Update on Greenland Ice Sheet Simulations in CISM and CESM

William Lipscomb, Jeremy Fyke and Lauren Vargo

Los Alamos National Laboratory

William Sacks

National Center for Atmospheric Research

9 February 2016

CISM 2

CISM 2.0 was released in Oct. 2014:

- Replaced CISM1 (shallow-ice model using older Glimmer code) as the ice sheet component of CESM
- Available at **http://oceans11.lanl.gov/cism/**; git repo at **https://github.com/cism**
- Parallel dynamical core (Glissade) with a suite of velocity solvers (including shallow-shelf, L1L2, Blatter-Pattyn)

CISM 2.1 is scheduled for release in spring 2016:

- Depth-integrated viscosity approximation (DIVA; Goldberg 2011) is similar in accuracy to Blatter-Pattyn, but ~10x faster
- A grounding-line parameterization has been added for marine ice sheets.

Goals for Greenland simulations

For CESM2 we plan to run Greenland Ice Sheet simulations

- with higher-order dynamics
- at moderately high resolution (~4 km)
- on century-to-millennial time scales (required to equilibrate the ice sheet and choose optimal parameters)
- under past, present and future forcing
  - SLICE project: (Bette Otto-Bliesner et al.): Simulate Greenland during the Pliocene, Last Interglacial and future to ~3000

CISM must be **robust**, **efficient** and **accurate** for these Greenland simulations.

Robustness

CISM with higher-order dynamics must not crash in standard operation.

- Parameter sweep, round 1 (July 2015): ~800 Greenland simulations with various parameter sets (Jeremy Fyke and Lauren Vargo). Most crashed within 1 model year.
- Various problems were diagnosed and fixed. Many were related to large surface elevation gradients and fast velocities in Greenland fjords.
- Parameter sweep, round 2 (Nov. 2015): Most tests ran 50 model years to completion. Several selected tests were extended successfully to 10,000 years.

Efficiency

Timing for 4-km Greenland simulations on yellowstone:

Number of cores	Core-hours / model year	Model years/ wall clock day
128	1.4	2200
240	1.7	3400
480	2.4	4800

Efficiency can be attributed to

- Large time step (0.5 yr, close to advective CFL limit)
- Vertically integrated velocity approximation (DIVA)
- Parallel Fortran preconditioned conjugate gradient solver

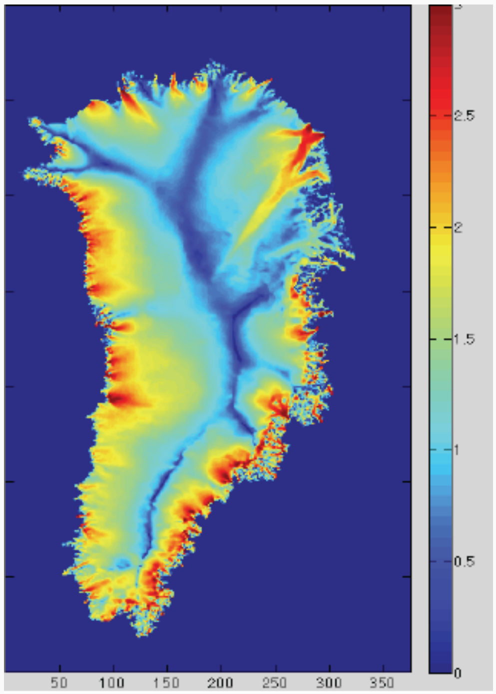
Accuracy

Accuracy requires

- a good surface mass balance from CLM (talk by Jan Lenaerts)
- physics parameterizations that are valid for past and future climates (not just the present day)

CISM can match present-day Greenland surface velocities with a tuned basal traction in each grid cell. But these traction values may not apply on long time scales.

We would like to have a simple basal sliding law that is generally valid.



Tuned surface speeds (Price et al. 2011)

CISM basal sliding options

The recent parameter sweeps included the following sliding options for Greenland:

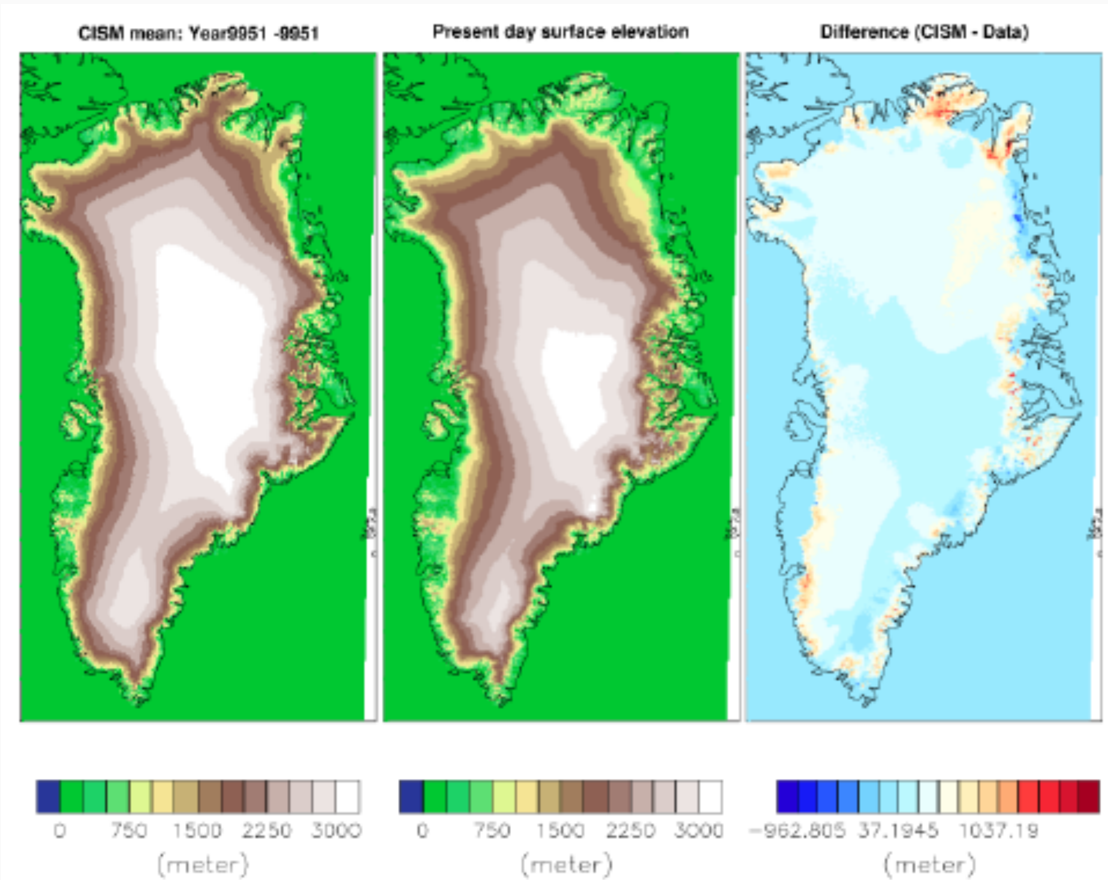
- No sliding
- 2D basal traction field read from file
- Linear sliding law: $\tau_b = \beta u$
  - Traction parameter β is large where the bed is frozen and small where the bed is thawed

Goals:

- Reproduce present-day velocity structure (including outlet glaciers)
- Generate something close to present-day geometry in a long run to equilibrium (ice-sheet-only with TG forcing in CESM).

No sliding

Surface elevation and velocity after a 10,000 year spin-up:

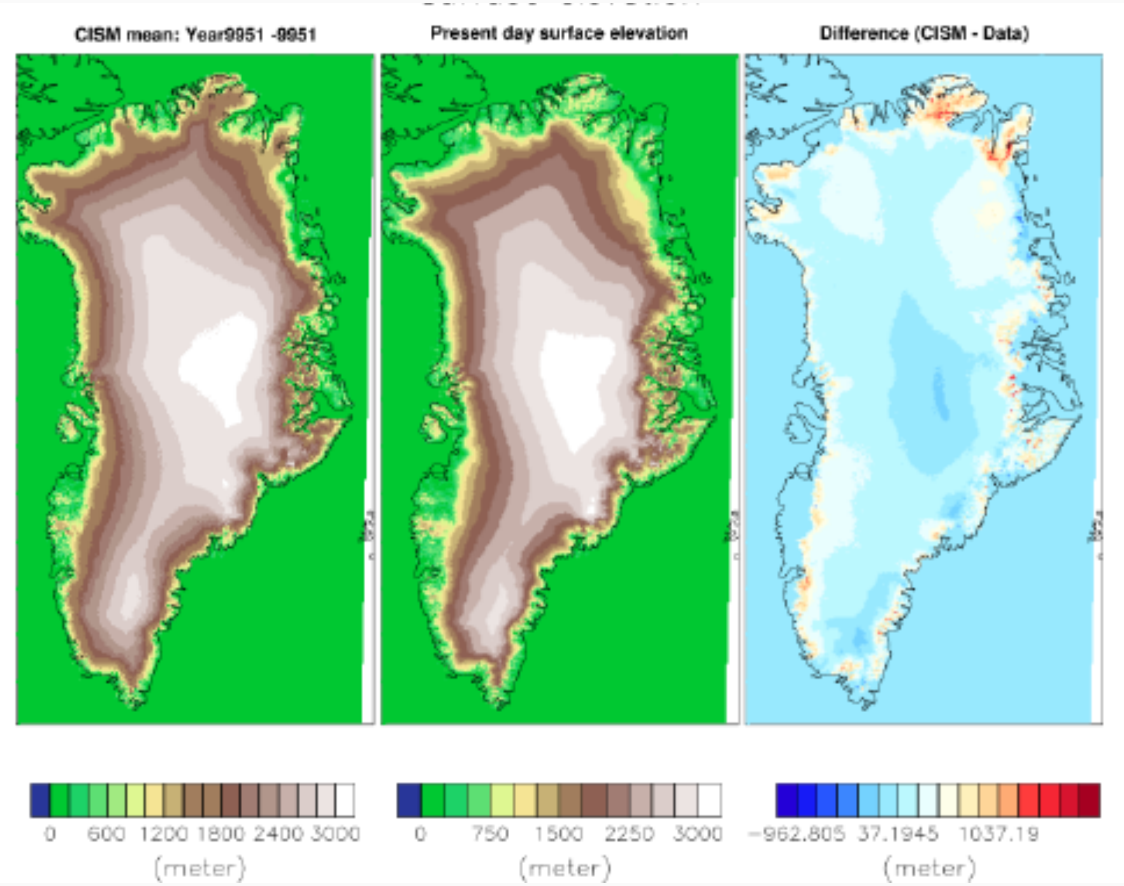


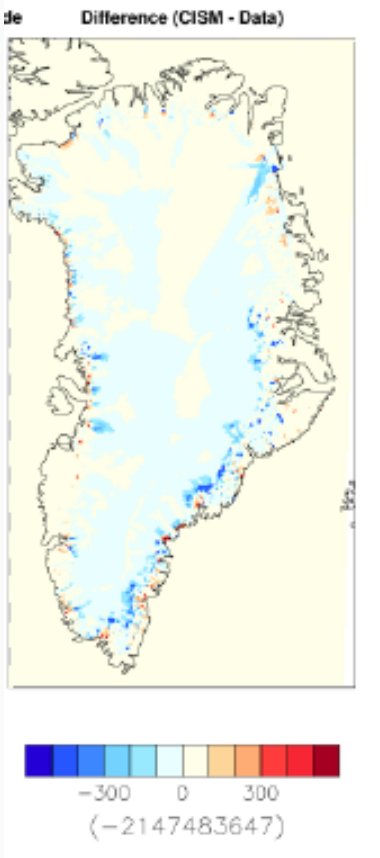
Left: CISM surface elevation (m)
Center: Observed surface elevation
Right: Difference

Surface ice speed (m/yr),
CISM minus observed.
CISM outlet glaciers are slow.

Linear sliding law

Surface elevation and velocity after a 10,000 year spin-up:





Left: CISM surface elevation (m)
Center: Observed surface elevation
Right: Difference (Note slumping in CISM.)

Surface ice speed (m/yr), CISM minus observed. Outlet glaciers are still slow.

Pseudo-plastic sliding law

- The Parallel Ice Sheet Model (PISM) uses a pseudo-plastic sliding law that varies from linear to power-law to plastic behavior, based on a tunable exponent:

$$\tau_b = \tan(\phi) N \frac{u}{u_0^q \, |u|^{1-q}}$$

  - N = effective pressure (proportional to overburden $\rho g H$, but reduced where basal water is present)
  - ϕ is an elevation-dependent friction angle
  - q is the tunable exponent (1 for linear, 0 for plastic)
  - u_0 is a threshold velocity

Pseudo-plastic sliding law

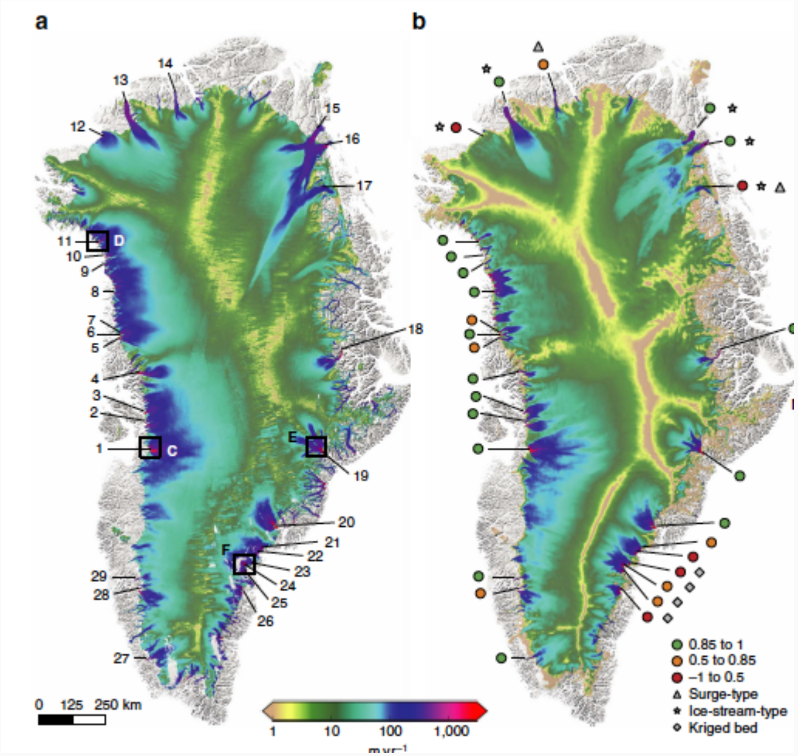
Aschwanden et al. (2016) have shown that PISM can reproduce Greenland surface speeds (including outlet glaciers) with high accuracy by tuning a small number of parameters.

- High resolution (< 1 km), mass-conserving bed (Morlighem et al. 2014), spatially varying geothermal fluxes (Shapiro & Ritzwoller 2004), simple hydrology model, $q = 0.6$.

Greenland surface speeds.

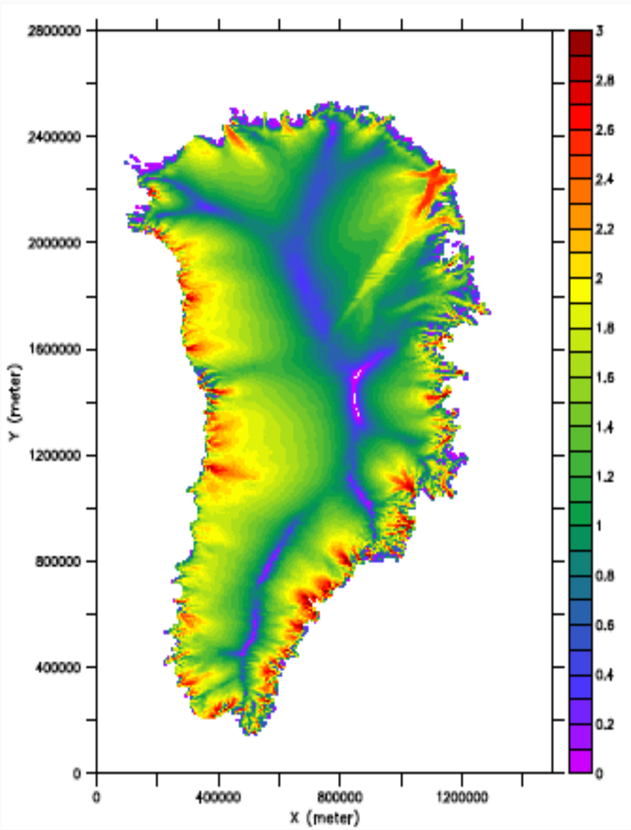
Left: Observed

Right: Modeled with PISM

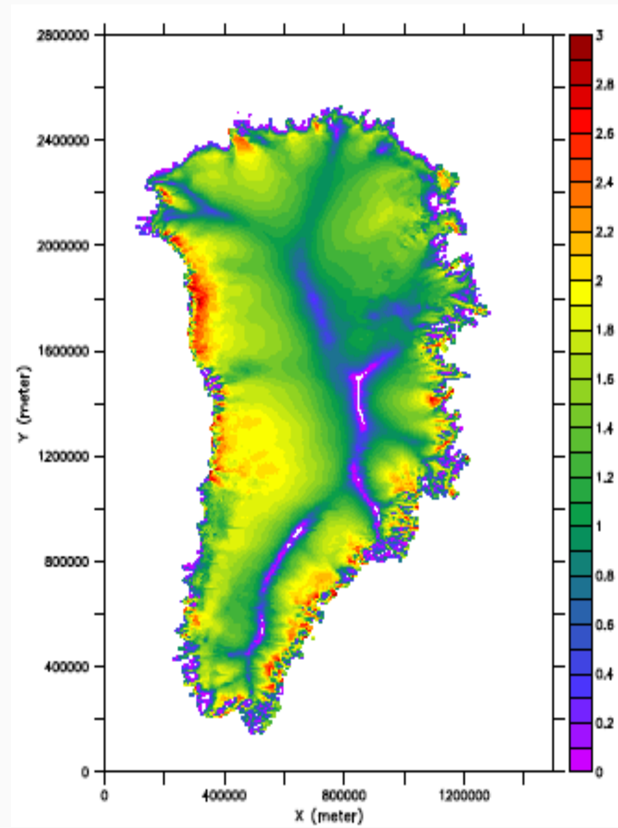


Pseudo-plastic sliding law

Preliminary results from CISM: initial solve (no long spin-up), 4-km resolution, SeaRISE bed, spatially uniform geothermal flux, *q* = 0.5, *N* reduced where bed is thawed. Starting to resolve outlet glaciers.



Log of surface speed (m/yr): optimized to match present day



Log of surface speed (m/yr): pseudo-plastic sliding law

Future modeling goals: Greenland

- Finer grid resolution (1 or 2 km)
  - Could improve the simulation of fast outlet glaciers
  - May require implicit time-stepping to avoid the restrictive diffusive CFL limit
  - Topographic data set may be important (talk by Ute Herzfeld)
- Spatially varying geothermal fluxes
  - Currently assume 0.05 W/m^2 everywhere
- Evolutionary basal hydrology
  - Prototype by Matt Hoffman
- Parallel isostasy model
  - Still using the serial model from Glimmer
- Ocean interactions
  - Allow ice to float and calve; estimate submarine melt rates

Future modeling goals: Antarctica

- Software infrastructure
  - Provide Antarctic data sets and scripting options, support multiple ice sheet instances
- Efficiency at high resolution
  - Need grid resolution of ~1 km to simulate grounding-line migration
  - May need implicit time-stepping, with improved preconditioning for shelf-dominated flow
- Ocean interaction
  - Damaged-based calving model (talk by Ryan Whitcomb)
  - Submarine melt rates (talk by Flo Colleoni)
  - In the long run, couple to an ocean model with dynamic sub-shelf cavities (e.g., MPAS Ocean)

Acknowledgments

- Matt Hoffman, Steve Price (CISM2 development, testing and consultation)
- Jan Lenaerts, Leo van Kampenhout, Marcus Löfverström (surface mass balance and snow modeling)
- Joe Kennedy, Andrew Bennett (upgrade of LIVV software)
- Gunter Leguy, Xylar Asay-Davis (grounding lines)
- Andy Aschwanden (conversations about basal sliding)
- Dan Goldberg (conversations about DIVA)