PISM (the Parallel Ice Sheet Model)

Latest 0.5 release, and
Where will this community take PISM?

Ed Bueler

University of Alaska Fairbanks

European PISM Workshop, May 2012

Outline

introduction to PISM (8 slides)

about the latest release (5 slides)

some recent UAF work (3 slides)

what we KNOW we need to improve (4 slides)

where is PISM going?

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where is PISM going?

PISM: new user's point of view

- website: www.pism-docs.org
- PISM runs on Linux, Unix, and Mac OSX: laptops to supercomputers
- stable releases once a year
- PDF User's Manual with real modeling examples
- `help@pism-docs.org`

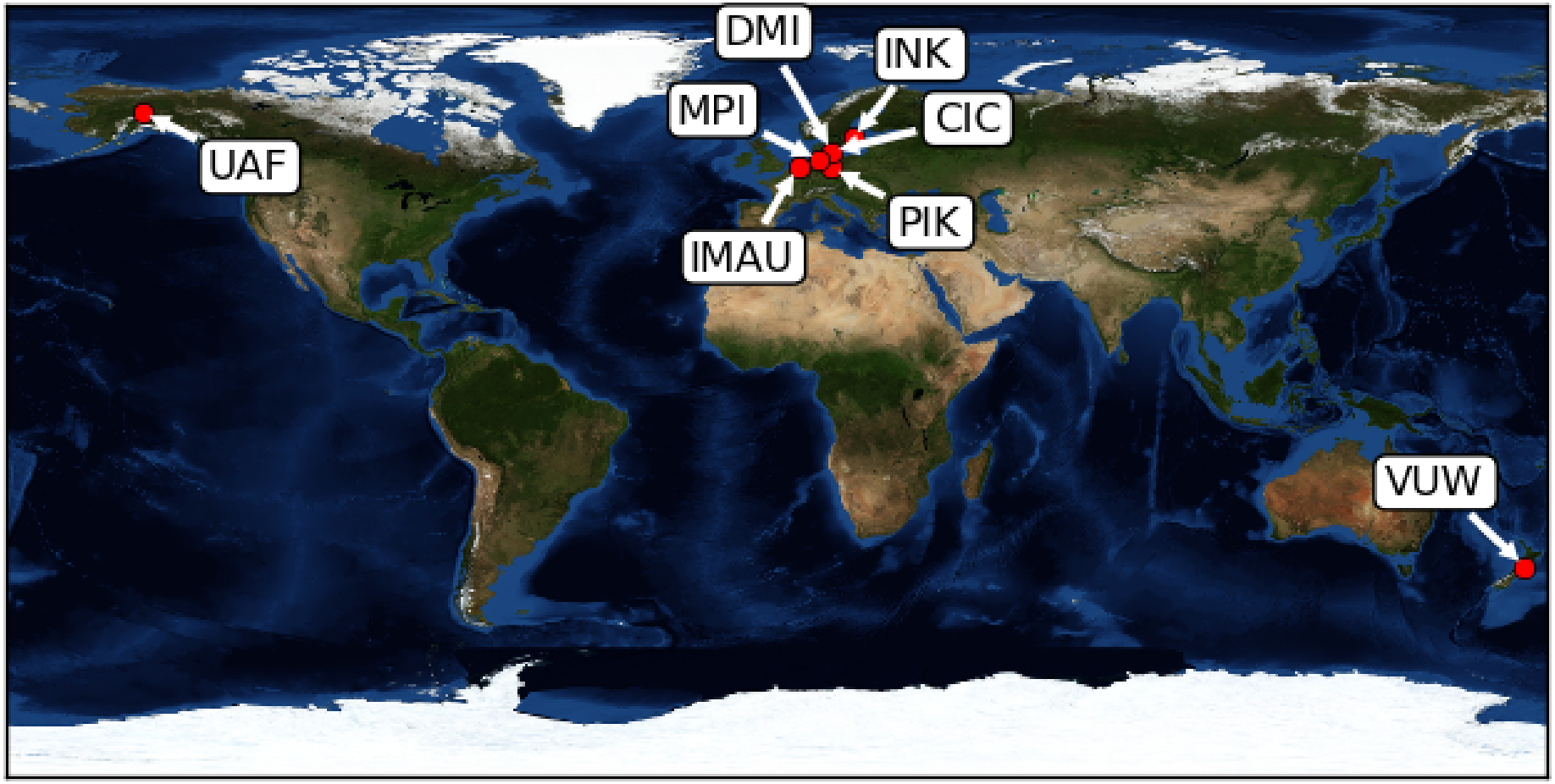
PISM: power user's point of view

- everything is parallel (PETSc and MPI)
  - whole Antarctica at 5 km resolution
  - whole Greenland at 1 km resolution for 100 model years
    - $\approx$ 100k processor-hours on 512 cores at ARSC
  - New Zealand LGM ice sheet at 500 m resolution (N. Gollege at VUW)
- effective, well-tested physics
  - shallow hybrid for stress balance
  - enthalpy method for conservation of energy
- open source (GPL)
  - hosted at `github.com/pism/pism`
  - modular (library-like) and extensible C++ code base
  - well-documented source code

who supports development?

- supported by the NASA Modeling, Analysis and Prediction grant NNX09AJ38G (2009–2013)
- 2003–2008: earlier NASA grant
- since April 2011: jointly developed by UAF and the Potsdam Institute for Climate Impact Research (PIK)
- a *community* of developers . . . likely to expand?

a community of users and developers



publications

- in the 17 months since the start of 2011: 14 papers using PISM have been published or are “in press”
- see the website:

Publications: applications of PISM

These are applications to real ice flow problems. There is also a separate page for publications on model development and numerical methods.

2012

- **W. J. J. van Pelt, J. Oerlemans** (2012) Numerical simulations of cyclic behaviour in the Parallel Ice Sheet Model (PISM). *Journal of Glaciology* 58 (208) pp. 347–360. doi [http://dx.doi.org/10.3189/2012JoG11J217] web [http://www.igsoc.org/journal/58/208/t11J217.pdf] bibtex
- **T. Albrecht, A. Levermann** (2012) Fracture field for large-scale ice dynamics. *Journal of Glaciology* 58 (207) pp. 165–176. doi [http://dx.doi.org/10.3189/2012JoG11J191] web [http://www.igsoc.org/journal/current/207/t11J191.pdf] bibtex
- **A. Levermann, T. Albrecht, R. Winkelmann, M. A. Martin, M. Haseloff, I. Joughin** (2012) Kinematic first-order calving law implies potential for abrupt ice-shelf retreat. *The Cryosphere* 6 pp. 273–286. web [http://www.the-cryosphere.net/6/273/2012/tc-6-273-2012.html] bibtex
- **R. Winkelmann, A. Levermann, K. Frieler, M. A. Martin** (2012) Uncertainty in future solid ice discharge from Antarctica. *The Cryosphere Discussions* 6 (1) pp. 673–714. web [http://www.the-cryosphere-discuss.net/6/673/2012/] bibtex
- **A. Solgaard, P. Langen** (2012) Multistability of the Greenland ice sheet and the effects of an adaptive mass balance formulation. *Climate Dynamics* doi [http://dx.doi.org/10.1007/s00382-012-1305-4] bibtex
- **F. Pattyn, C. Schoof, L. Perichon, 15 others** (2012) Results of the Marine Ice Sheet Model Intercomparison Project, MISMIP. *The Cryosphere* pp. in press. web [http://www.the-cryosphere-discuss.net/6/267/2012/tcd-6-267-2012.html] bibtex
- **N. Golledge, A. Mackintosh, 8 others** (2012) Last Glacial Maximum climate in New Zealand inferred from a modelled Southern Alps icefield. *Quaternary Science Reviews* pp. in press. bibtex
- **R. Winkelmann, A. Levermann** (2012) Linear response functions to project contributions to future sea level. *Climate Dynamics* 38 pp. in press. web [http://www.pik-potsdam.de/~anders/publications/winkelmann_levermann12c.pdf] bibtex
- **A. Aschwanden, G. Adalgeirsdottir, C. Khroulev** (2012) Using observations to address ice sheet model sensitivity to initial states. ***SUBMITTED*** bibtex

2011

- **A.M. Solgaard, N. Reeh, P. Japsen, T. Nielsen** (2011) Snapshots of the Greenland ice sheet configuration in the Pliocene to early Pleistocene. *Journal of Glaciology* 57 (205) pp. 871–880. web [http://www.ingentaconnect.com/content/igsoc/jog/2011/00000057/00000205/art00011] bibtex
- **M. A. Martin, R. Winkelmann, M. Haseloff, T. Albrecht, E. Bueler, C. Khroulev, A. Levermann** (2011) The Potsdam Parallel Ice Sheet Model (PISM-PIK) – Part 2: Dynamic equilibrium simulation of the Antarctic ice sheet. *The Cryosphere* 5 pp. 727–740. web [http://www.the-cryosphere.net/5/727/2011/tc-5-727-2011.pdf] bibtex
- **A. Levermann** (2011) When glacial giants roll over. *Nature* 472 pp. 43–44. web [http://www.pik-potsdam.de/~anders/publications/levermann11.pdf] bibtex

one paper per month featured at website

All "PISM Applications of the Month"

February 2012

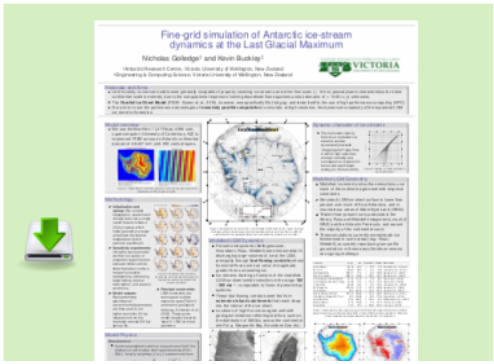
Click on the thumbnail to get PDF from the J. Glaciol. site.

Fracture field for large-scale ice dynamics	
ice sheet:	Antarctic ice sheet
investigators:	Torsten Albrecht and Anders Levermann
venue:	Journal of Glaciology

A macroscopic fracture-density field is introduced into PISM. Its evolution includes the initiation and growth of fractures as well as their advection with two-dimensional ice flow. To first approximation, fracture growth is assumed to depend on the spreading rate only, while fracture initiation is defined in terms of principal stresses. The inferred fracture-density fields compare well with observed elongate surface structures. The aim of this study is to introduce the field and investigate which of the observed surface structures can be reproduced by the simplest physically motivated fracture source terms.

2012/02/01 00:01 · Ed Bueler

January 2012



Fine-grid simulation of Antarctic ice stream dynamics at the Last Glacial Maximum	
ice sheet:	Antarctic ice sheet (LGM)
lead investigator:	Nick Golledge
venue:	INQUA 2011 and SCAR International Symposium on Antarctic Earth Sciences, 2011

The Antarctic Research Centre is using PISM to study Antarctic ice sheet behaviours during key periods of the past, particularly the LGM and the mid-Pliocene.

minimal history

- 1984–2001: Craig Lingle does ice sheet/stream modeling in AK
- 2002–2004:
  - Craig recruits Jed Brown and me as developers
  - Jed decides on PETSc
- 2005: first draft is "COMMVNISM"
  - C++ Object-oriented Multi-Modal Verifiable Numerical Ice Sheet Model
- 2006: first PISM release on `gna.org`
- 2008:
  - Constantine
  - PIK visits Alaska . . . branch
- 2009: Andy
- 2011:
  - merge PISM-PIK
  - move to `github.com`

who answers help@pism-docs.org?

Constantine Khroulev

Andy Aschwanden

Outline

`0.5` release of PISM in June 2012

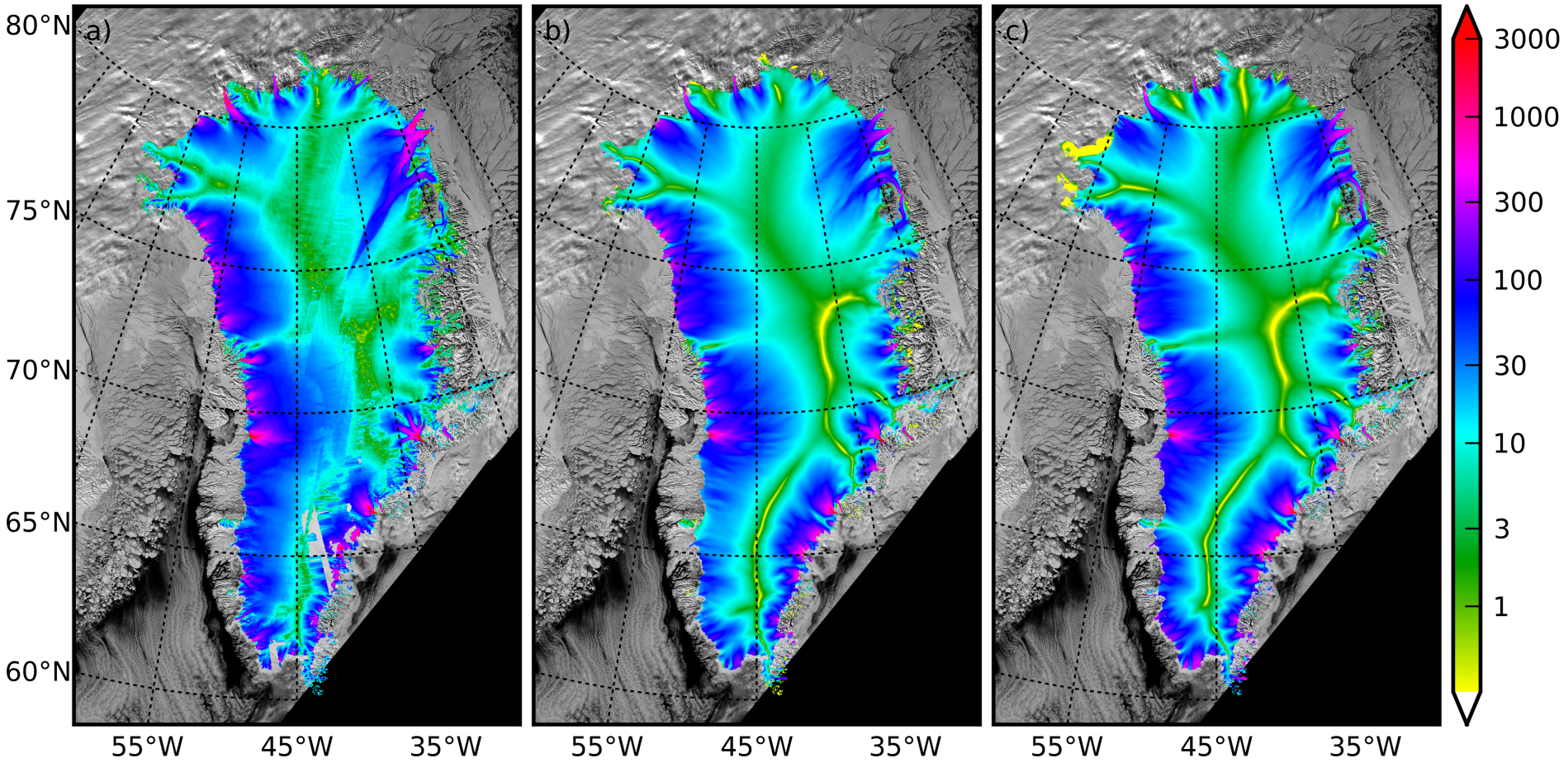
- get pre-release now:

  ```
  git clone git://github.com/pism/pism.git pism0.5
  ```

- June "official" release after more testing, documentation
  - watch for CYROLIST announcement
  - ...then do "`git pull`" and recompile
- changelog from `pism0.4`:
  - more improvements to usability than new features
  - requires PETSc 3.2
  - `-o_format [netcdf4_parallel, pnetcdf]`
  - better calendar handling
  - more complete climate-forcing "couplers"
  - improved documentation of climate-forcing

0.5 update: NetCDF4 means bigger scales

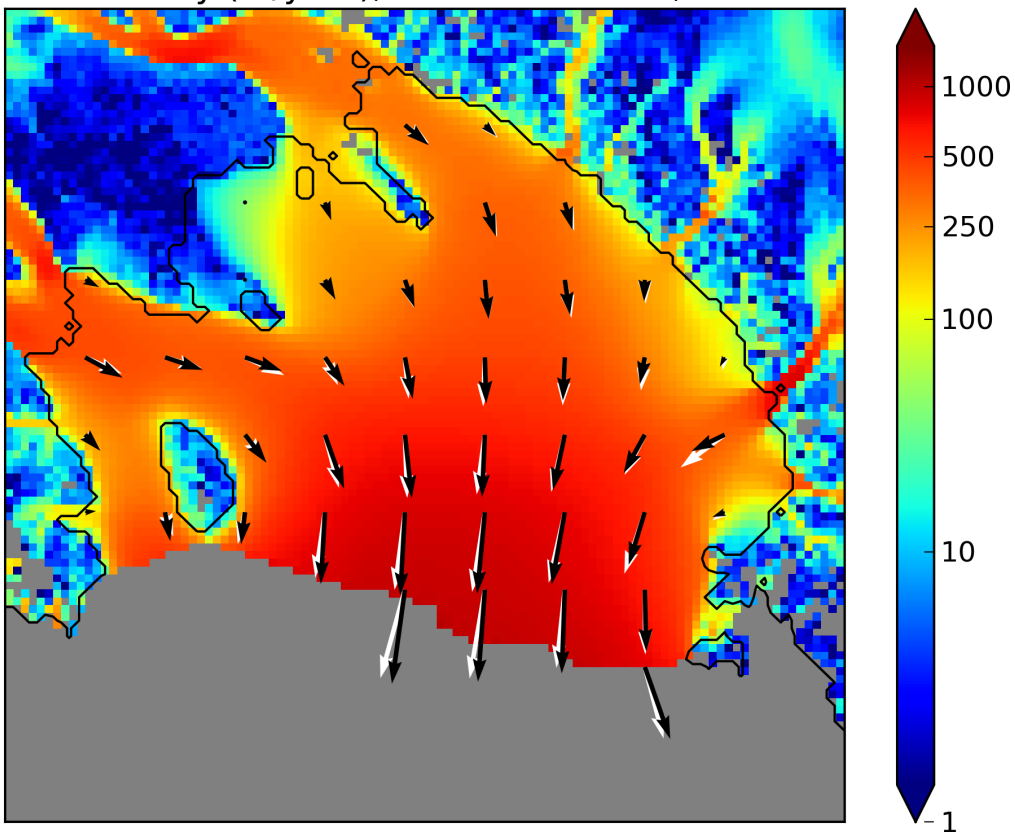
- previous limitation: can't write very large ($>$ 4Gb) model results
- *new*: optional use of parallel NetCDF4 or `pnetcdf`
- *get*: 1km Greenland runs for 100 model years
  - 10^9 temperature and velocity unknowns

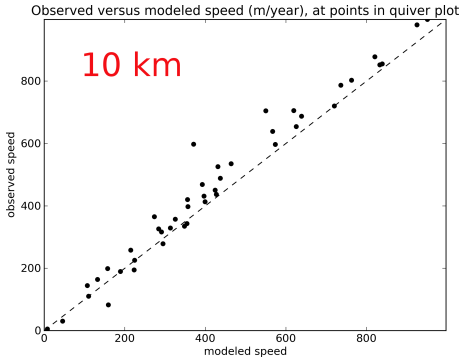


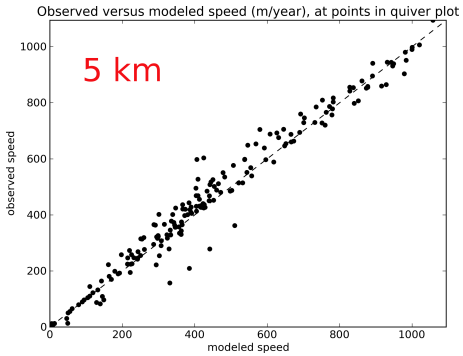
0.5 update: the Ross ice shelf example

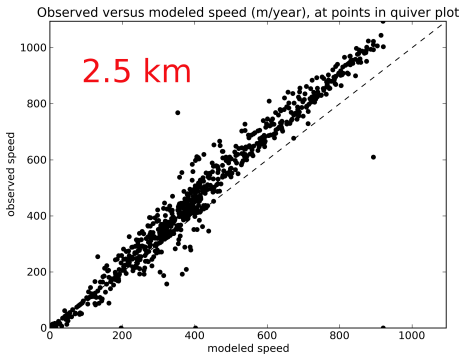
- "diagnostic" ice shelf example in User's Manual
- based on extract from 5km ALBMAP and MEASURES (2011) data
  - not old EISMINT-Ross data

Ross ice velocity (m/year); white=observed, black=model







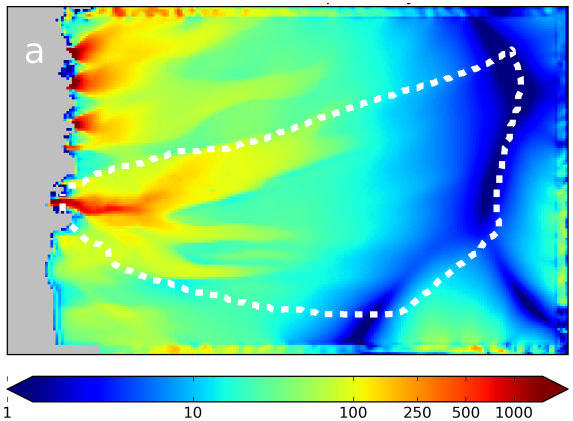


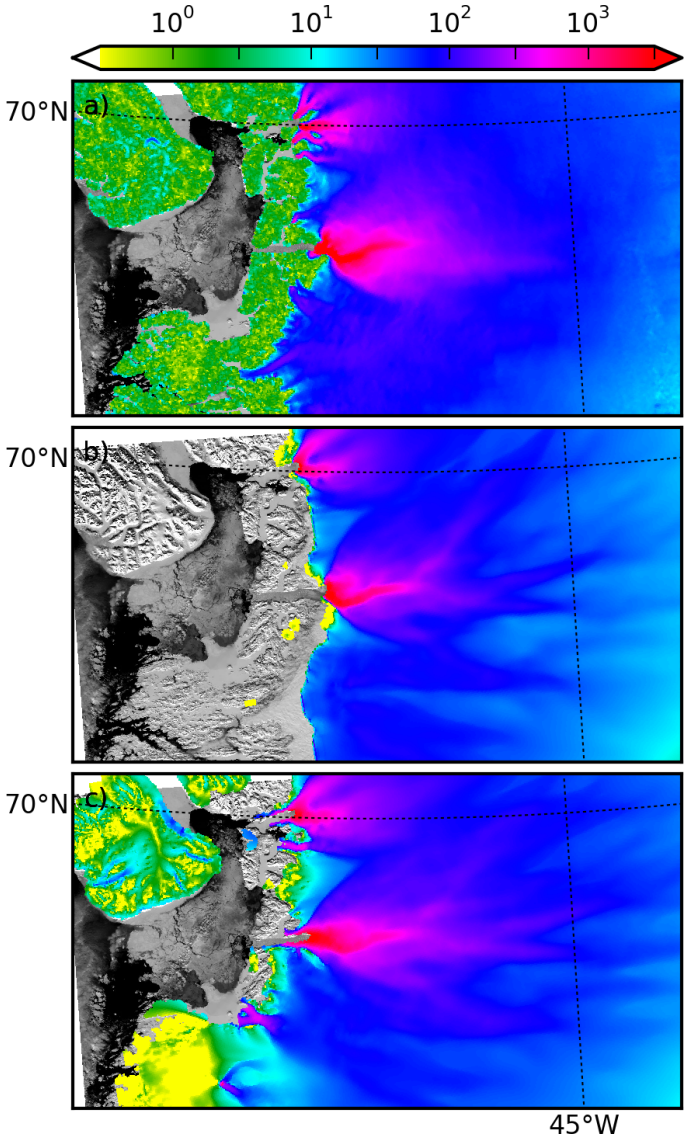
0.5 update: regional tools

outlet glacier models

- regional models allow large parameter studies on fine grids
- automated drainage basin identification from DEM (below)
- outside of drainage basin is *not* modeled
- 1km results for Jakobshavn Isbræ (right)

top: observed
middle: regional model (present-day geom. outside)
bottom: whole ice sheet model with evolving margins





D. Dellagiustina MS Thesis (2011)

`git clone git://github.com/pism/regional-tools.git`

update 0.5: some option combinations

- running PISM and setting the grid (alternatives):

```
$ pismr -boot_file data.nc -Mx 76 -My 141 -Mz 101 -Mbz 11 \
       -Lz 4000 -Lbz 2000
$ pismr -i prev-state.nc
```

- setting the duration (alternatives):

```
...  -ys YEAR -ye YEAR
...  -ys YEAR -y DURATION
```

- a sliding model possibility:

```
...  -ssa_sliding -topg_to_phi 5.0,30.0,-300.0,700.0 \
       -pseudo_plastic -pseudo_plastic_q 0.25 \
       -plastic_pwfrac 0.98
```

- ice shelf calving front model (alternatives):

```
...  -ocean_kill bar.nc -cfbc -kill_icebergs
...  -pik -eigen_calving -eigen_calving_K 1e17 \
       -thickness_calving -calving_at_thickness 50.0
```

- main point: these options can be combined

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where is PISM going?

enthalpy model

main point: basal melt rate from better energy conservation

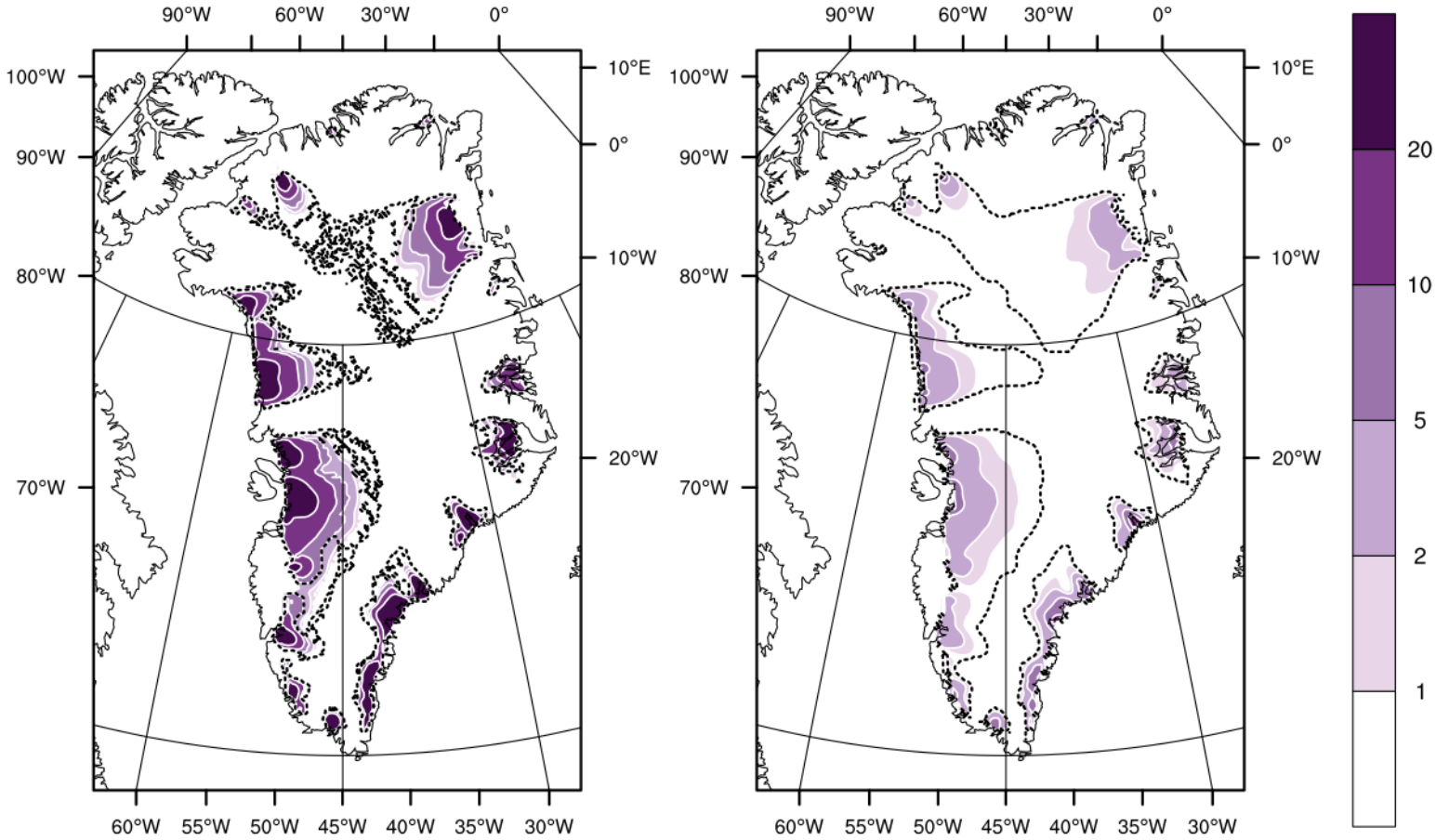


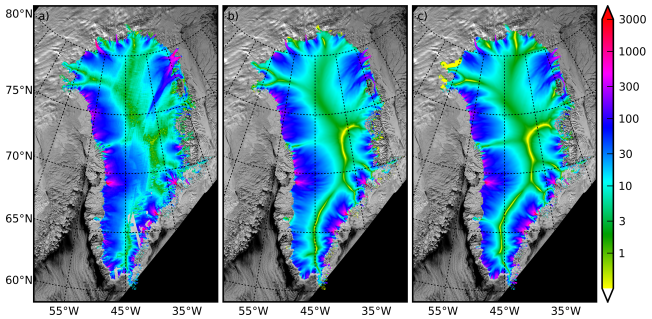
Figure 8. Basal melt rate for the ENTH run (left) and the TEMP run (right). Values are in millimeters per year. The dashed line is the cold-temperate transition surface.

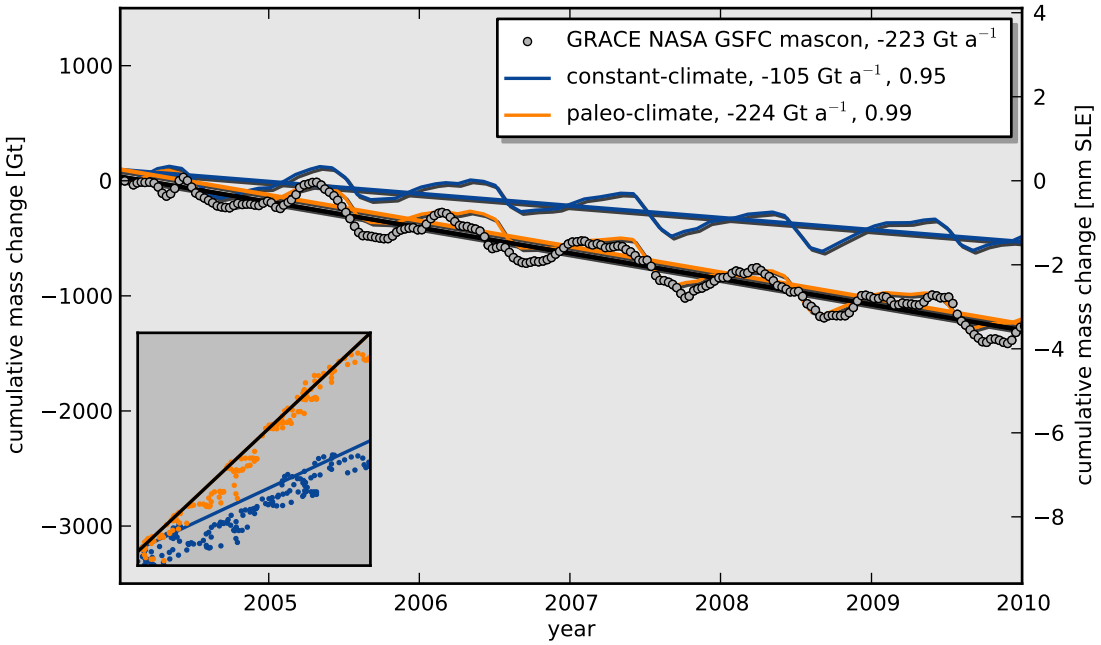
Aschwanden, Bueler, Khroulev, Blatter (2012) *An enthalpy formulation for glaciers and ice sheets*, J. Glaciol. 58 (209), 441–457.

analysis of “initial states” for Greenland

main point: good agreement with observed-period observations without inversion

- using HIRHAM 1989–2009 mean air temp. and SMB
- using ice2sea 1km bed topography





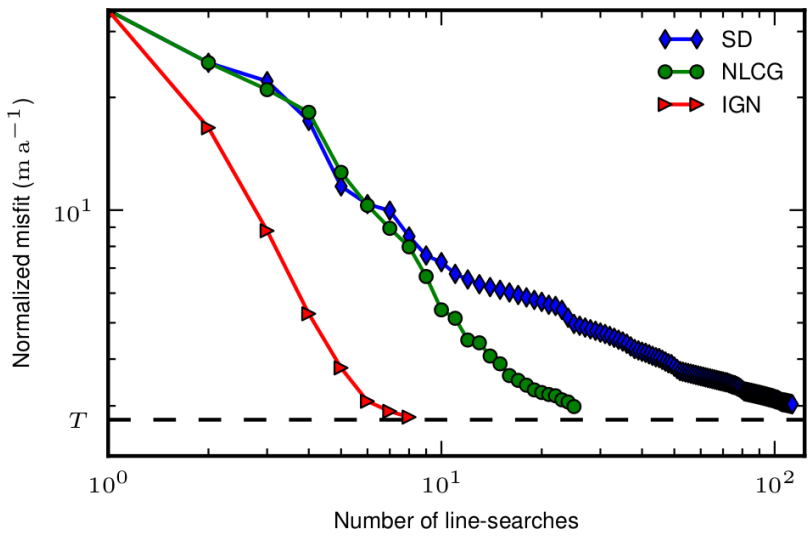
Aschwanden, Aðalgeirsdóttir, Khroulev (submitted) *Using observations to address ice sheet model sensitivity to initial states*

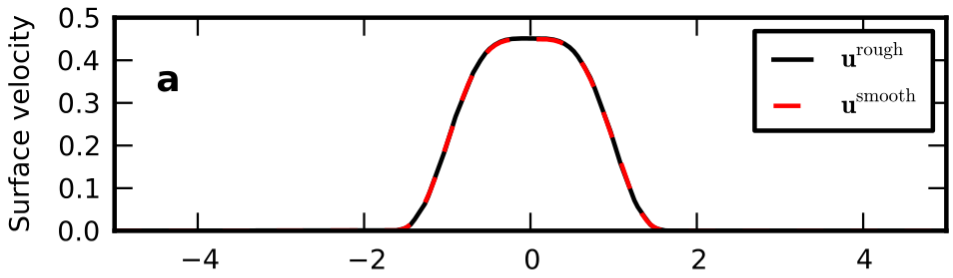
inversion of SSA (and hybrid) for basal shear stress

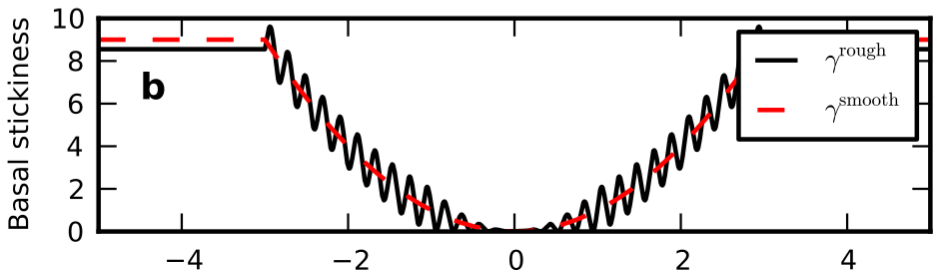
main point: inversion must be done with care

- new fast method of computing basal basal shear stress from surface velocities by inverting SSA
  - "incomplete Gauss-Newton" by David Maxwell (top figure)
  - uses `-ssa_method fem`
  - new python tools:

    `git@github.com:damaxwell/siple.git`
- preliminary inversions at Jakobshavn using PISM (not shown)
- David says "inversion is an exercise in managed expectations" (bottom)





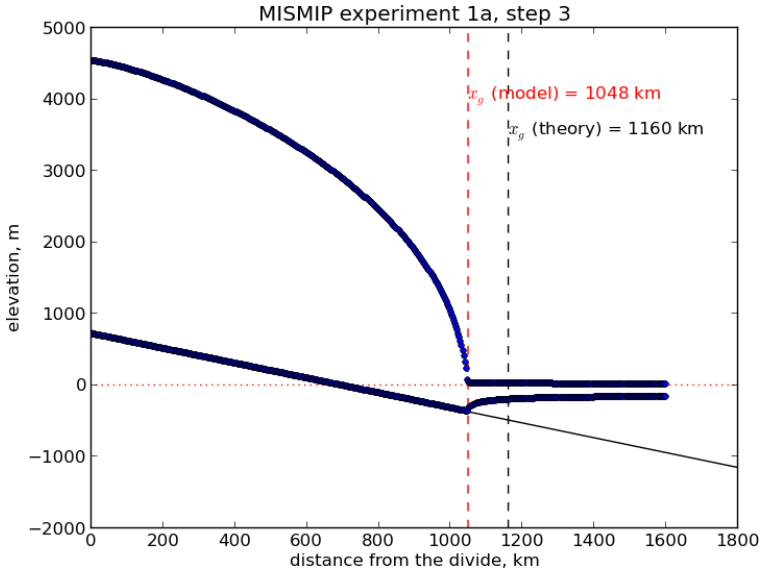


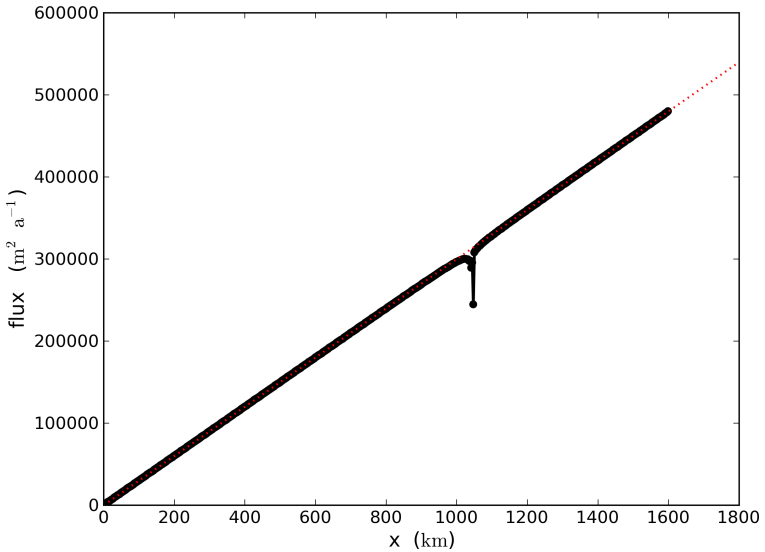
Habermann, Maxwell, Truffer (2012)
Reconstruction of basal properties in ice sheets using iterative inverse methods, J. Glaciol., to appear

Outline

to improve: better grounding line motion

- three "facts" from MISMIP etc. understanding:
  1. stress balance and mass continuity equations are irregular across grounding lines
  2. this is not a "higher order" issue
  3. enough grid refinement near the grounding line does solve the problem
- but the known fix (3 above) is hard to use in a structured-grid model like PISM
- current PISM has these problems:
  - grounding line "sticks" (top)
  - flux computed as uH has wiggle (bottom)





to improve: add "higher-order" stress balance

- "higher-order stress balance" balances more stresses, in one solution process, than in either the SIA or SSA stress balances
  - *note*: Stokes stress balance is *not* planned for PISM
- a Blatter stress balance solver* is present in the PISM dev branch
  - but all it can do is ISMIP-HOM
  - needs moving margins
- unknown: how "higher-order" is the current SIA+SSA hybrid?
  - first purpose of Blatter model in PISM is to compare results
  - we will probably continue to use SIA+SSA mostly

*see Jed's paper **Brown et al**, *Achieving textbook multigrid efficiency for hydrostatic ice sheet flow*, submitted to SIAM J. Scientific Computing.

to improve: better subglacial hydrology model

- the current PISM hydrology model is very simplified:
  - no lateral transport of liquid water
  - liquid water not conserved
  - model is probably suitable for Siple coast ice streams (Tulaczyk 2000)
  - not so good for temperate and high-driving-stress (outlet) glaciers
- start on a new model (van Pelt & Bueler):
  - inspired by Hewitt (2011) and Schoof et al. (2012)
  - mass of water is conserved
  - lateral transport of water driven by pressure gradient (Darcian)
  - elliptic equation determines water pressure
  - physical models for opening (wall melt, sliding) and closure (creep)
  - great danger in building a model whose parameters cannot be identified
  - I'll give an update on our progress at IGS Fairbanks June 24–29

to improve: better transport schemes

- we are currently using first-order upwinding schemes for transport
- *note*: ice sheet flow is a diffusion at large scale, so numerically-diffusive transport schemes are often not noticeable
- but:
  - transport in conservation of energy needs improvement
  - age equation is pure transport
    - needs improvement so we can validate with isochrones

Outline

where is PISM going?

(where will you lead it?)

- everyone can (and should) branch the code and try new things
- merging successful ideas from branches
  - is really important!
  - requires decisions and synoptic view of code
  - central scientific programmer (= Constantine Khroulev) is vital
- thanks for listening!

- where are we going? let's talk right now