Recent developments in the GLIDE CISM dycore to create high-resolution, continent-scale simulations

Kate Evans, ORNL

Steve Price, LANL

Andy Salinger, Sandia

Pat Worley, ORNL

Matt Norman, ORNL

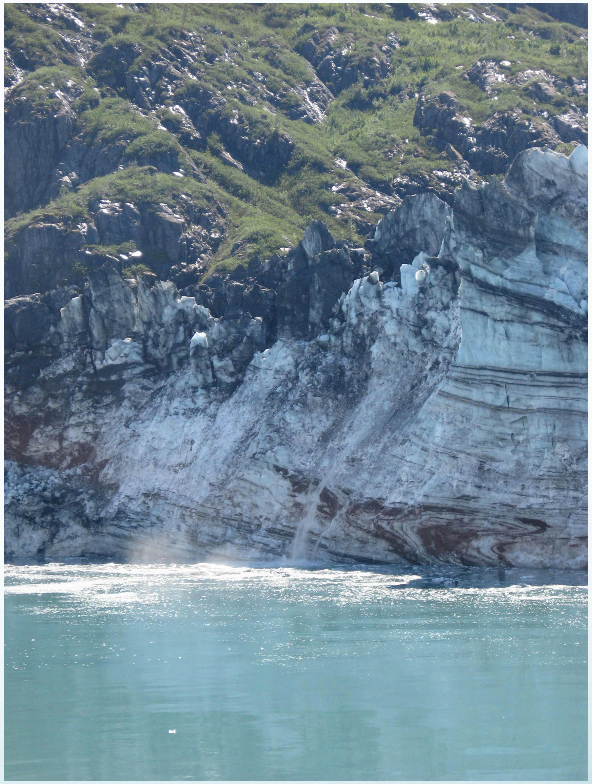
Bill Lipscomb, LANL

Irina Kalashnikova, Sandia

Oak Ridge National Laboratory
Managed by UT-Battelle for the Department of Energy

Sandia National Laboratories

Los Alamos National Laboratory EST. 1943



Consultation/Assistance from:
Jim Edwards, NCAR
Bill Sacks, NCAR
Mariana Vertenstein, NCAR
Mauro Perego and Max Gunzburger, FSU
GLIMMER Steering committee

U.S. Department of Energy

ASCR

Thanks to DOE ASCR for supporting ice sheet model development!

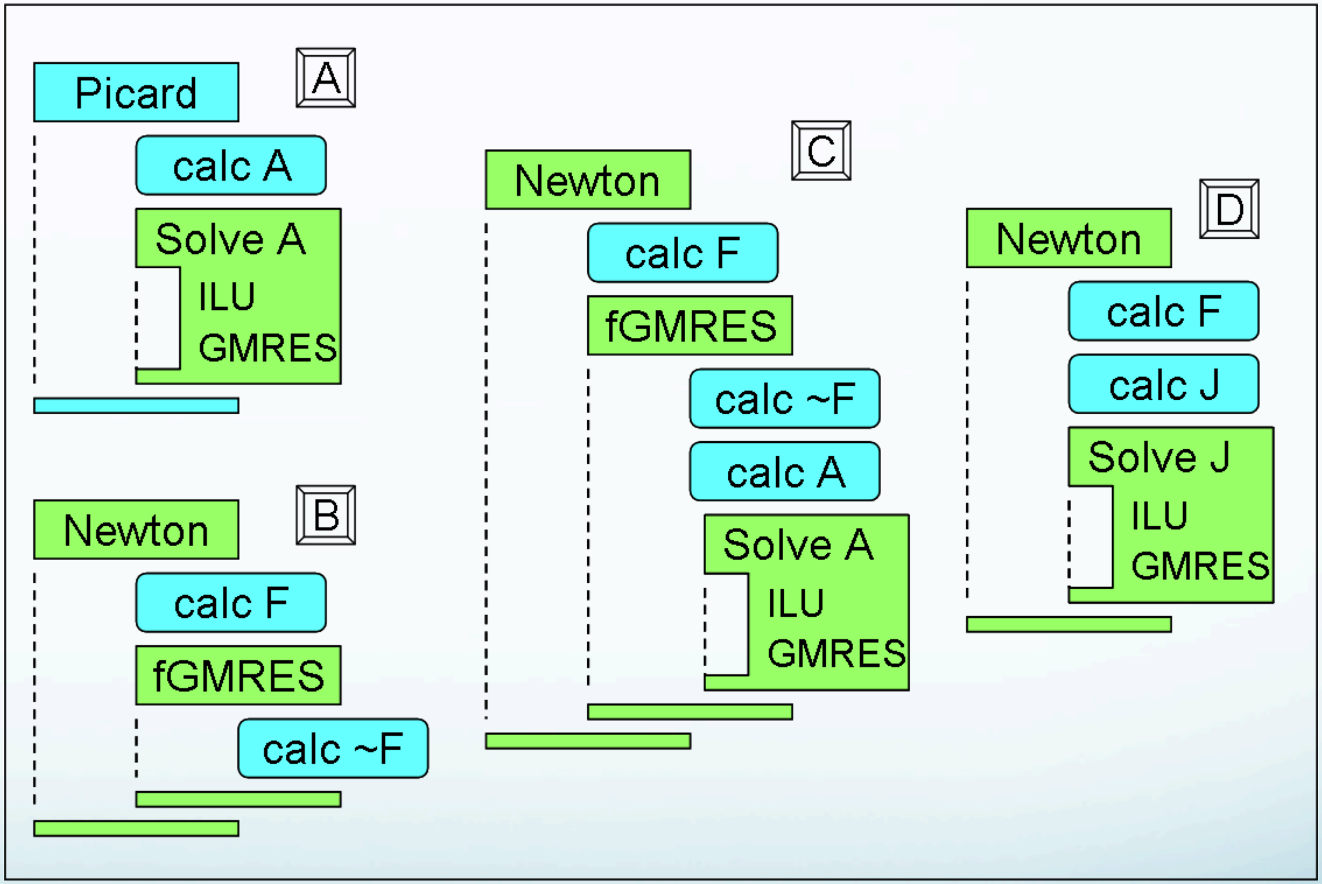
Integrating a scalable CISM in the CESM

- The parallel JFNK version of the HO dycore is a merged branch on the CESM/CISM repository
- Fully parallel velocity (2km GIS case, 82.5M DOF runs on 12500 procs on the jaguar xk6)
  - Subcycled advection option
  - One-sided boundary condition option
- JFNK solver option more robust for ~10M DOF and larger problems (~5km GIS and finer)
- Biggest computational roadblocks: good initial conditions and the portability of mixed language code

Interfacing the Trilinos package with CISM, and eventually CESM

A: Current version in the CESM repo 2.0 CISM release

C: Currently on CISM branch, next release



4 methods for interfacing the solver to Glimmer-CISM. Version C uses function pointers to G-CISM to evaluate the nonlinear solution and call the preconditioner

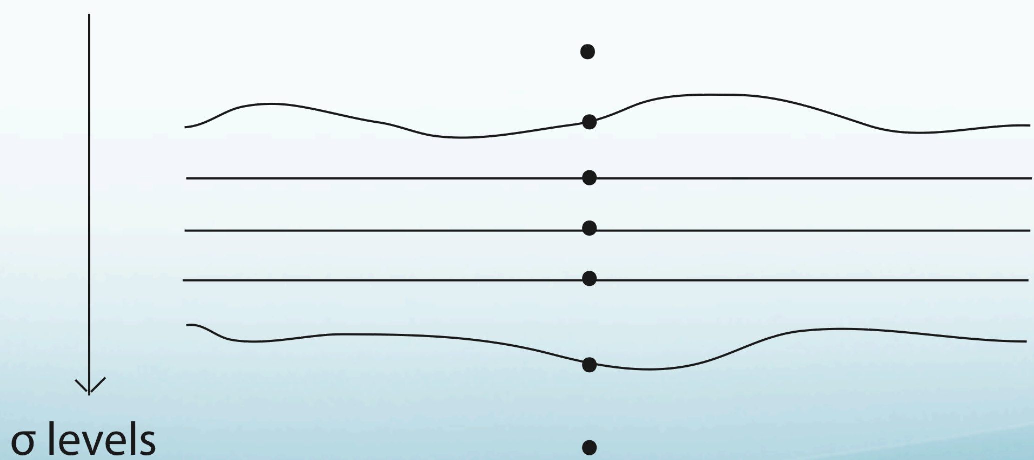
Basal and surface boundary conditions

Issues with current BC

- Even with no-slip problems, coefficients for basal velocity equation are much larger than the rest of the column (basal viscosity to enforce no-slip), and off-diagonal, so matrix is difficult to solve

Implementation

- Use second order one-sided differences to calculate the BC, and thus place the large coefficients on the diagonal of the velocity matrix to be solved



ML preconditioner

- Basal boundary condition:

$$\eta \frac{\partial u}{\partial z} = -\beta^2 u \qquad \text{for } z = b(x)$$

Central Implementation

$$\begin{pmatrix} -\frac{\eta}{2h} & \beta^2 & \frac{\eta}{2h} & 0 & 0 & 0 \\ \frac{\eta}{h^2} & -\frac{2\eta}{h^2} & \frac{\eta}{h^2} & 0 & 0 & 0 \\ 0 & \frac{\eta}{h^2} & -\frac{2\eta}{h^2} & \frac{\eta}{h^2} & 0 & 0 \\ 0 & 0 & \frac{\eta}{h^2} & -\frac{2\eta}{h^2} & \frac{\eta}{h^2} & 0 \\ 0 & 0 & 0 & -\frac{\eta}{2h} & 0 & \frac{\eta}{2h} \end{pmatrix}$$

One-Sided Difference Implementation

$$\begin{pmatrix} \beta^2 - \frac{\eta}{h} & \frac{\eta}{h} & 0 & 0 \\ \frac{\eta}{h^2} & -\frac{2\eta}{h^2} & \frac{\eta}{h^2} & 0 \\ 0 & \frac{\eta}{h^2} & \frac{-2\eta}{h^2} & \frac{\eta}{h^2} \\ 0 & 0 & -\frac{\eta}{h} & \frac{\eta}{h} \end{pmatrix}$$

- Ifpack preconditioner optimal for problems with vertical coupling.
- ML preconditioner expected to be better alternative than ILU preconditioner for case with:
  - **Basal sliding (horizontal shear and coupling among horizontal cells).**
  - **Very large problems run on many processors (ILU may not scale well).**

ML preconditioner

		Ifpack (1 overlap, 1 level-of-fill)	ML
old (central diff) BC	$\|\|F\|\|$	$9.334e-5$	$4.158e2$ (FAILED)
	# iter nonlinear solver	14	100 (FAILED)
	utime (s)	27,593	921,431
new (one-sided diff) BC	$\|\|F\|\|$	$3.817e-5$	$3.862e-5$
	# iter nonlinear solver	10	10
	utime (s)	45,402	39,638

- Behavior of preconditioners is as expected (10 km Greenland problem on 512 processors):
  - **Central difference BC implementation: linear solver with ILU preconditioner converges but linear solver with ML preconditioner fails to converge.**
  - **One-sided central difference BC implementation: linear solver converges with both ILU and ML preconditioners.**
  - **ML preconditioner can yield shorter total solve time.**

Subcycled Advection

- The CFL condition that defines stability for the mass transport in CISM goes by ~

$$\Delta t \leq \frac{\Delta x^2}{2D}$$

- With grid refinement
  - explicit advection is very limiting
  - Increased nonlinear coupling of **v** to T and h
- A simple subcyling feature has been implemented to allow larger time steps
- Long term model development includes an implicitly based advection scheme

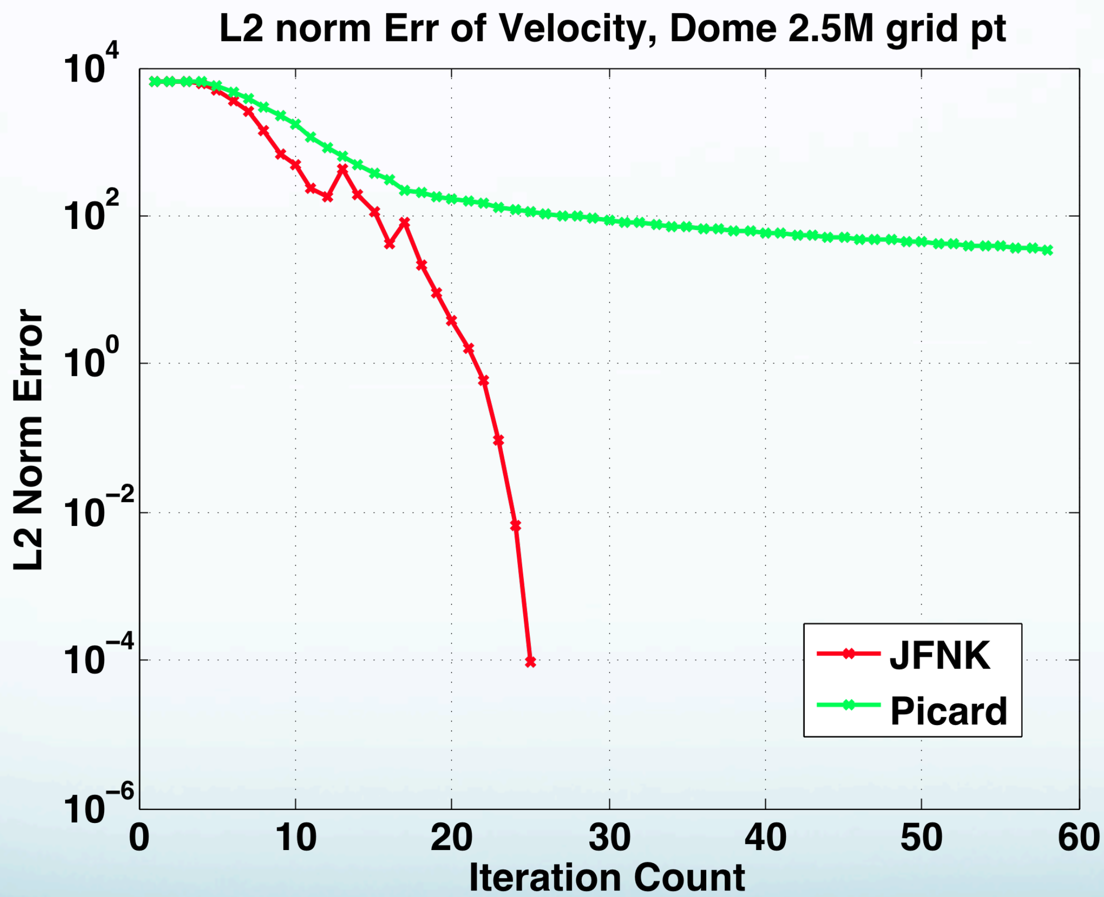
Solver behavior for simple dome of ice test case, constant Glenn's A and T

Prob size (grid pts)	# processors	Solver option	#nlin iterations
144K	144	JFNK "0"	10
2.5M	420	JFNK "0"	24
2.5M	420	JFNK "1"	15
2.5M	1600	JFNK "1"	16
2.5M	420	Picard	N/A

144K equivalent to 20km GIS, 2.5M ~ 5km GIS

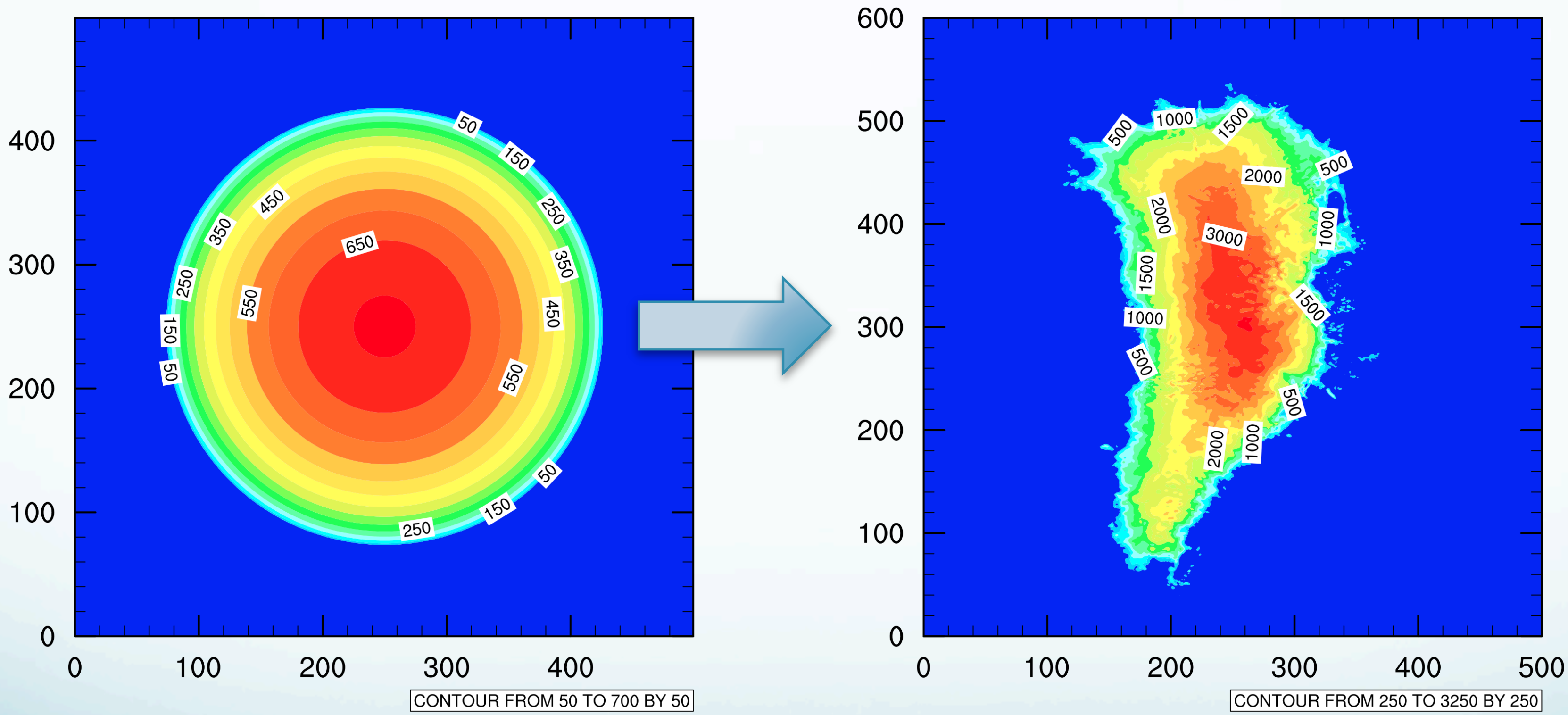
JFNK uses a PICARD preconditioner, which solves **v** using GMRES with an ILU preconditioner. Setting "0" uses no backtracking, ILU has no overlap or fill, JFNK "1" has backtracking, overlap=1, level of fill=4

Convergence behavior: JFNK, Picard 2.5M dome test case, basic ILU precon



Note: Picard eventually blows up in about 50+ more iterations, Regardless of precon settings

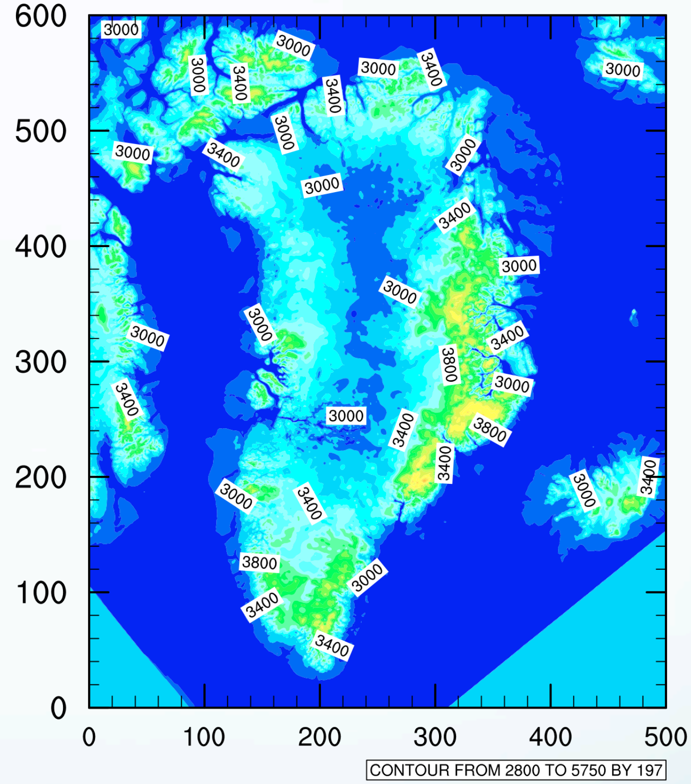
Convergence with realistic 5km GIS is more challenging



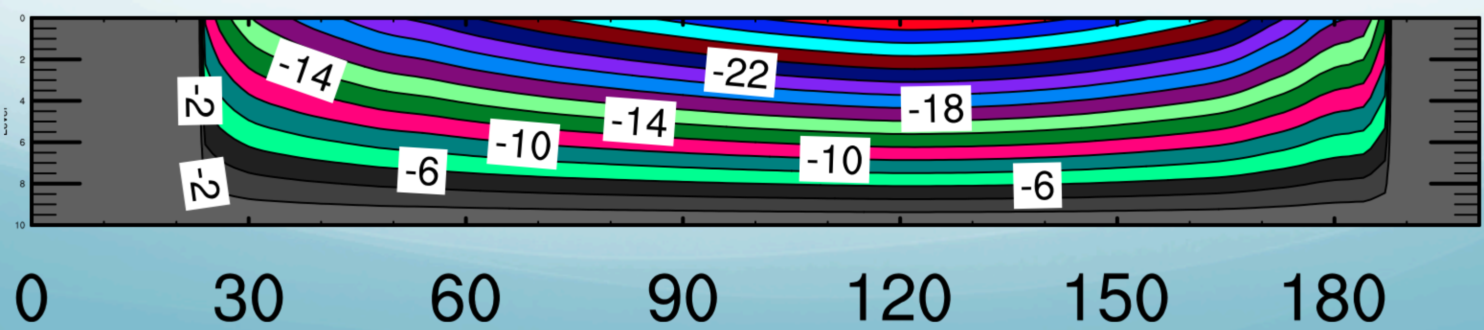
5km GIS configurations using new ice2sea initial dataset

- flow law rate factor calculated from idealized, simplified vertical temperature profile (vertical slice below)
- New 1 km res. Greenland Ice2Sea dataset, courtesy of Jonathan Bamber and Jenny Griggs from Univ. of Bristol. Surface elevations around the margins are much higher-res and more accurate, in general.
- More detailed than "isothermal based flow runs using Bamber et al (2000) DEM
- Thin ice settings at sheet edges

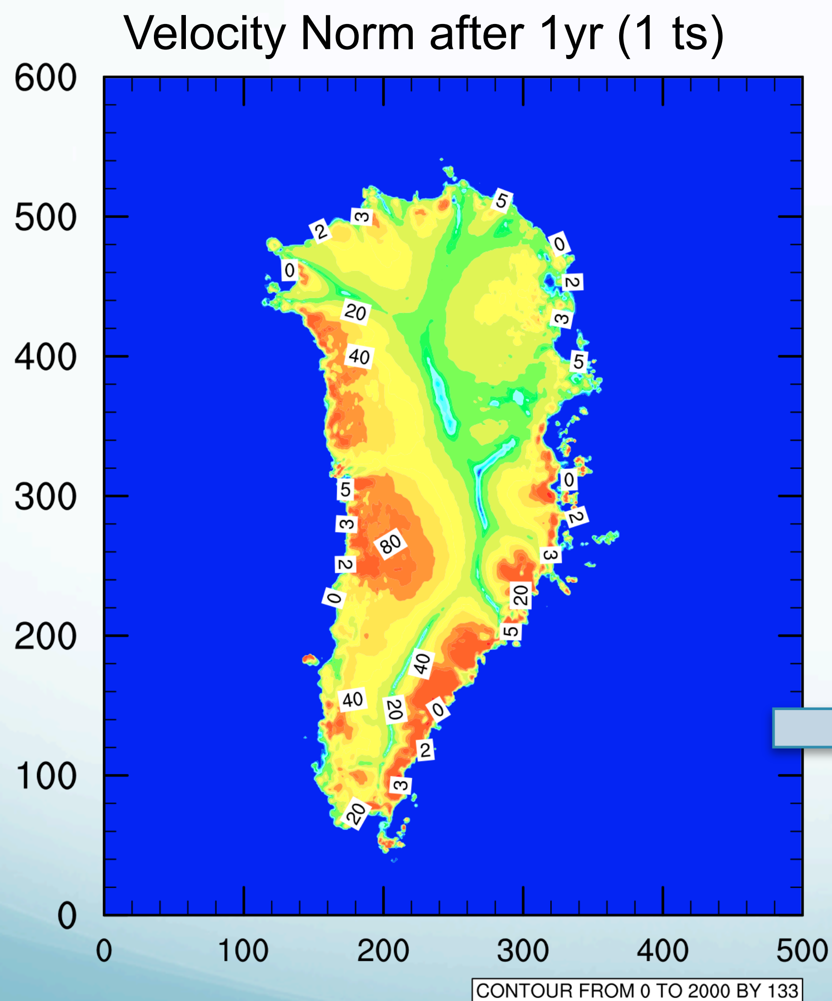
bedrock topography

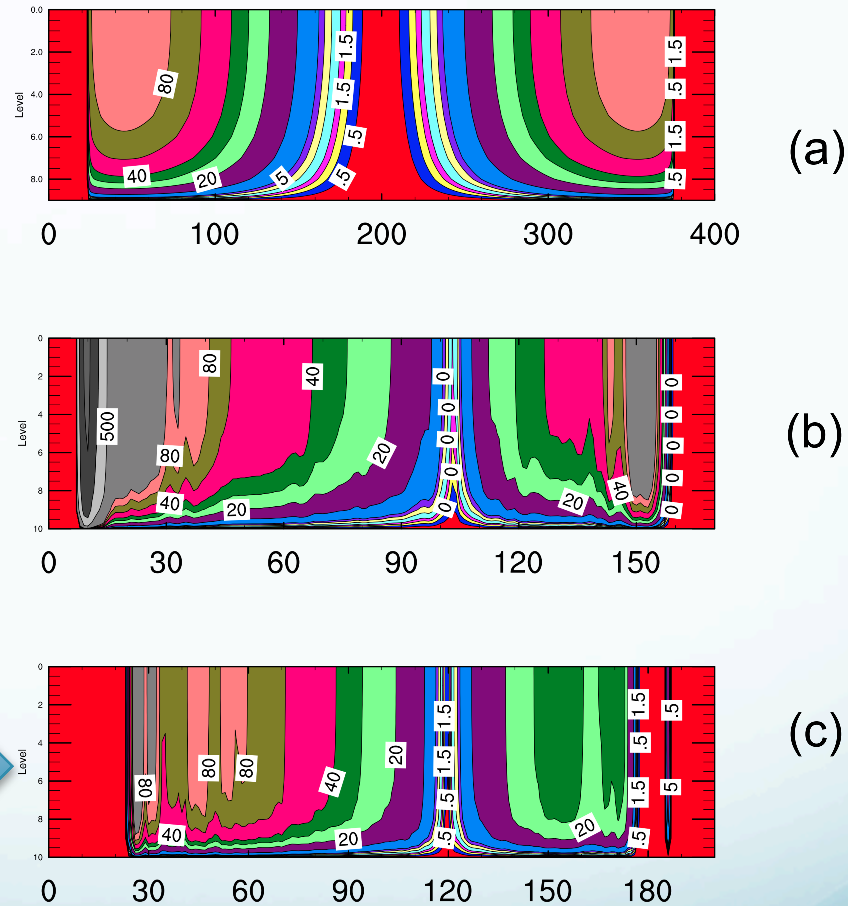


Initial Temperature contours for 5km GIS



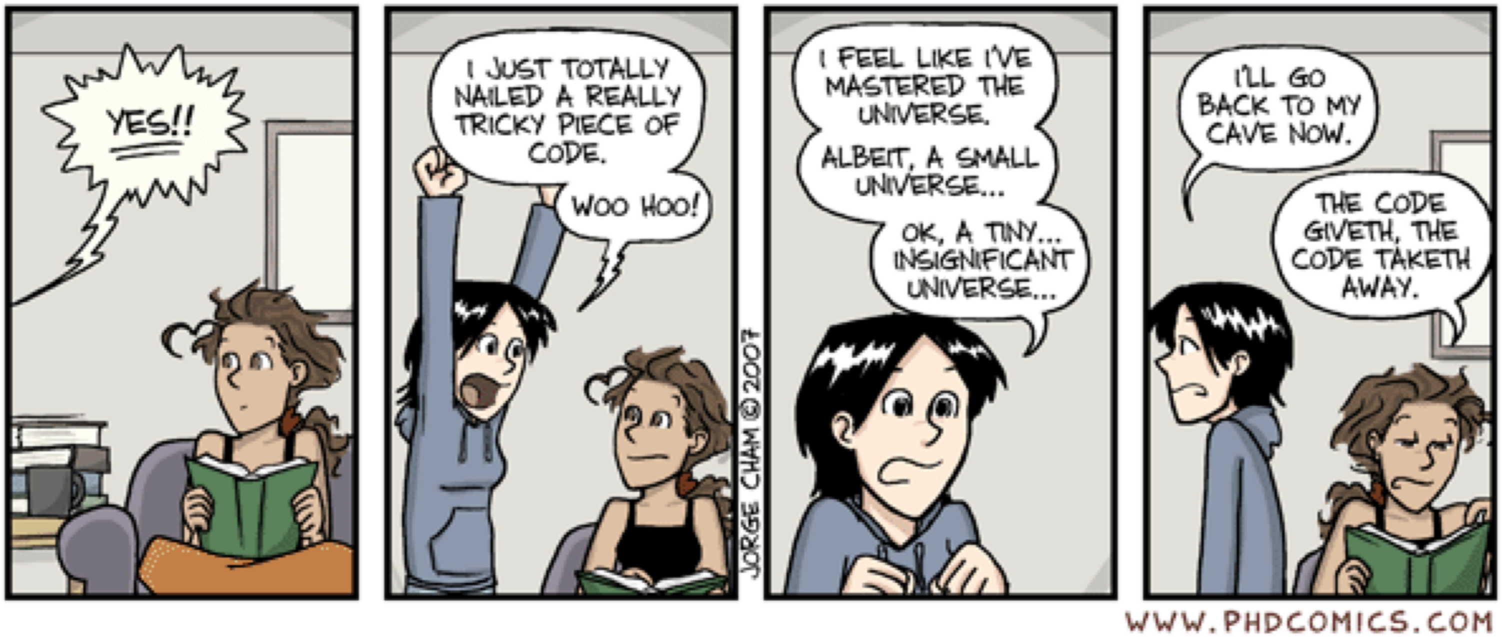
5km GIS velocity solution using new ice2sea initial dataset





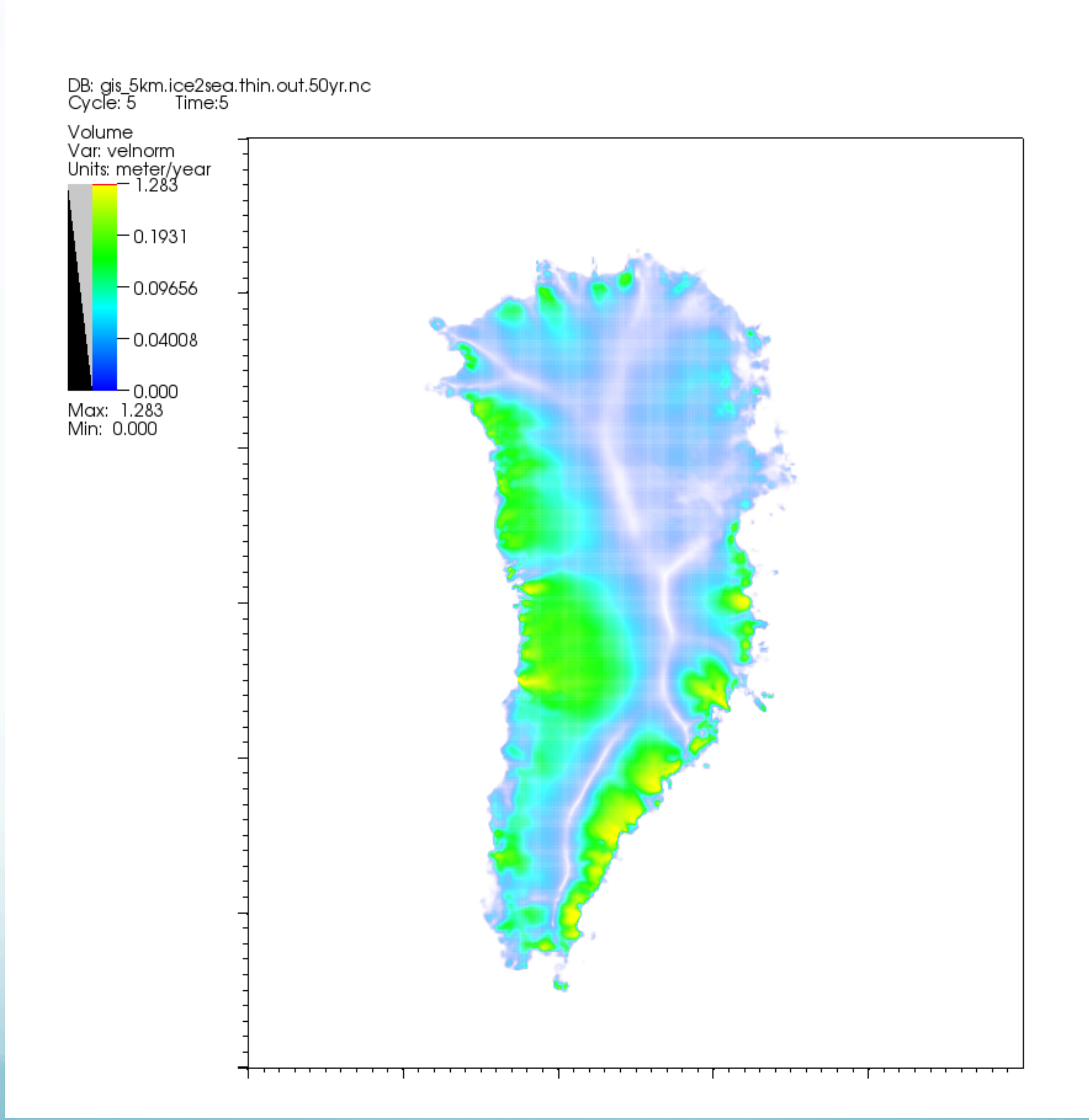
Hoz slices of velocity norm.
(a) "dome" (b) GIS with isothermal based flow, (c) new GIS

Piled Higher and Deeper *by Jorge Cham*　　www.phdcomics.com

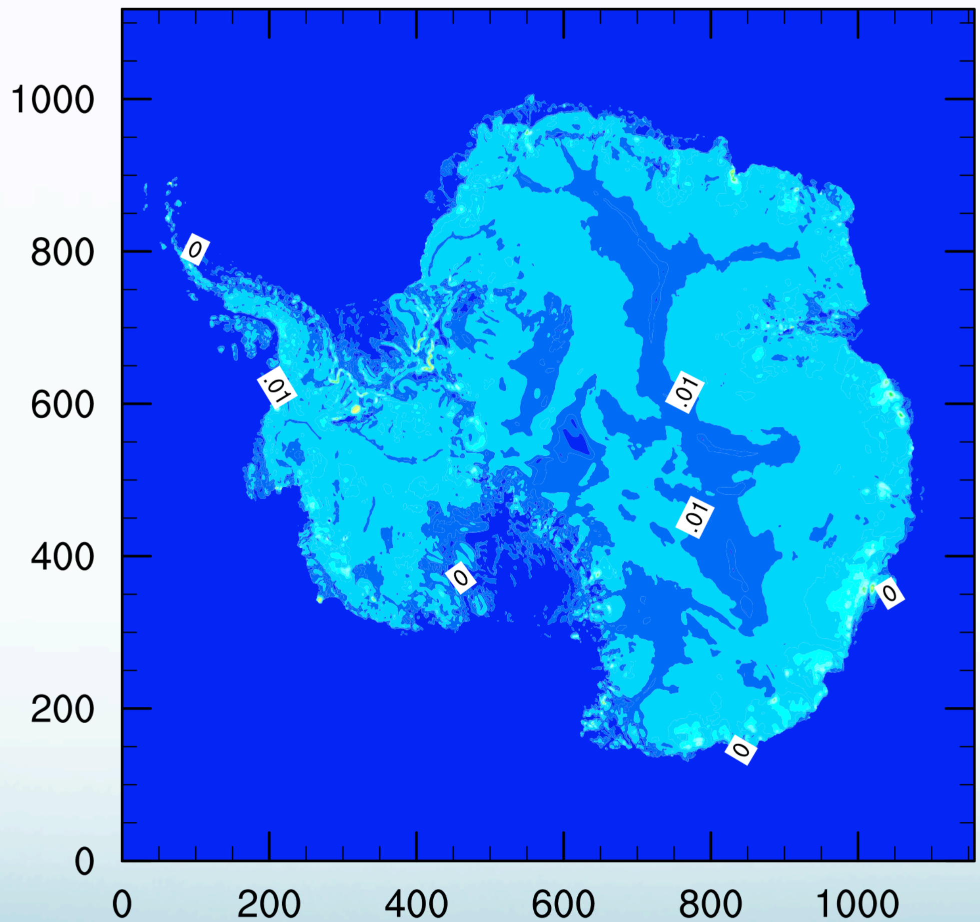


title: "Master of the Universe" - originally published 11/30/2007

GIS surface velocity 50 year adjustment to steady state



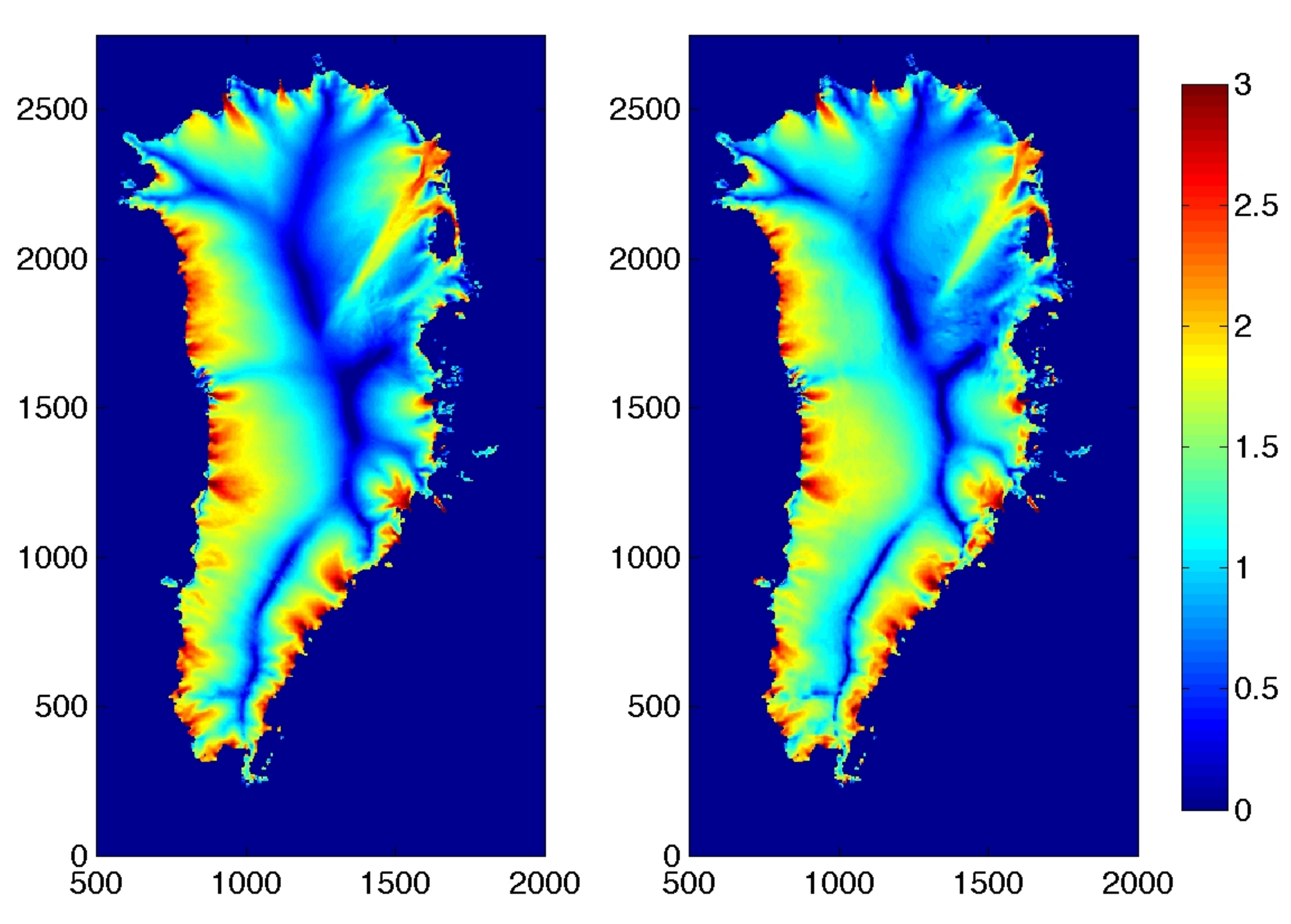
5km Antarctica initial surface velocity (norm)



Concluding remarks:

- Can run big problems with simple test cases, limited by memory, I/O, nonlinear convergence – all of these are work-in-progress
- More robust convergence with GIS using datasets interpolated from coarser grids and simpler flow, BC
- Next steps for GLIDE: start looking at the answers, e.g. better T, tuning of basal parameters, V&V, UQ
  - Challenge to provide standard solver and parameter settings for large, realistic problems to ice sheet modelers
  - Extensive preconditioner development and increased coupling is the next stage of work

Recent ice sheet model results using parallel JFNK Trilinos solver in HO CISM: 5 km



Left panel: balance velocities (log10 of m/yr) based on modern-day observations (ice2sea GIS geometry (Bamber, Griggs); SMB from Ettema et al., *GRL*, **36**, 2009)

Right panel: depth-ave. velocity from 1st-order CISM with tuned basal parameters.