Version 2 of the Community Ice Sheet Model

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CESM Land Ice Working Group, 18 June 2014

Contributors

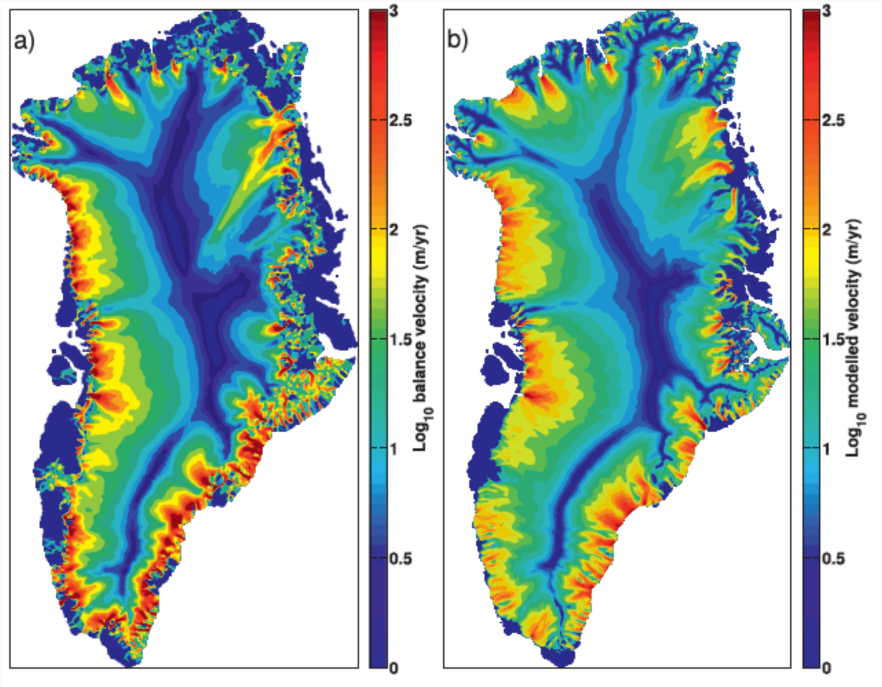
- LANL land-ice team
  - **Steve Price**, **Matt Hoffman**, Jeremy Fyke, John Dukowicz
- DOE SciDAC developers (ISICLES, PISCEES)
  - Pat Worley, Andy Salinger, Bill Sacks, Doug Ranken, Mauro Perego, Matt Norman, Irina Kalashnikova, Kate Evans and others

Outline

- A short history of CISM2
- CISM2 capabilities
- Future plans

Glimmer Community Ice Sheet Model, v. 1

- Documented by Rutt et al. (2009)
  - Shallow-ice dynamics (valid for slow interior flow), implicit diffusion-based thickness solver, serial code
- Included in CESM1
  - Simulates Greenland ice sheet on a 5 km grid, with surface mass balance received from CLM



(a) Greenland balance velocities based on observed thickness and the SMB of Ettema et al. (2009)

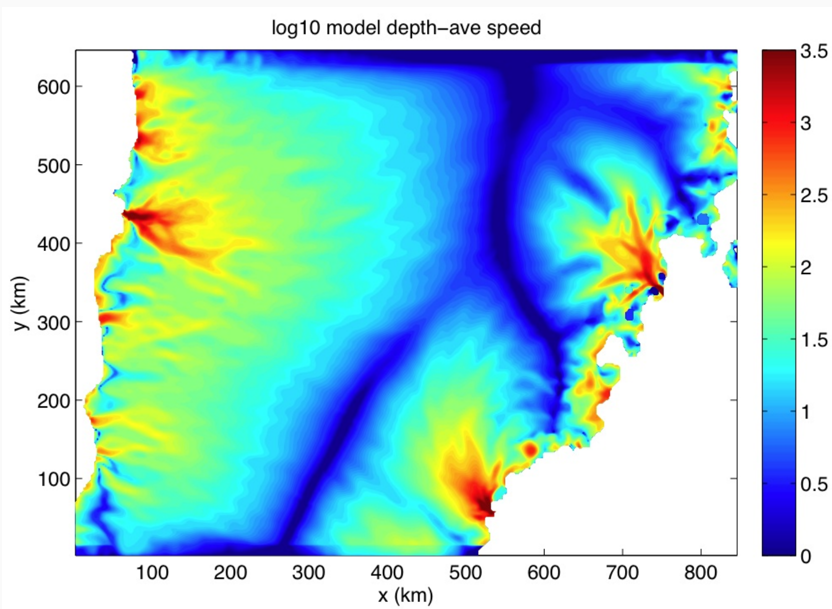
(b) Vertically averaged Greenland velocities simulated by Glimmer-CISM in CESM (top-ranking ensemble member, Lipscomb et al. 2013).

Toward Glimmer-CISM version 2

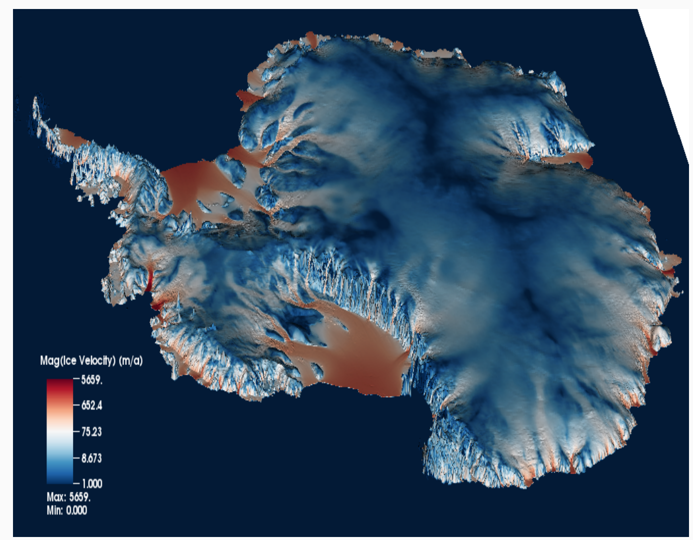
- **2008**: LANL workshop, *Building a Next-Generation Community Ice Sheet Model* (Lipscomb et al., 2009)
  - Consensus on need for **higher-order approximations** of Stokes flow (for ice streams and ice shelves), **finer grid resolution** (requiring scalable parallel codes), **improved physics** (basal sliding, iceberg calving)
- **2009-2012**: DOE Ice Sheet Initiative for Climate Extremes (**ISICLES**). Multiple dynamical cores ("dycores") developed at various institutions.
  - **SEACISM** (Evans, Price, Salinger et al.): Start from Glimmer-CISM1 (Glide dycore, regular structured mesh). Developed a parallel, first-order, finite-difference velocity solver (Glam) with hooks to **Trilinos** solvers
  - **BISICLES** (Martin, Cornford et al.): Created a first-order dycore based on **Chombo** adaptive mesh refinement software

Toward Glimmer-CISM version 2

- New higher-order dycores used for SeaRISE and Ice2sea projects
- SEACISM useful for science (Shannon et al. 2013; Edwards et al. 2014a,b) but underlying discretization is fragile; requires expert users
- BISICLES useful for science (Cornford et al. 2013; Favier et al. 2014); *and* robust; to be linked to CISM as an external dycore in future releases



SEACISM: Greenland depth-averaged ice speed with 3D higher-order solver, 2-km resolution (S. Price)



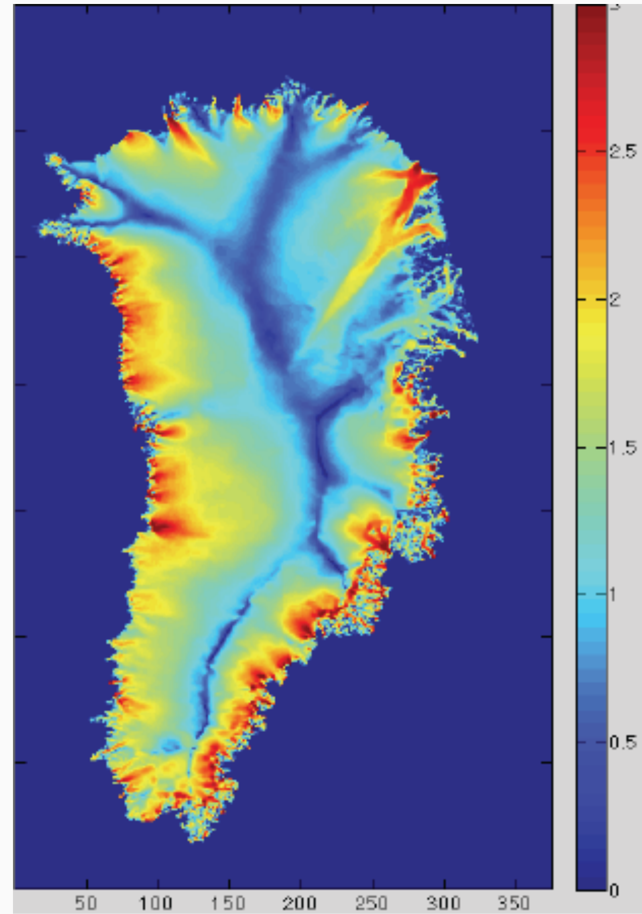
BISICLES: Antarctic ice speed with 2D higher-order solver on an adaptive mesh (Martin et al. 2013; 2014)

Toward Glimmer-CISM version 2

- **2012+**: DOE Predicting Ice Sheet and Climate Evolution at Extreme Scales (**PISCEES**)
    - Continued development of BISICLES
    - FELIX finite-element solver: hierarchy of solvers in unstructured-mesh framework of Model for Prediction Across Scales (MPAS)
    - New dycores subject to DOE code-sharing policies; not for immediate public release
- **2012–2014**: Continuing work on CISM2 (Lipscomb, Hoffman, Price)
    - **Glissade dycore**: Uses parallel infrastructure, Trilinos hooks, and transport/temperature scheme from SEACISM, but modified velocity solver. Solves the same equations as Glam using more robust numerical techniques (Dukowicz et al. 2010, Perego et al. 2012)
    - New test cases, coupling capabilities, documentation, etc.

CISM2: Dynamical core

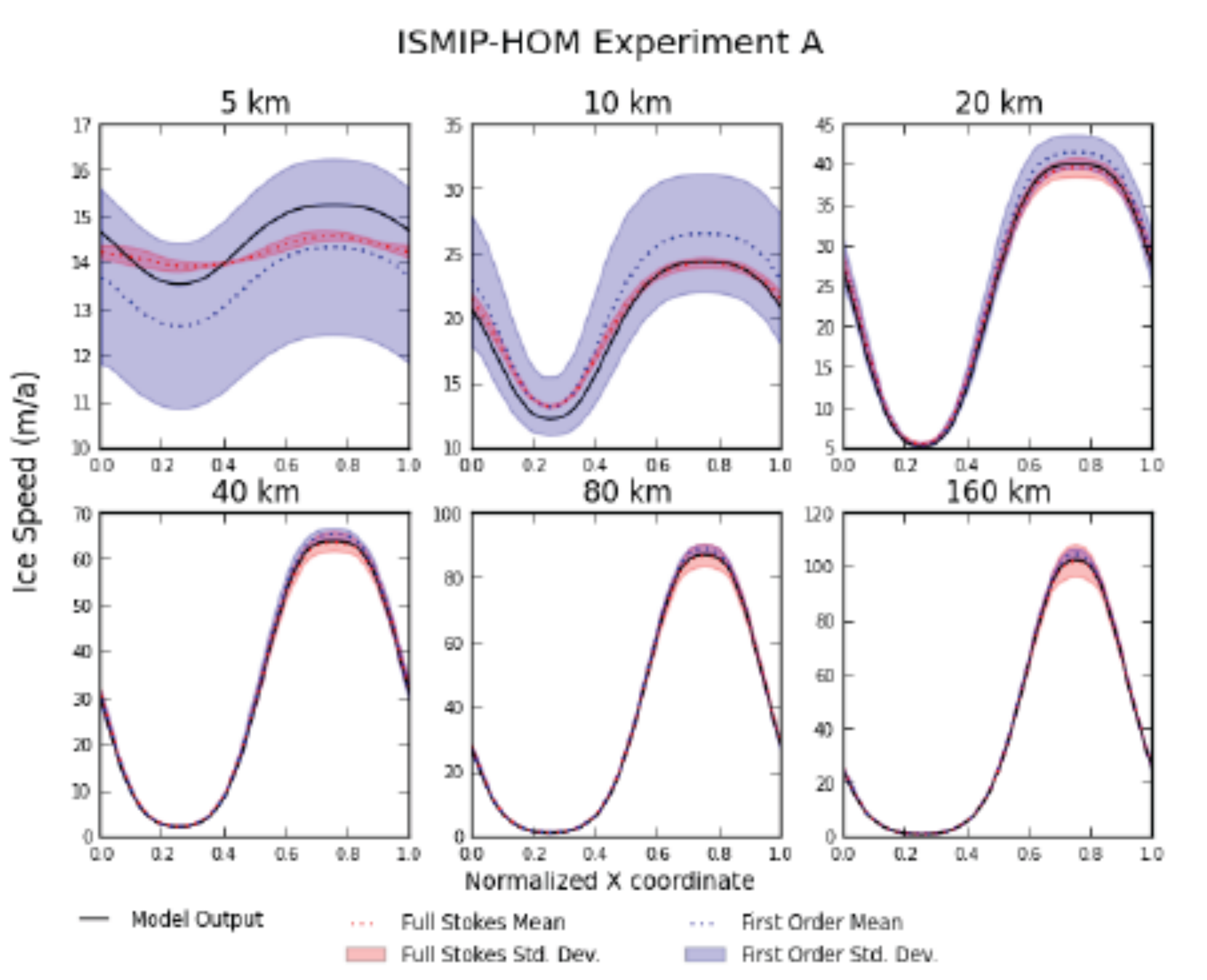
- Same mesh and data structures as Glimmer-CISM 1
- 3D parallel dycore (**Glissade**)
    - First-order velocity solver
        - Verified for various test cases
        - Robust for Greenland simulations on 1/2/4/8 km mesh
        - Native PCG solver, plus hooks to Trilinos solvers
    - Incremental remapping for explicit mass and temperature transport; CFL diagnostics included
    - Vertical temperature solver



Modeled Greenland surface velocities: 4 km mesh, log scale, basal traction tuned to fit observations (S. Price)

CISM2: ISMIP-HOM

- Excellent agreement with ISMIP-HOM community benchmarks for higher-order models (Pattyn et al. 2008)



ISMIP-HOM Test A: Sinusoidal pattern in basal topography at 6 grid sizes (Glissade output shown by black lines)

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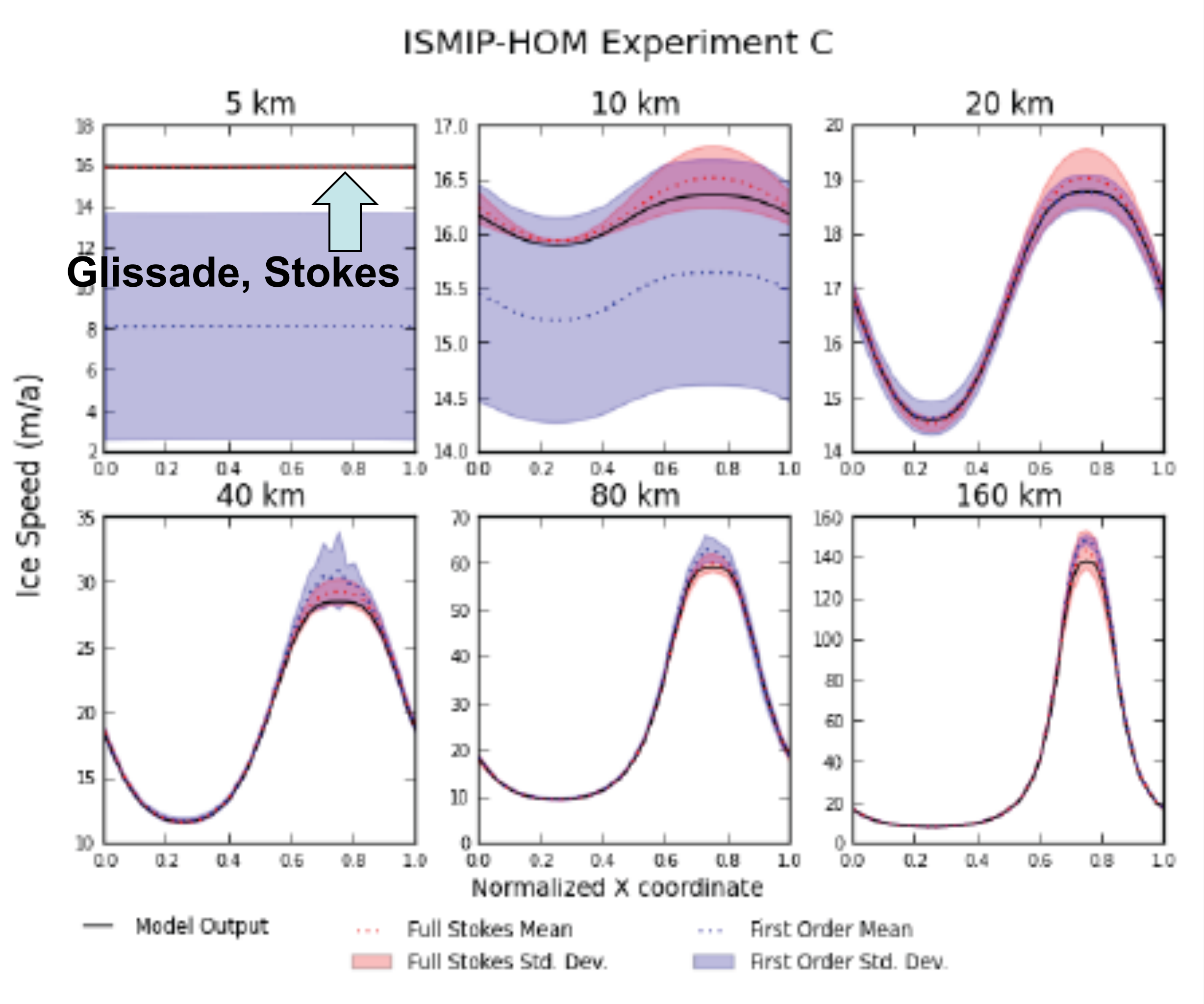
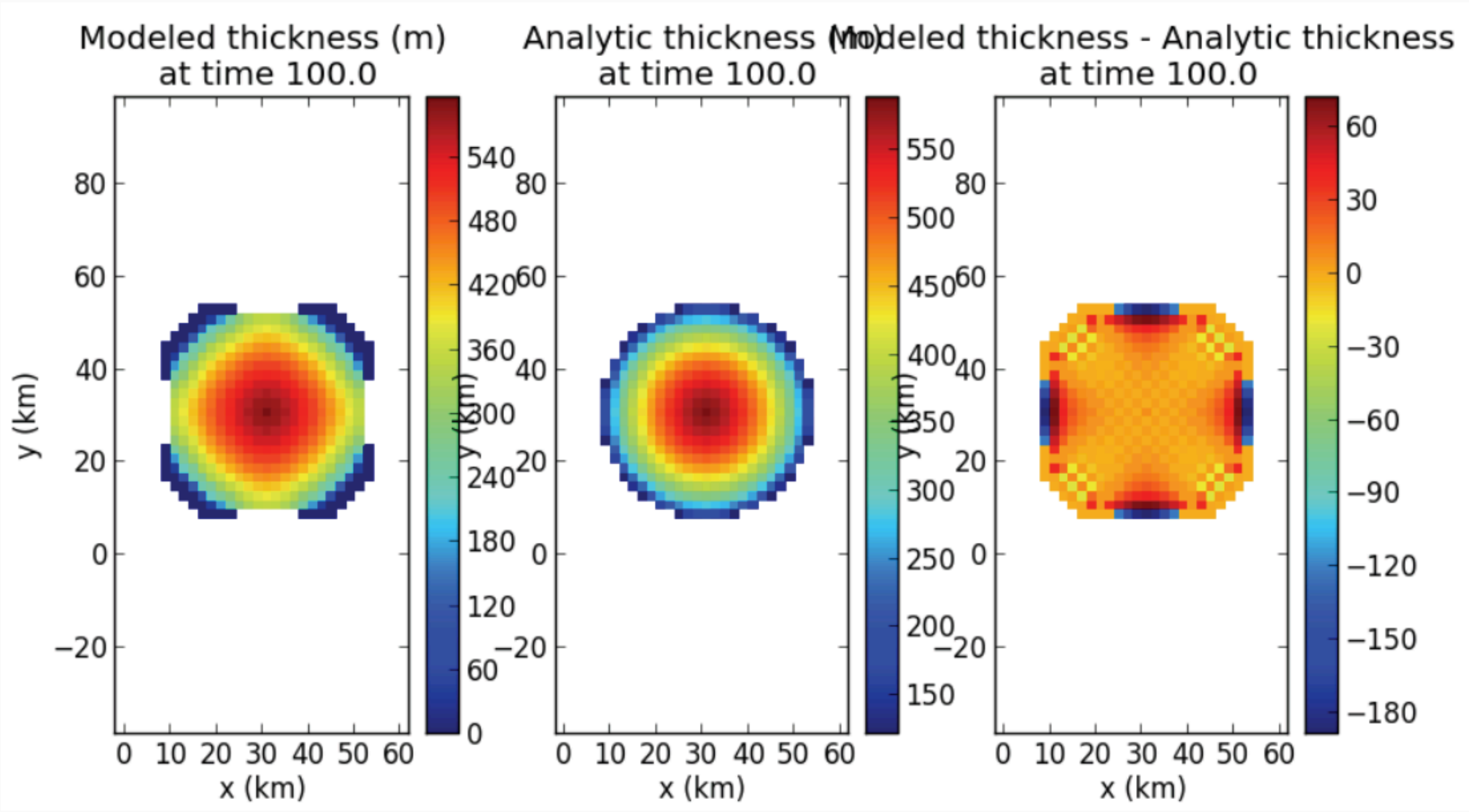


ISMIP-HOM Test C: Sinusoidal pattern in basal traction at 6 grid sizes (Glissade output shown by black lines)

CISM2: Halfar SIA test

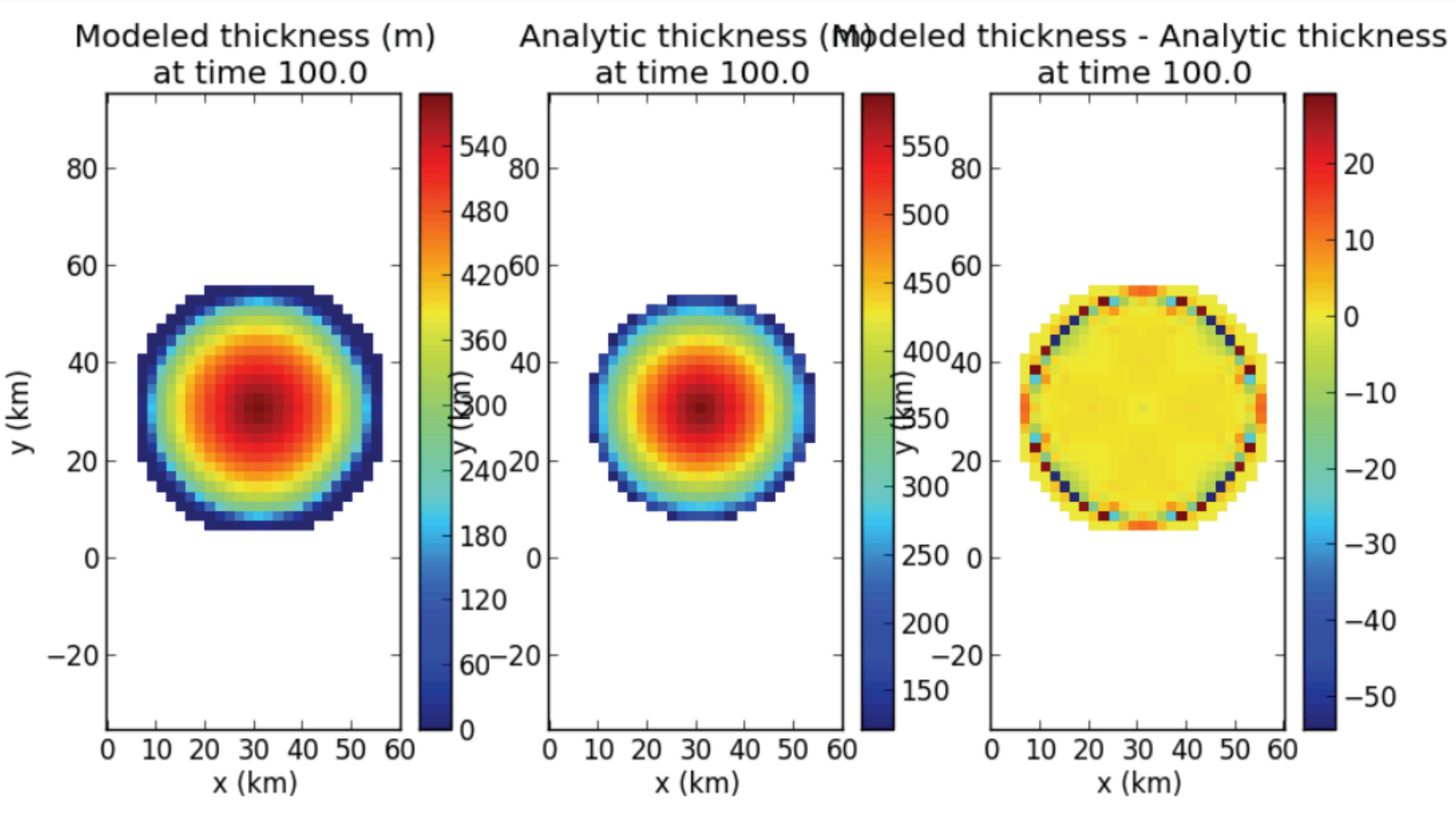
- **Halfar test**: Time-dependent analytic solution for shallow-ice dynamics
- Initial results showed checkerboard noise in thickness field



rms error = 44 m

CISM2: Halfar SIA test

- The checkerboard noise is a B-grid artifact: This mode is invisible to the dynamics when the surface elevation at four adjacent corners is averaged to give ∇s.
- Using a second-order upstream gradient removes this noise.



rms error = 11 m

CISM2: Solver options

There are two parallel options for iterative solution of linear systems of equations:

- Native Fortran preconditioned conjugate gradient (PCG) solver
  - Preconditioned using the local shallow-ice equations
  - Chronopoulos-Gear algorithm for fewer global sums
- Solve with Trilinos (trilinos.sandia.gov)
  - Many options available
  - Default is Block GMRES with ILU preconditioning

Both are robust for flow dominated by vertical shear (e.g., Greenland Ice Sheet), but can fail to converge for flow dominated by horizontal-plane stresses (e.g., Antarctic ice shelves).

CISM2: Parallel performance

Greenland Ice Sheet, 4-km mesh, 20 timesteps, dt = 0.05 yr, 2048 processes on DOE OLCF Titan (thanks to Pat Worley):

- **Native PCG solver**: 151 wallclock seconds
- **Trilinos GMRES**: 507 wallclock seconds (3.4*x* slower)

Why is the native solver faster?

- Fewer global reductions (only 1 per linear iteration)
- Lower setup costs
- Fortran90 v. C++?

But Trilinos offers many solver options that have not yet been tested (e.g., ML for multigrid preconditioning). These may run faster, scale better, and be more robust for harder problems.

CISM2: Other improvements

- **New test cases** for shallow-ice and higher-order models
  - Halfar (SIA), ISMIP-HOM, ice shelf (idealized, Ross), ice stream
  - Python tools for plotting results and comparing to standard solutions
- Replacement of Autotools build with more robust **cmake build**
  - Supported for Titan, Hopper, Yellowstone, Mac, Linux
- **Changes in Glint interface** to support two-way coupling with climate models
- **New driver** allowing for more flexible integration of external dycores (FELIX, BISICLES)
- **New documentation** (in progress)
- Ready for release pending documentation and code cleanup

CISM2 in CESM

- Bill Sacks ported the CISM2 code base to CESM in 2013
- He has now run the parallel code successfully on yellowstone for 3 model years.
- Exact restart is not working; need to fix roundoff-level differences.
- Aiming for 2015 release in CESM 1.3

Wish list (CISM 2.1?)

- **More efficient and robust solver for ice shelves** (e.g., West Antarctica)
  - Current preconditioners (SIA, ILU) work well only where the flow is dominated by vertical shear
  - Multigrid preconditioning may be more robust and scalable
- **Improved physics**
  - Enthalpy-based thermodynamics (starting to test CU code)
  - Better grounding-line physics (Leguy et al. scheme?)
  - Evolving basal hydrology (M. Hoffman)
  - More realistic calving
  - Parallelized isostasy


Thank you