Evaluating the sensitivity of an ice sheet model to changes in bed elevation and inclusion of membrane stresses

Andy Aschwanden[1], Ed Bueler[2], and Constantine Khroulev[3]

[1]Arctic Region Supercomputing Center
University of Alaska Fairbanks, USA

[2]Dept of Mathematics and Statistics,
University of Alaska Fairbanks, USA

[3]Geophysical Institute
University of Alaska Fairbanks, USA

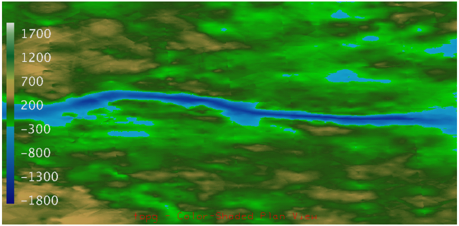
EGU 2010

Acknowledgments

- Arctic Region Supercomputing Center
- Martin Truffer (UAF)
- Heinz Blatter (ETH)

Motivation

- follow-up to Jim Fastook's talk at WAIS and AGU 2009
- new high-resolution (< 5km) bedrock elevlation data available for Jakobshavn Isbræ and Petermann Glacier (from CReSIS, `http://www.cresis.ku.edu`)
- more outlet glaciers coming soon



Jakobshavn Isbræ: CReSIS bed elevation

Working Hypotheses

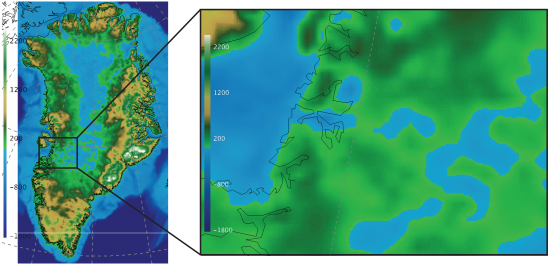
1. Ice sheet models are highly sensitive to changes in bedrock elevation
2. At horizontal grid resolutions close to, or below, one mean ice thickness we are approaching the limit of the shallow ice approximation

We use the Parallel Ice Sheet Model (PISM, www.pism-docs.org) for all simulations

- see posters XY363, XY362, XY359, XY352 during the poster session today

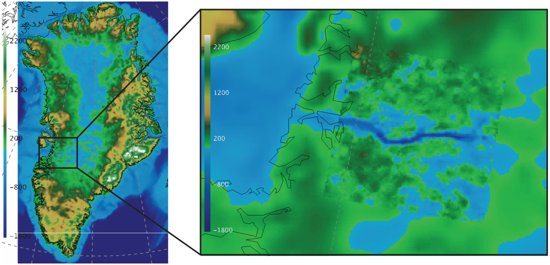
Bedrock Elevation

- SeaRISE data set on 5km grid, compiled by Jesse Johnson, Brian Hand, Tim Bocek (University of Montana)
- CReSIS bedrock data on 125m grid
- interpolate 5km bed (Bamber et al., 2001) onto 1km grid, average Jakobshavn CReSIS bed onto 1km grid
- quick & dirty, cut & paste, no boundary-smoothing (worst case for stability/time-stepping)



Bedrock Elevation

- SeaRISE data set on 5km grid, compiled by Jesse Johnson, Brian Hand, Tim Bocek (University of Montana)
- CReSIS bedrock data on 125m grid
- interpolate 5km bed (Bamber et al., 2001) onto 1km grid, average Jakobshavn CReSIS bed onto 1km grid
- quick & dirty, cut & paste, no boundary-smoothing (worst case for stability/time-stepping)



Stress Balances

Shallow Ice Approximation

The well known “classic” non-sliding SIA

Hybrid Stress Balance

The Bueler Brown Approximation (BBA) is a hybrid stress balance (Bueler and Brown, 2009). In detail it comprises 3 layers

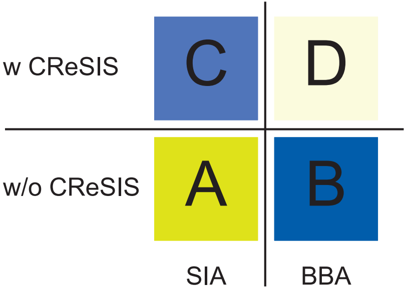
- top: non-sliding shearing ice mass (SIA) drives the membrane deformation
- bottom: layer to define resistance (Coulomb friction law)
- middle: membrane to handle membrane stresses between the
  - driving force of top (SIA) layer and
  - resistive force of bottom layer

Experimental Design

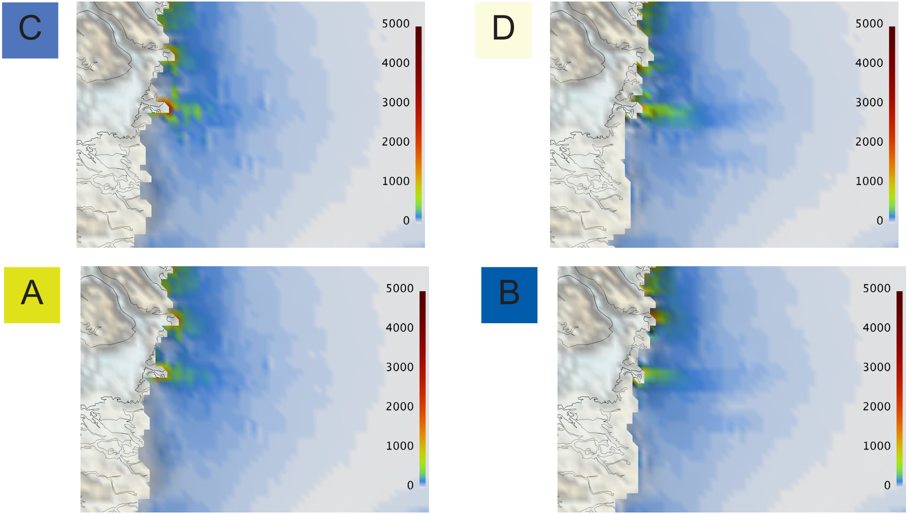
A 4-way qualitative not a quantitative experiment with:

- constant climate
- same resolution for the whole ice sheet, no nesting
- same physical parameters for all runs

grid size	run length	cpus
10 km	25'000 a	128
	$\Downarrow$ regridding	
5 km	1'000 a	256
	$\Downarrow$ regridding	
3 km	20 a	384-512

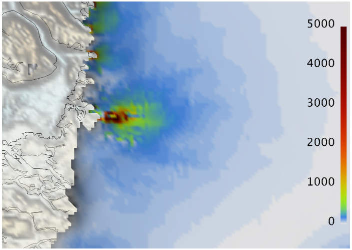


Results: 10km grid

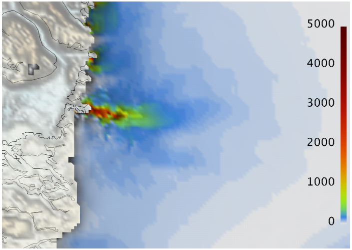


Results: 5km grid

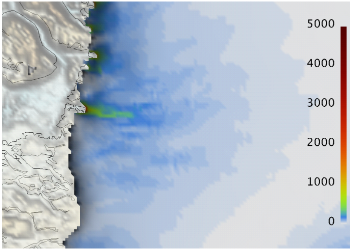
C



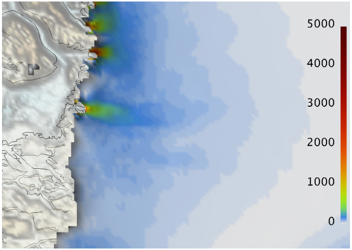
D



A

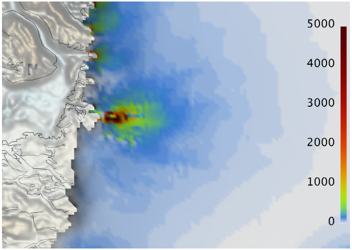


B

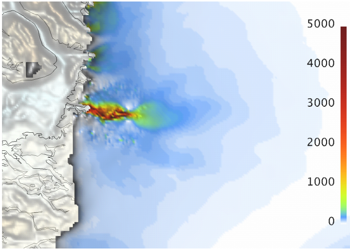


Results: 3km grid

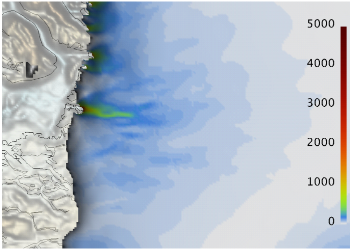
C



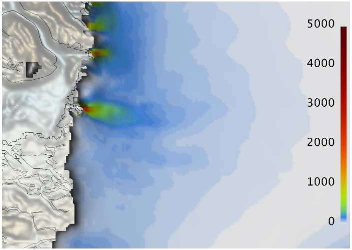
D



A



B



Simulated U_{max}

How is SIA doing compared to BBA?

	A	B	C	D
	w/o CReSIS		w CReSIS	
grid size	SIA	BBA	SIA	BBA
10 km	8 km a^{-1}	16 km a^{-1}	7 km a^{-1}	11 km a^{-1}
5 km	5 km a^{-1}	11 km a^{-1}	*235 km a^{-1}	8 km a^{-1}
3 km	3 km a^{-1}	6 km a^{-1}	*1'040 km a^{-1}	6 km a^{-1}

* only at a few grid points

The Otherside Of The Coin

- with a (relatively conservative) explicit, adaptive time-stepping scheme, PISM is robust with respect to rough bedrock topography
- however, with CReSIS bedrock data, run times are about 10$\times$ longer
    - rougher beds means higher driving stresses
    - therefore the diffusivity of the surface kinematical equation can be higher too
- We will explore this in the future

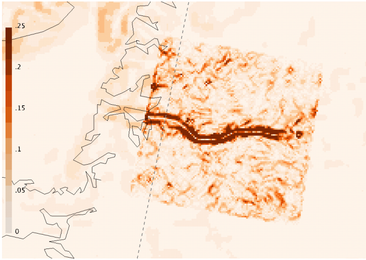


Figure: "bed roughness" mag(∇b)

Summary

High-resolution bedrock data of outlet glaciers

- is worthwhile incorporating because fast-flowing ice streams are modeled more realistically but be aware of the additional costs
- requires a careful choice of stress balance approximation (limits of the applicability of the shallow ice approximation)
- poses a new challenge to ice sheet modelers and ice sheet models

$\Rightarrow$ The SeaRISE community and CReSIS are working together on improving bedrock elevation data

References

Bamber, J., R. Layberry, and S. Gogenini (2001). A new ice thickness and bed data set for the Greenland ice sheet 1: Measurement, data reduction, and errors. *J. Geophys. Res. 106 (D24)*, 33,773–33,780.

Bueler, E. and J. Brown (2009). Shallow shelf approximation as a “sliding law” in a thermodynamically coupled ice sheet model. *J. Geophys. Res. 114*. F03008, doi:10.1029/2008JF001179.