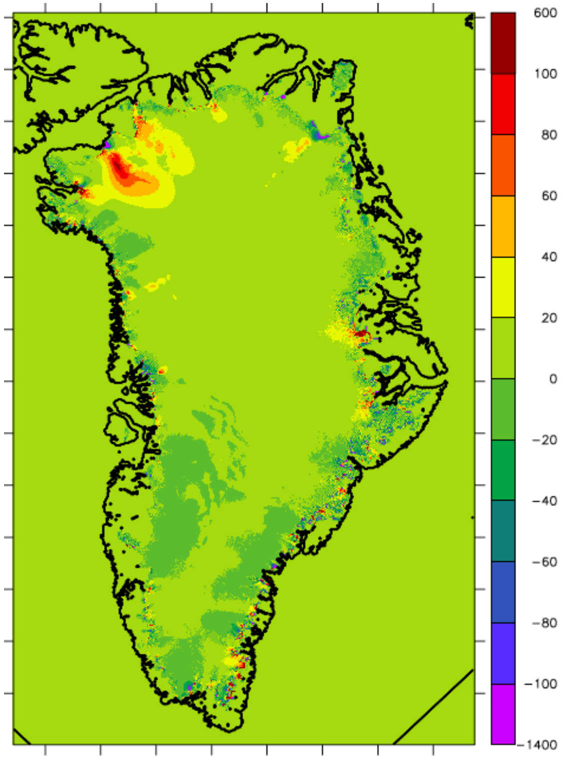
Basal water depth (m) in CISM;
blue = frozen (no basal water),
red = thawed (water present).

Standalone Greenland simulations

- Results with the efficient DIVA solver (~1000 model yr/wall clock hr) are similar to those with the more expensive Blatter-Pattyn solver. Thickness differences at most a few tens of meters.



Ice thickness (m) after 10 ka spin-up, Blatter-Pattyn solver



Difference between Blatter-Pattyn and DIVA thickness (m)

CISM2.1 release

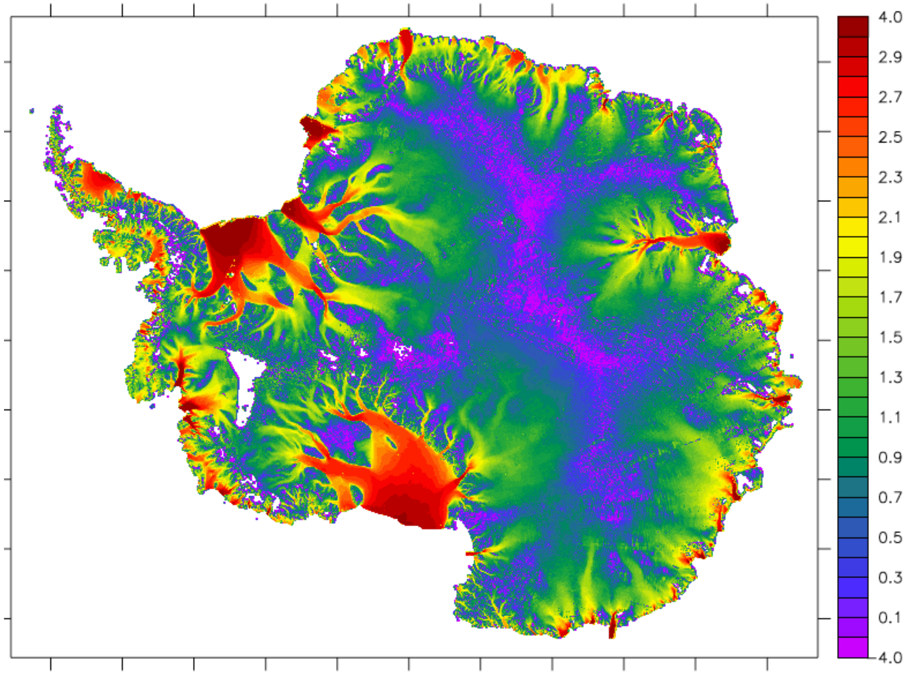
- Physics development has been frozen, apart from minor bug fixes.
- Now cleaning up code, updating the documentation, and finishing a model description paper (to be submitted to *The Cryosphere*).
- A public model release will roughly coincide with the CESM2 release.
- Future development will likely take place on a public github repository.

Future CISM development

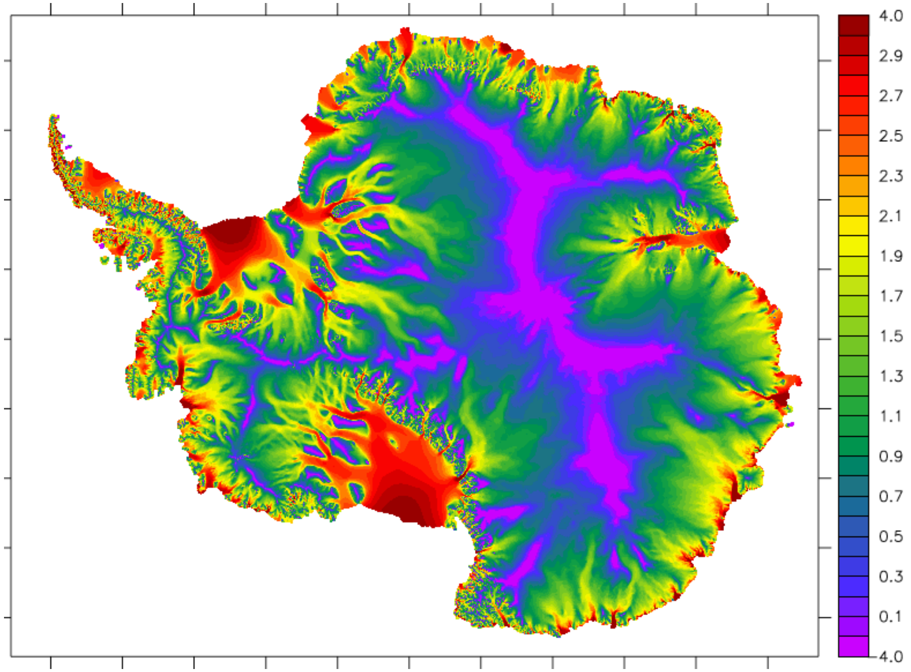
- **Inversion for basal sliding parameters and subshelf melt rates**
  - Now being tested for Antarctic simulations
- **Damage-based calving scheme**
  - Damage tracer evolves in response to stress, SMB and BMB
  - Ice fractures when sufficiently damaged (damage => 1)
- **Sub-shelf plume model**
  - Inexpensive steady-state model of 2D circulation beneath ice shelves
  - Plume velocity and temperature give sub-shelf melt rates
- **Hydrofracture** (leading to calving and shelf breakup)
- **Evolutionary basal hydrology**
- **Code speedup** (e.g., better preconditioning for floating ice)
- Various software improvements (flexible time manager, reorganized config file, remove deprecated code, …)

Inversion for basal parameters

- The goal is to spin up Antarctica to a steady state consistent with modern observations, given a prescribed SMB from RACMO.
- Method: Nudge basal traction parameters (for grounded ice) and sub-shelf melt rates (for floating ice) to match observed ice thickness.



Observed surface speed for Antarctica (m/yr, log scale)



Modeled surface speed in CISM with inversion (m/yr, log scale)

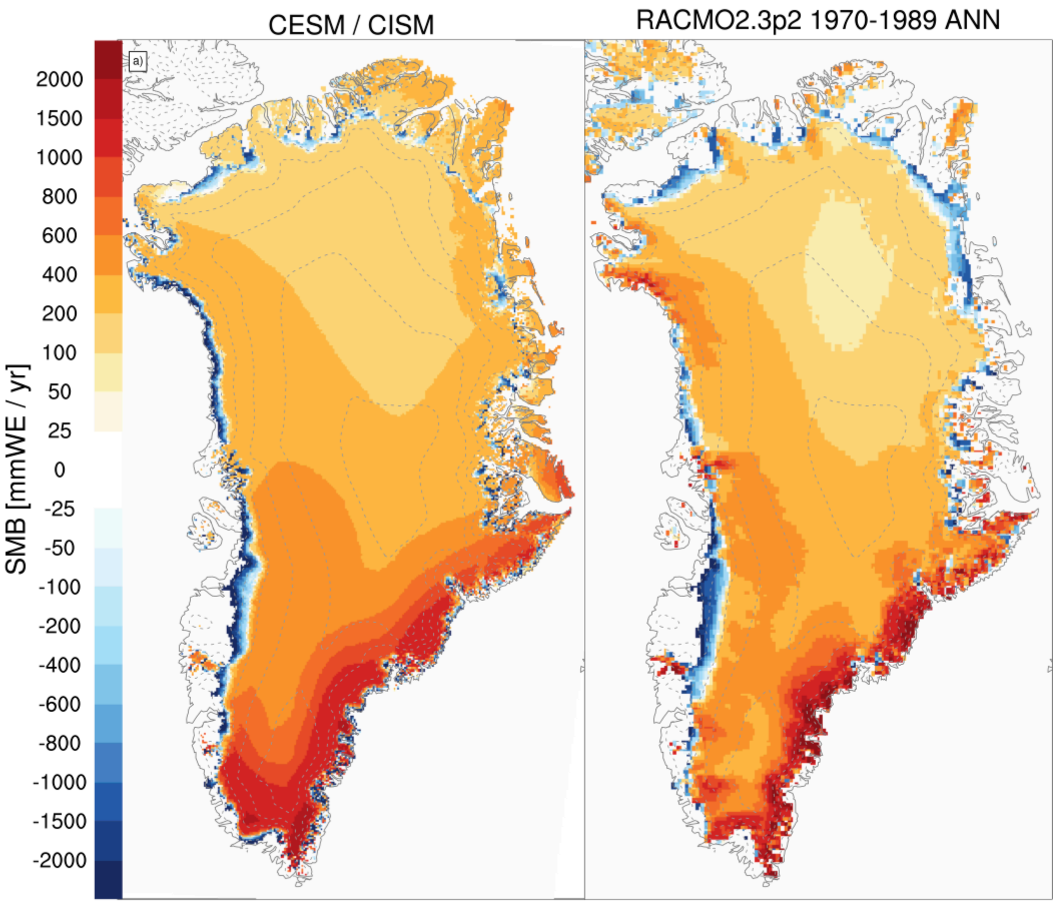
CISM in CESM2

- For most standard configurations, CISM is set to **no-evolve**
  - Ice sheets are fixed, and the SMB is computed for all glaciated cells
  - User can specify single v. multiple/virtual elevation classes
- CISM can evolve with **one-way coupling**
  - SMB and surface temperature from CLM to CISM
  - Fixed elevation and 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)

- Out-of-the-box Greenland settings:
  - 4 km grid, dt = 0.25 yr
  - DIVA velocity solver
  - Pseudoplastic basal sliding with local till
  - No ice shelves (floating ice calves instantly)
  - Other settings optimized from standalone runs

Greenland SMB in CESM2

Greenland climate/SMB, Jan Lenaerts (CU Boulder) and Leo van Kampenhout (Utrecht Univ.)

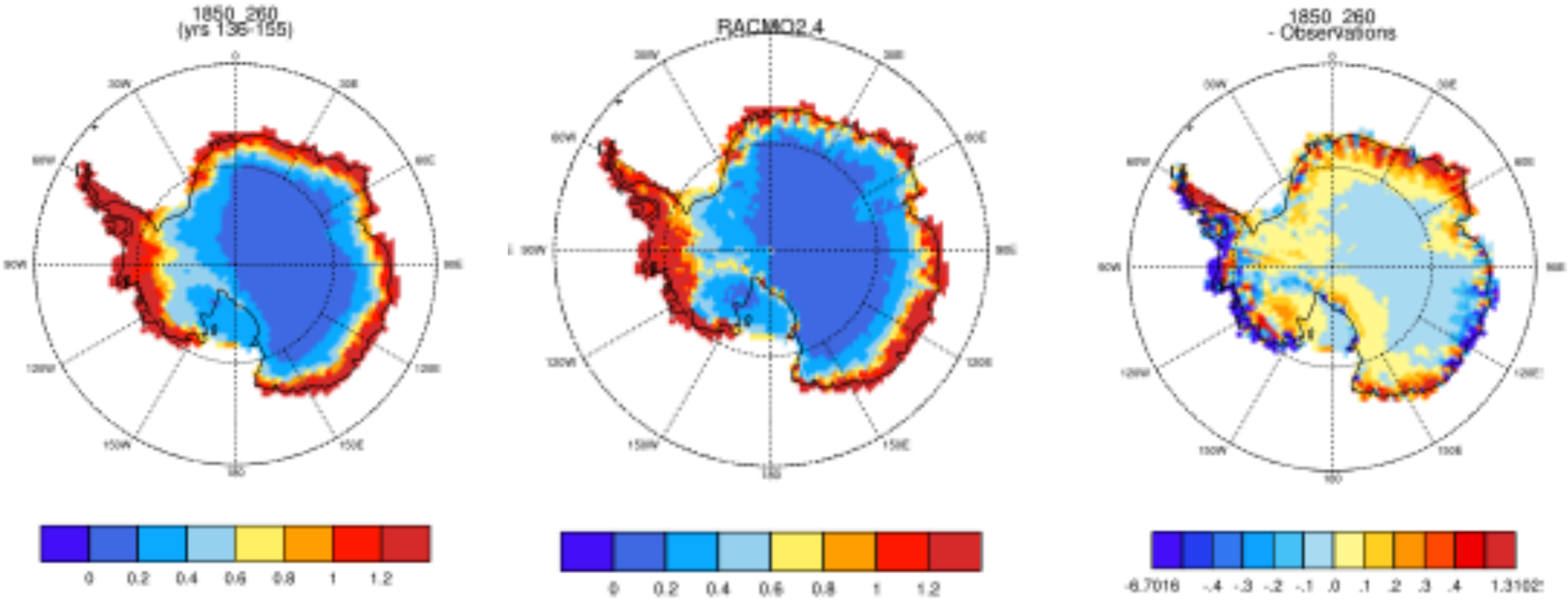


- RACMO is averaged between 1970 and 1989.
- CESM/CISM averaged from 1850
- Good agreement between CESM and RACMO in the ablation zone (blue).
- Narrower southwest ablation zone in CESM2 could be due to earlier time period.
- CISM set to no-evolve: ice is not added where there is no ice originally. (But CLM can form ice over bare tundra.)

More during: Jan's talk during SLR session this afternoon
Leo's talk tomorrow morning during the joint session

Antarctic SMB in CESM2

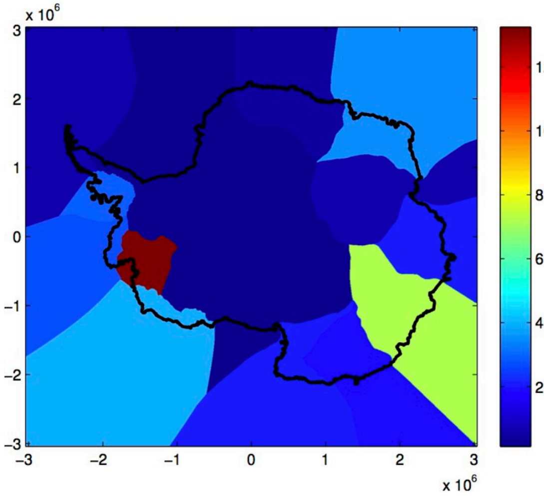
- CESM2 has a very good simulation of Antarctic surface mass balance.
- Some of the improvement since CESM1 is associated with a deeper snowpack, new snow physics parameterizations, and bug fixes (van Kampenhout et al. 2017).



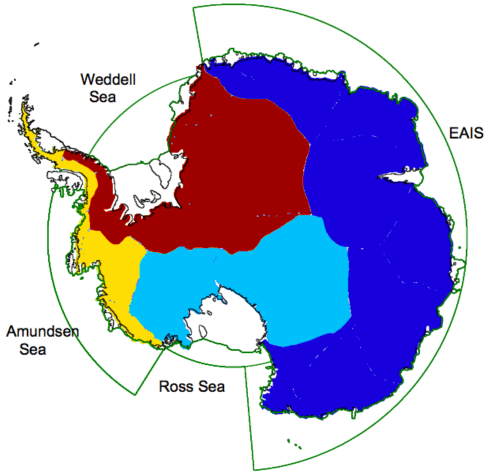
Antarctic annual snowfall (m). *Left:* CESM2 simulation 260 (1850 climate). *Center:* RACMO2.4. *Right:* Difference between CESM2 and RACMO.

CISM2 and intercomparison projects

- **initMIP-Greenland** (led by Heiko Goelzer) and **initMIP-Antarctica** (led by Helene Seroussi), part of ISMIP6, http://www.climate-cryosphere.org/
  - Ice sheet response to initialization (GIS and AIS), SMB anomaly (GIS and AIS) and basal melt rate anomaly under ice shelves (AIS).
- **LARMIP** (Linear Antarctic Response MIP, https://www.pik-potsdam.de/larmip, suggested by Anders Levermann and Ricarda Winkelmann)
  - Linear response of Antarctic Ice Sheet to basal ice shelf melting. Apply basal melt rate under ice shelves in 4 sub-regions (1-32 m/a)
- **ABUMIP** (Antarctic Buttressing MIP, suggested by Franck Pattyn and Nicholas Golledge):
  - Ice sheet response to (1) complete loss of ice shelves and (2) extreme ice shelf melting



Basal melt rates for initMIP-Antarctica (above) and LARMIP (below)



Current collaborations

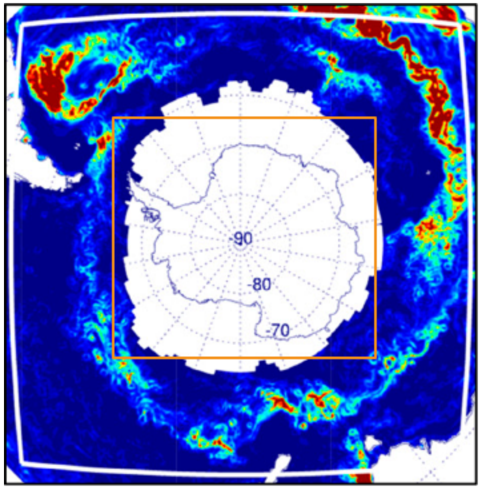
Nathan Urban, Mira Berdahl, Alice Barthel, Matthew Hecht (LANL)

Modular framework for sea level rise uncertainties

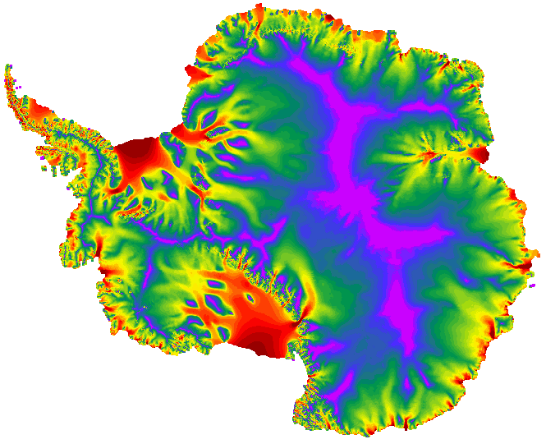
- Small ensemble of circum-Antarctic ocean projections to quantify uncertainty in changes to eddy transport of heat to ice shelves
  - ROMS @ 5km
  - Forced by CMIP5 multi-model boundary conditions
- Larger ensemble of Antarctic ice sheet projections to quantify uncertainty in SLR
  - CISM @ 2–4km
  - Forced by range of basal melt scenarios
- Link together statistical response function models of ocean and ice ensembles to produce SLR emulator incorporating multi-model uncertainties

More in Nathan's talk during SLR session this afternoon

ROMS ocean ensemble



CISM land ice ensemble



Current collaborations

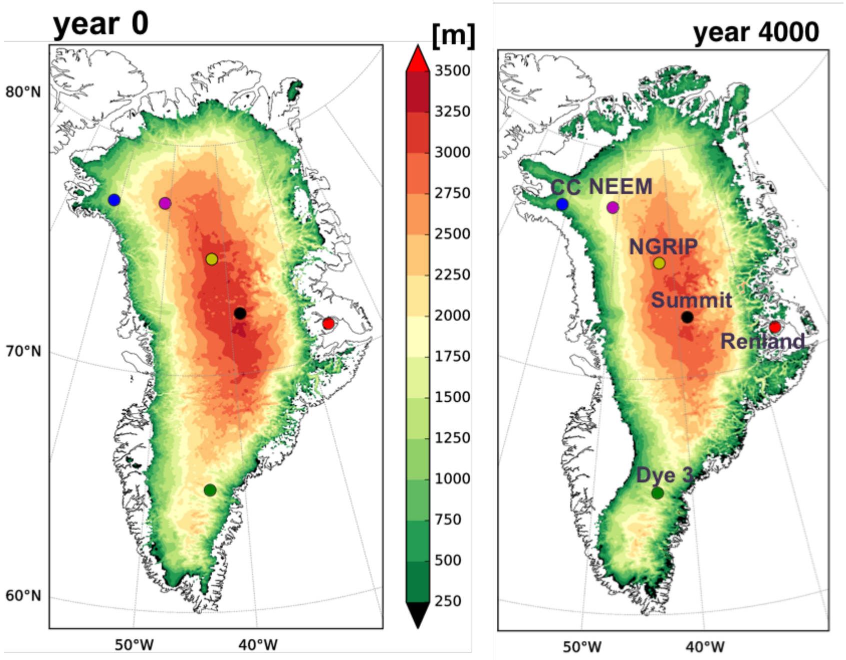
Bette Otto-Bliesner, Marcus Lofverstrom, Bill Lipscomb, Jeremy Fyke, Shawn Marshall, Ran Feng, Bill Sacks:

Studying the long term evolution of the climate and Greenland Ice Sheet during the Last Interglacial

- CISM1 (4km) coupled to CESM1.5 (FV1x1).
- Stable GHG concentrations similar to late Holocene
- Continental and oceanic configurations almost identical to modern

- ~ Thickness change at ice cores

CampCentury	-450m
NEEM	-400m
NGRIP	-200m
Summit	-40m
Renland	+20m
Dye 3	-200m



Ice thickness comparison from early LIG (128-124 ka)

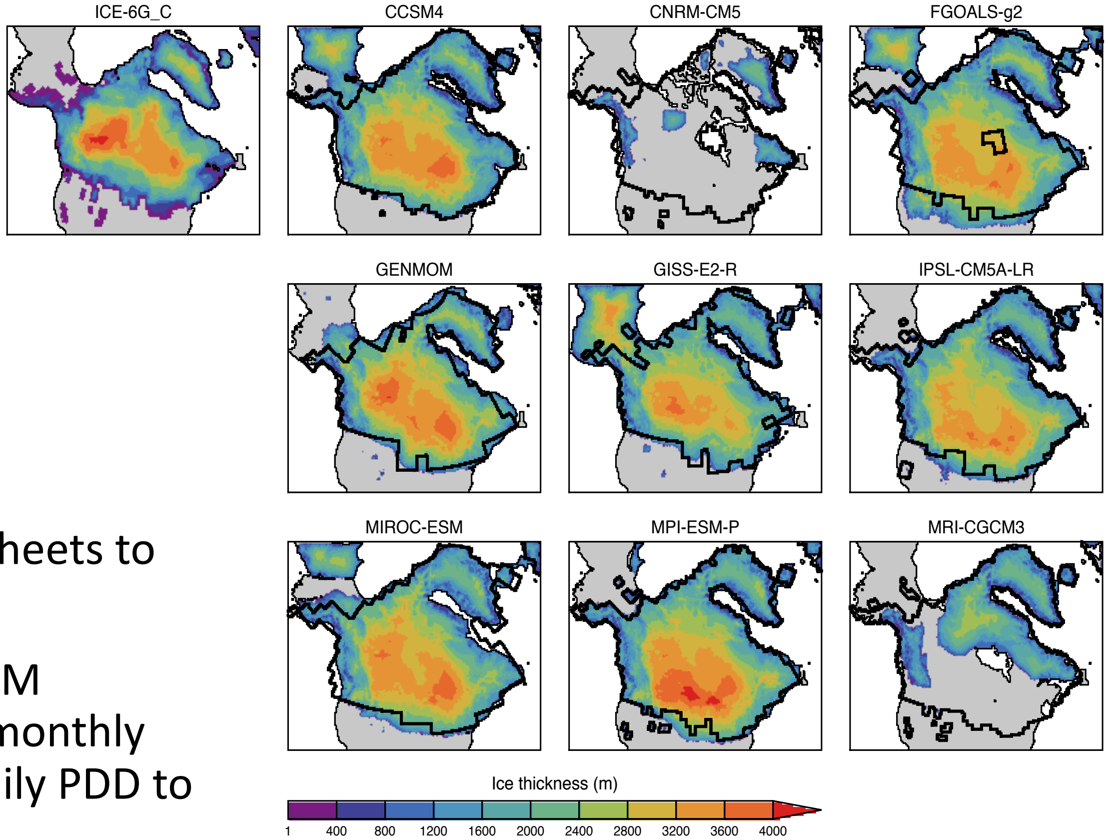
More in Bette's talk in the joint session tomorrow morning

Current collaborations

Jay Alder (USGS): **Driving CISM2 with PMIP3 Last Glacial Maximum GCM output**

- CISM as sensitivity tool
- Using CISM (offline) to test if the GCM temperature and precipitation output would support the LGM ice sheets

- Initialize CISM with the ICE-6G reconstruction and allow the ice sheets to evolve over 50K model years
- Annual PDD is being used with GCM climatologies, but we are testing monthly time series and exploring using daily PDD to add variability
- 7 GCMs support the Laurentide, but 4 develop spurious ice in Beringia



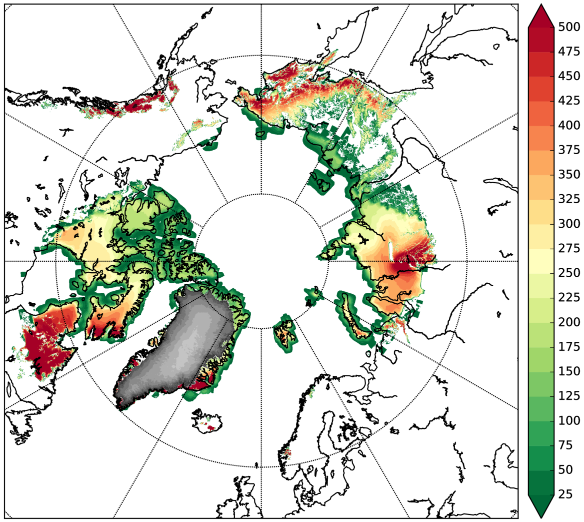
Alder and Hostetler, USGS

Current collaborations

Marcus Lofverstrom and Bette Otto-Bliesner (NCAR)

- Greenland paleoclimate simulation using CESM2 during the Last Interglacial (LIG) and investigation of how much sea level Greenland may have contributed under the last LIG warm period.
- Glacial inception study in a fully coupled Earth-system model using an extended CISM grid

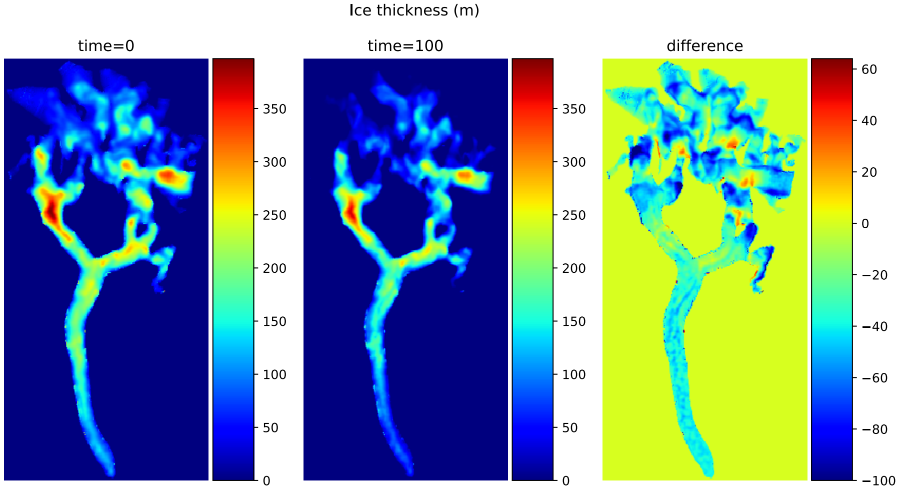
More in Marcus's talk during SLR session this afternoon



Glacial inception study: ice thickness after 1000 yr simulation under 116 ka low boreal insolation forcing.

Kimberly Casey (USGS)

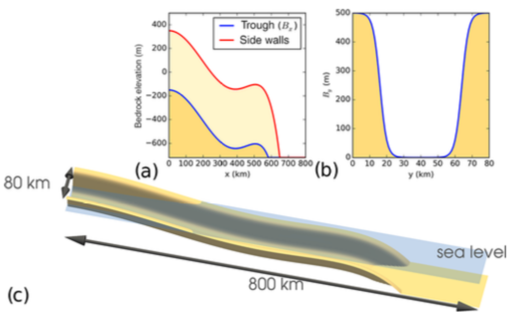
- Modeling ice dynamics and the transient response of Himalayan glaciers.
- Constant SMB and temperature
- Bed topography and Digital Elevation Model data from literature



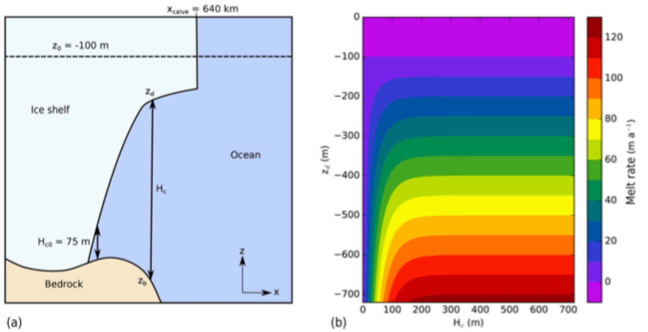
100 yr simulation of a single Himalayan glacier

Testing CISM using idealized MIPs

(MISMIP+, Asay-Davis et al. 2016)

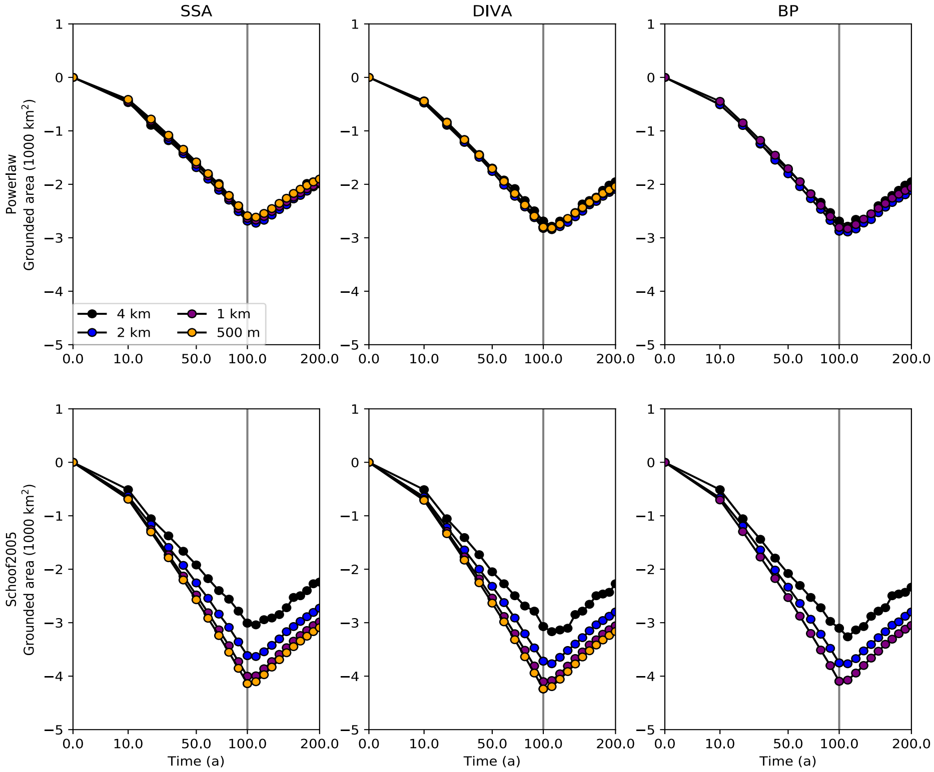


Bed topography



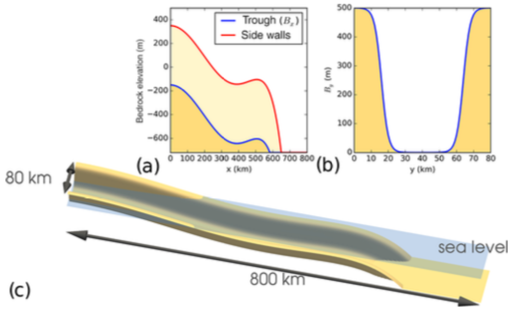
Melt function applied under ice shelves

Convergence of grounding line positions



1. For either friction laws or Stokes approximations, running at a resolution of higher than 1 km does not provide much benefit compared to the increased computational cost.
2. Ice streams in Coulomb regime are more sensitive to ocean warming.
3. Under the assumption of isothermal ice, DIVA and BP show similar grounding line results.

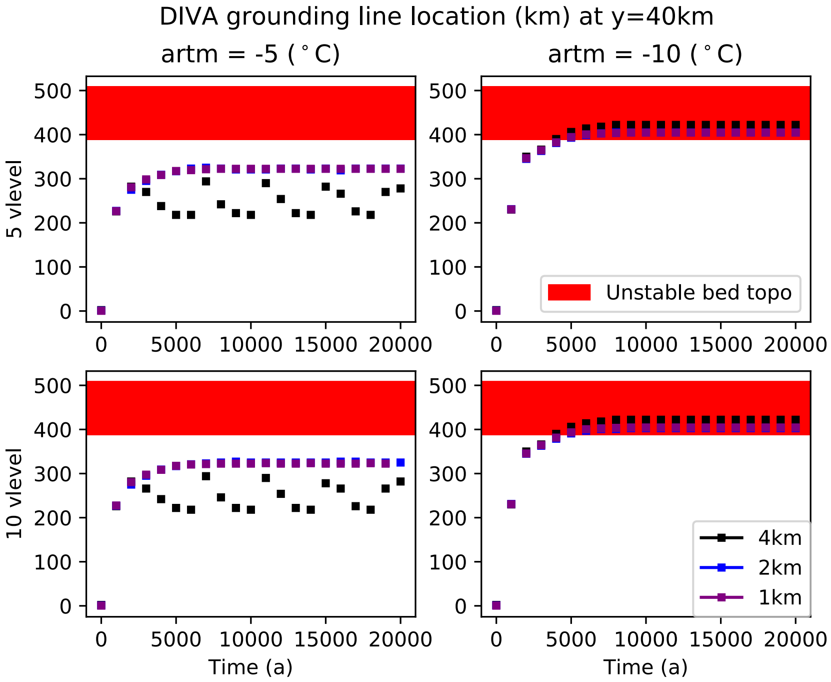
Ongoing work: The impact of thermodynamics on numerical requirements (using MISMIP+ setup)



Bed topography

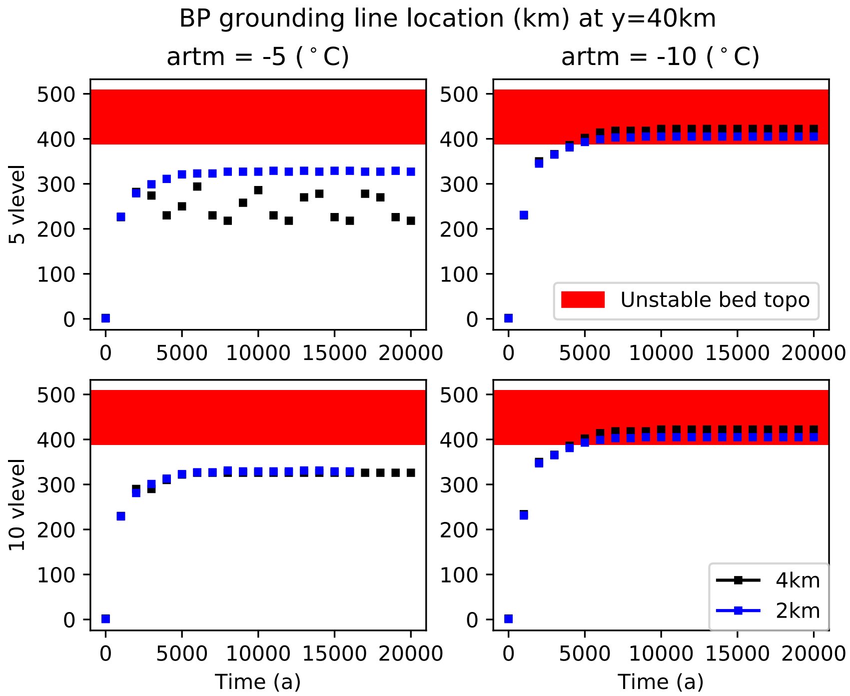
Initial findings:

1. Numerical oscillations in grounding line position for "warm" artm and resolution of 4 km.
2. Oscillations disappear with: increasing horizontal resolution (DIVA and BP), colder artm, increasing vertical resolution (BP).
3. When using DIVA, a resolution of 2 km or higher is the safest choice for numerical stability.


DIVA grounding line location (km) at y=40km

artm = -5 (°C)

artm = -10 (°C)


BP grounding line location (km) at y=40km

artm = -5 (°C)

artm = -10 (°C)

Contacts for CISM questions or collaborations

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Gunter Leguy: gunterl@ucar.edu

Bill Sacks: sacks@ucar.edu

Merci beaucoup