Regional Modeling of Greenland's Outlet Glaciers

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I. Introduction

PISM is an open source C++ code developed at the UAF. For more information please check out:

www.pism-docs.org

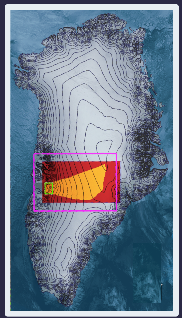
This work focuses on the capability of PISM to support regional modeling of Greenland's outlet glaciers. This allows for high-resolution modeling of an outlet glacier (e.g. $\leq$ 1km grid resolution) without modeling the entire ice sheet. At present, most ice sheet models only support continental scale modeling. **The largest uncertainty in constraining sea level contribution from Greenland, however, lies in the ability of a model to capture changes in the outlet system** (Truffer and Fahnestock, 2007).

In particular, the Jakobshavn Isbræ is the most active outlet glacier in Greenland. It lies on Greenland's west coast and drains about 7% of the ice sheet area (Thomas et al., 2009). Modeling the entire ice sheet (1,800,000 km^2) has some resolution limitations (e.g. 2 km), while considering only the area of the Jakobshavn Isbræ catchment (225,000 km^2) can allow much higher resolution modeling (e.g. 500 m).

II. Regional Modeling with PISM

- The purpose of this work is to demonstrate the ability of PISM to perform ice sheet modeling on a regional scale.
- We have extended the capability of PISM by adding tools for regional modeling. They include:
  1) A "drainage basin generator", able to automatically generate the basin of an outlet glacier
  2) A "force-to-thickness" mechanism which is applied outside of the identified drainage basin to isolate the evolution of the modeled ice surface within the basin from the dynamics of other basins
  3) In a narrow strip around the boundary, the surface gradient & driving stress calculations are modified to avoid differentiating a steep jump. The whole ice sheet model has a periodic computational domain.

Potentially, these tools can be automatically applied basin-by-basin to each outlet system in an ice sheet.



LEFT: DEM of Greenland processed for regional modeling. Orange highlights the drainage basin, and red indicates where the "FTT" mechanism is applied. The pink & green boxes are initial guesses of the regional & terminus areas.

III. Drainage Basin Generator

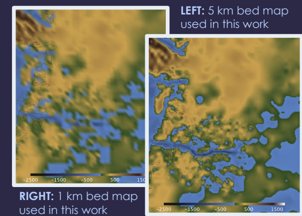
- **The drainage basin of an outlet glacier is defined by merely supplying a DEM & identifying the glacier terminus**
- The ice surface gradient and streamlines are calculated to determine where interior ice will eventually exit the ice sheet.
- A new regional grid, with a clearly defined drainage basin, is generated
- By determining a clearly defined drainage basin, we can divide the regional model into two distinct areas:
  1) The outlet glacier catchment,
  2) The exterior ice (which does not drain through the outlet glaciers' terminus).

This allows us to identify the specific region in the ice-sheet that we are concerned with modeling accurately, and the exterior ice which we are not concerned with modeling accurately.

References:[1] Truffer M. & M. Fahnestock (2007) Rethinking ice sheet time scales, Science, 315, 1508–1510.**[2]** Thomas R., E. Federick, W. Krabill, S. Manizade, & C. Martin (2009) Recent changes on Greenland outlet glaciers, J. Glaciol., 55, 147–162. **[3]** Joughin I., Smith B., Howat I. Scambos T., & T. Moon, (2010) Greenland flow variability from ice-sheet-wide velocity mapping. J. Glaciol., 56, 415-430.

VI. "Force-to-Thickness" Mechanism

- Special considerations must be made to assign boundary conditions, and also to prevent fluxes through the domain boundary.
- PISM addresses these considerations by holding the surface gradient at the edge of the domain constant, and applying a "force-to-thickness" mechanism, which:
  1) Works by adding or ablating mass in order to offset ice thickness perturbations in the exterior ice.
  2) Keeps ice **outside** of the drainage basin near the present ice-thickness, while allowing ice **inside** the drainage basin to evolve fully according to the user-specified stress balance scheme (e.g. SIA, SSA, SIA+SSA hybrid).
  3) Allows for the evolution of the ice at the interface between the outlet glacier and the exterior ice



LEFT: 5 km bed map used in this work

RIGHT: 1 km bed map used in this work

V. Modeling Input & Parameters

- The CReSIS **Bedrock Topography** for Jakobshavn Glacier (left). Notice that significant features at 1 km (e.g. trough S-curve) are not resolved on the 5 km grid.
- **Surface Mass Balance** (SMB) and **2m Air Temperatures** are interpolated from results of Ettema et al., 2009's Greenland regional climate model
- **Basal Strength** is determined as a function of the bed elevation. In the future, we will infer the basal strength from surface velocity measurements using an iterative inverse method.
- All other standard model inputs have been taken from the publically available SeaRISE 1km Greenland data set.

VI. Results & Conclusions

- The PISM regional model of Jakobshavn was run at resolutions of 5 km, 2 km, and 1 km, respectively, at the Arctic Region Supercomputer Center in Fairbanks, AK.
- Runs were performed using SSA+SIA stress balance scheme & highly simplified SMB model. No model parameters have been tuned to produce these results.
- **Figures below show the ice-surface speed results of each run. InSAR observations are shown for comparison** (Joughin et al., 2010)
- These results indicate the importance of high-resolution modeling. As bedrock topography improves (from 5 km to 1 km) the model is able to better capture observed features (e.g. S-curve in surface speeds), even on small timescales.
- These results demonstrate the ability of PISM to perform "good" ice sheet modeling at high resolution on the regional scale.