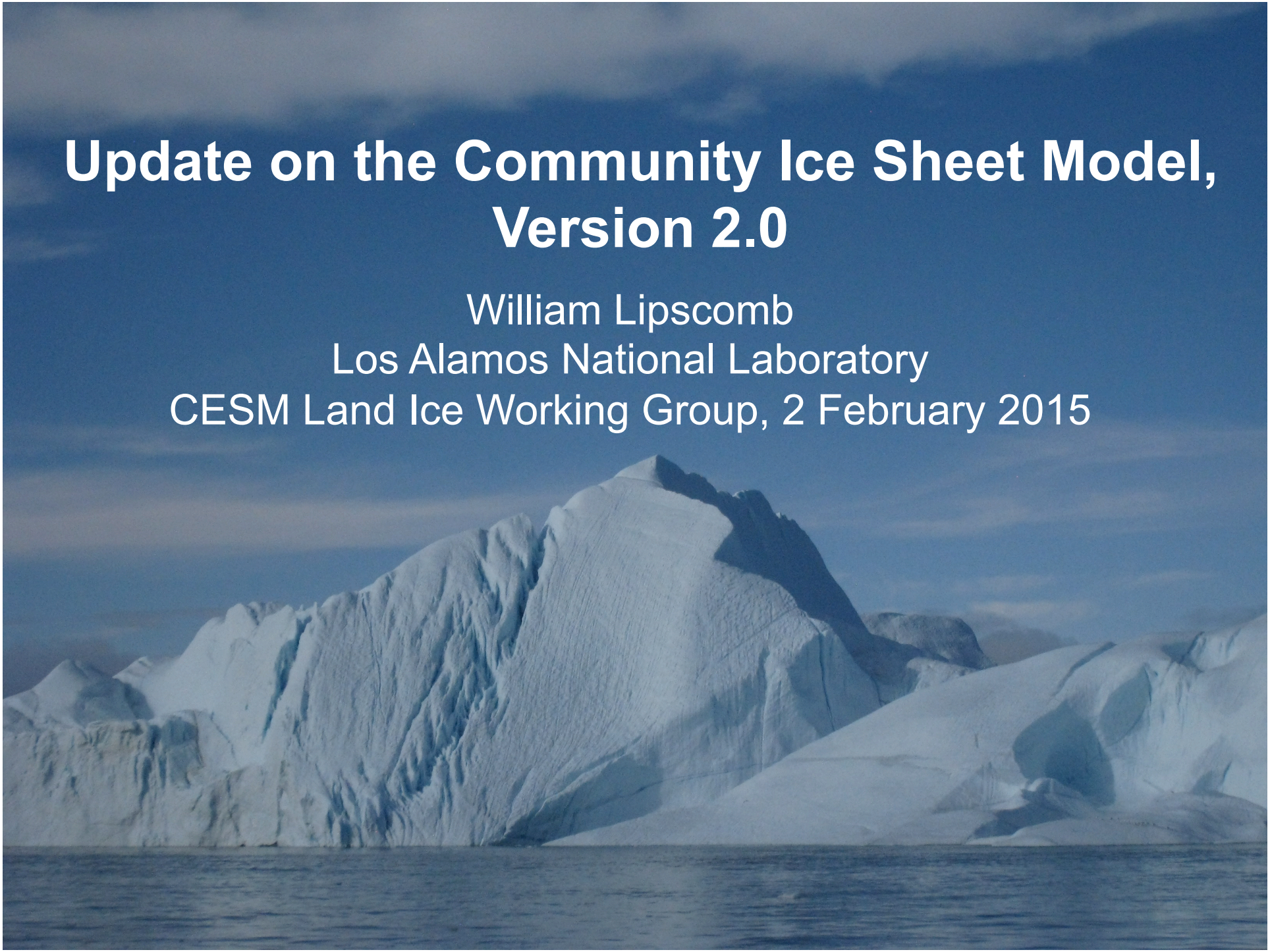


Update on the Community Ice Sheet Model, Version 2.0

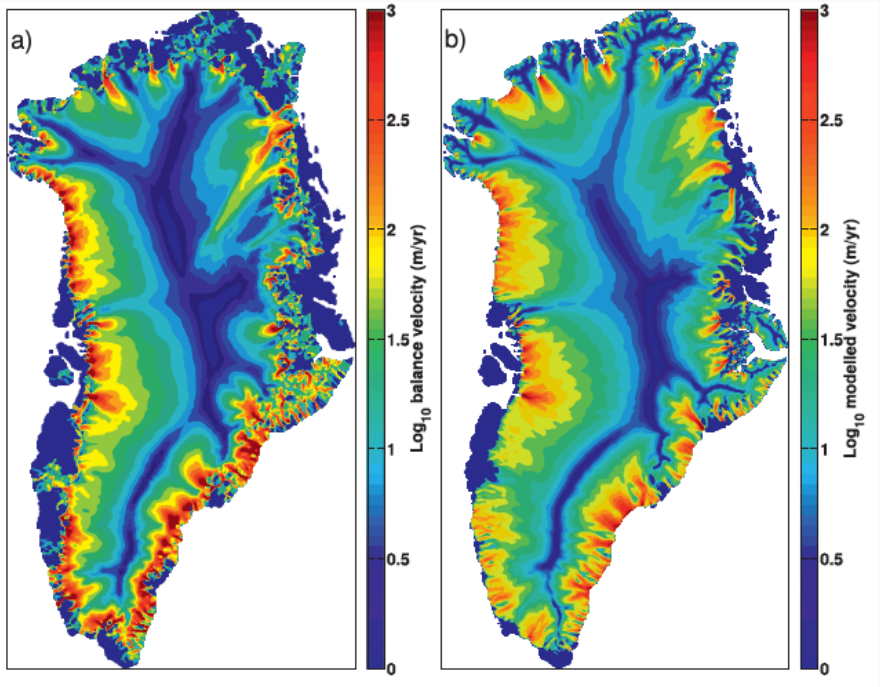
William Lipscomb
Los Alamos National Laboratory
CESM Land Ice Working Group, 2 February 2015

CISM2 code authors

- **LANL:** Bill Lipscomb, Steve Price, Matt Hoffman, Jeremy Fyke, Doug Ranken, Erin Barker
- **ORNL:** Kate Evans, Jeff Nichols, Matt Norman, Trey White, Pat Worley
- **SNL**: Andy Salinger, Irina Kalashnikova, Ryan Nong, Mauro Perego
- **LBL:** Dan Martin
- **NYU**: J.-F. Lemieux
- **NCAR:** Bill Sacks, Jon Wolfe
- **U. Montana:** Jesse Johnson, Tim Bocek, Josh Campbell, Glen Granzow, Brian Hand, Tim Wylie
- **Glimmer developers:** Magnus Hagdorn, Tony Payne, Ian Rutt, Felix Hebeler

Glimmer Community Ice Sheet Model, v. 1

- Documented by Rutt et al. (2009)
  - Shallow-ice approximation (**Glide** dycore, valid for slow 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

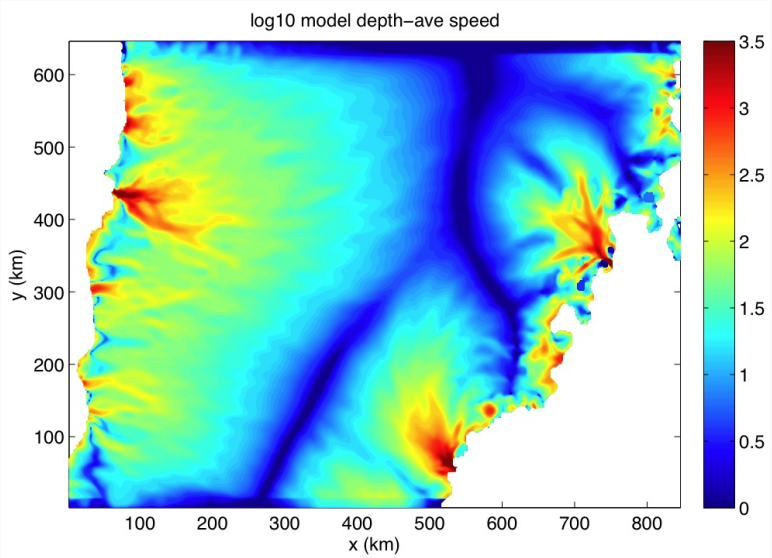


(a) Greenland balance velocities based on observed thickness and the SMB of Ettema et al. (2009)

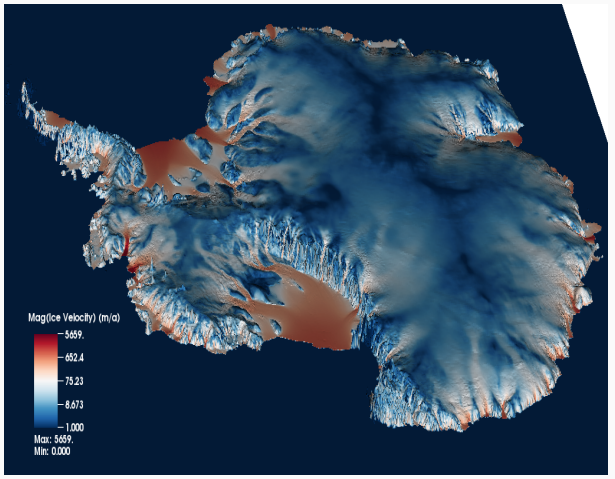
(b) Vertically averaged Greenland velocities simulated by Glimmer-CISM in CESM (top-ranking ensemble member, Lipscomb et al. 2013).

Toward CISM version 2

- **BISICLES** (Martin, Cornford et al.): Created a higher-order dycore based on **Chombo** adaptive mesh refinement software; linked to CISM
- **SEACISM** (Evans, Price, Salinger et al.): Starting from Glide, developed a parallel, higher-order, finite-difference velocity solver, **Glam**, with hooks to **Trilinos** solvers. Fragile discretization; requires expert users.
- **Glissade**: Glam successor, using more robust finite-element techniques



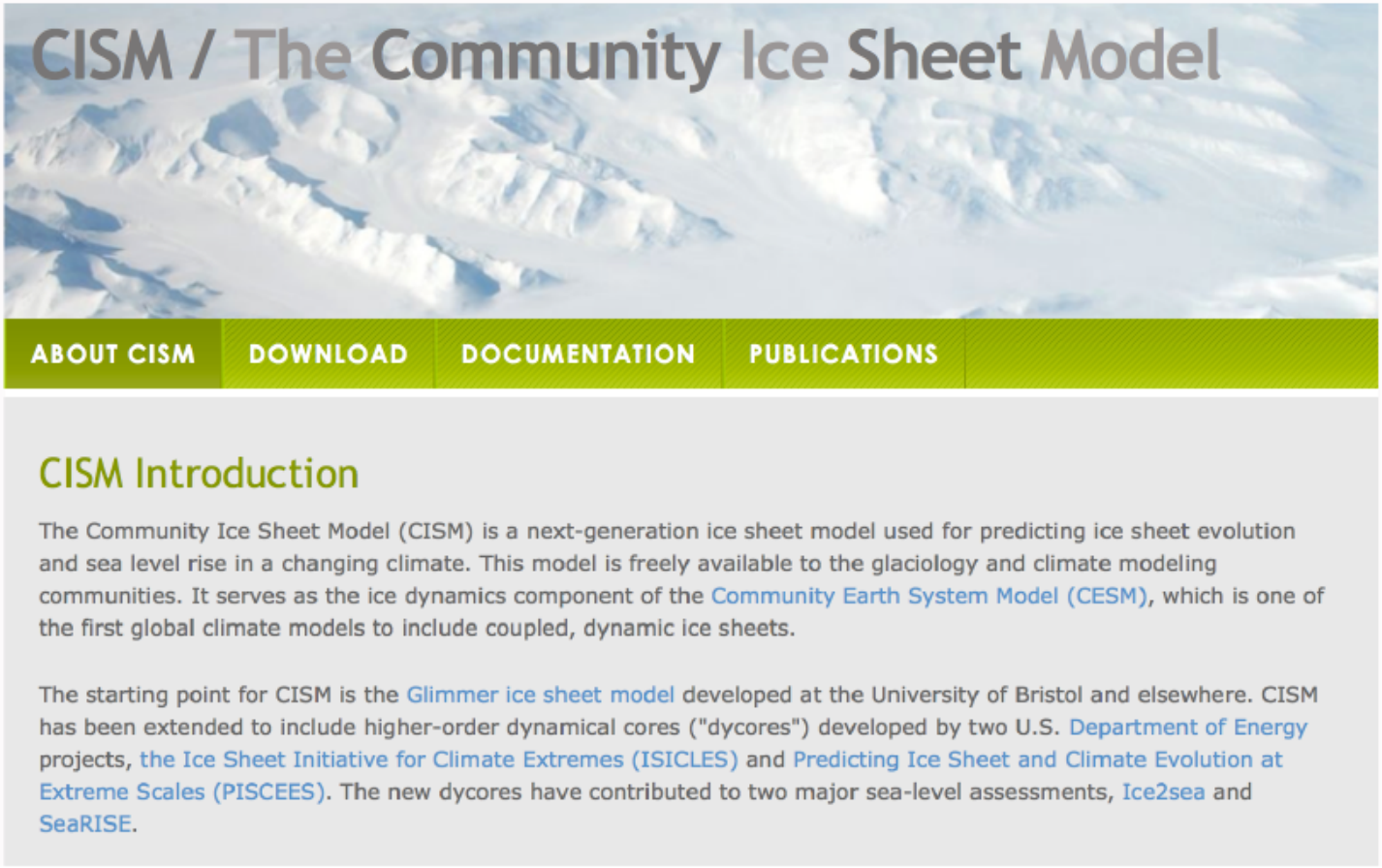
SEACISM: Greenland depth-averaged ice speed with 3D higher-order solver, 2-km resolution (S. Price)



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

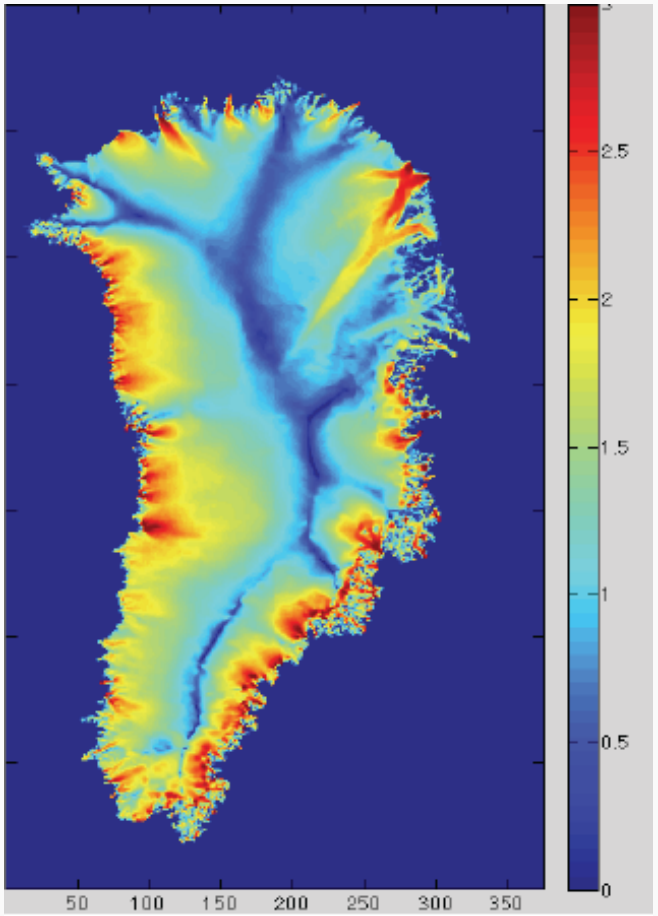
October 2014: CISM2 release

- Freely available at http://oceans11.lanl.gov/cism/
- **Git repo** for ongoing development at https://github.com/cism



CISM2: Dynamical core

- Same mesh and data structures as Glimmer
- **3D parallel dycore (Glissade)**
  - Blatter-Pattyn higher-order velocity solver, plus L1L2, SSA, SIA
  - Verified for standard 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



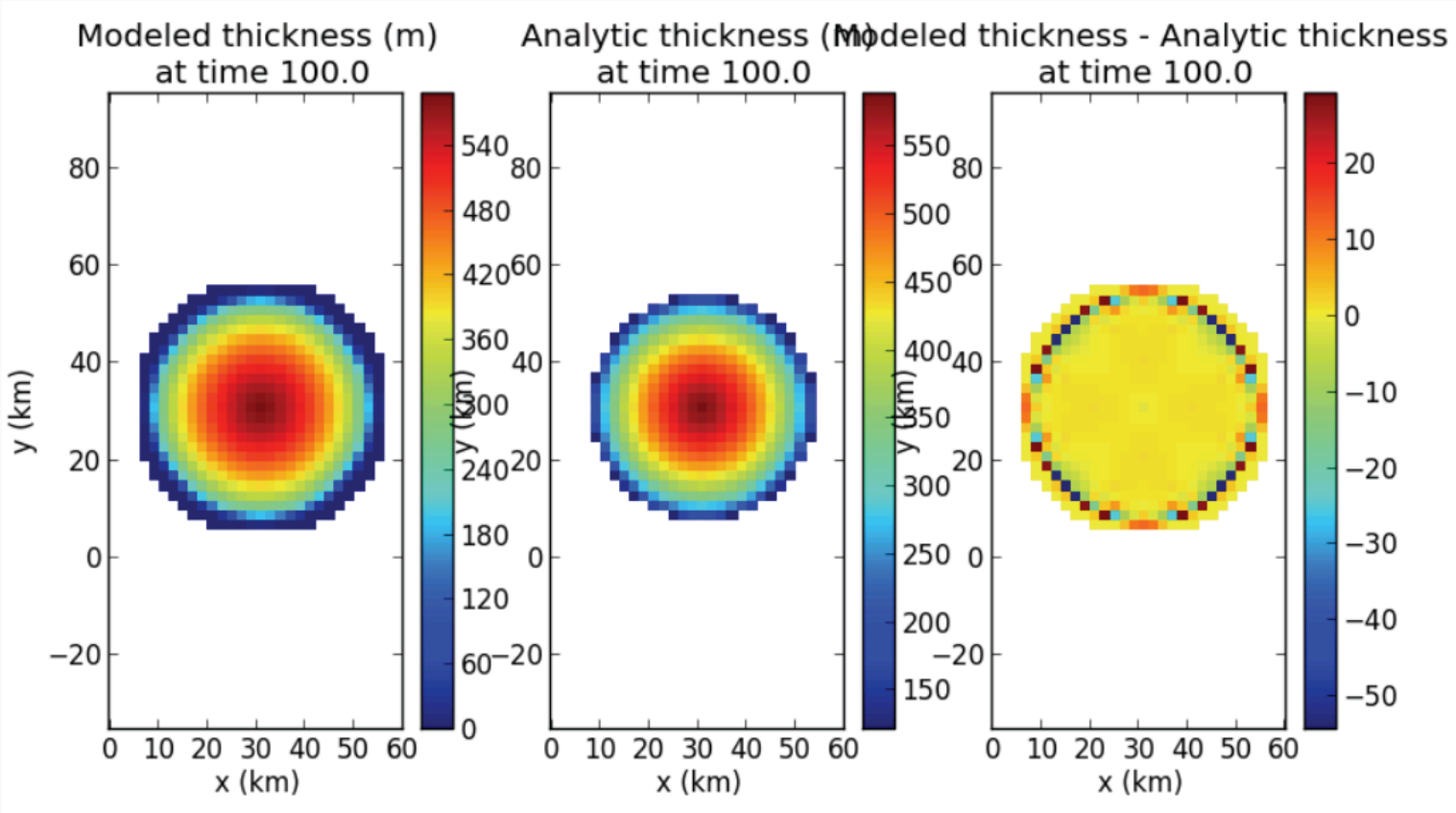
Modeled Greenland surface velocities: 4 km mesh, log scale, basal traction tuned to fit observations (S. Price)

CISM2: Other improvements

- **New test cases** for shallow-ice and higher-order models
- **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 (BISICLES, Felix)
- **Updated documentation:** **http://oceans11.lanl.gov/cism/data/cism_documentation_v2.0.pdf**

CISM2: Halfar shallow-ice test

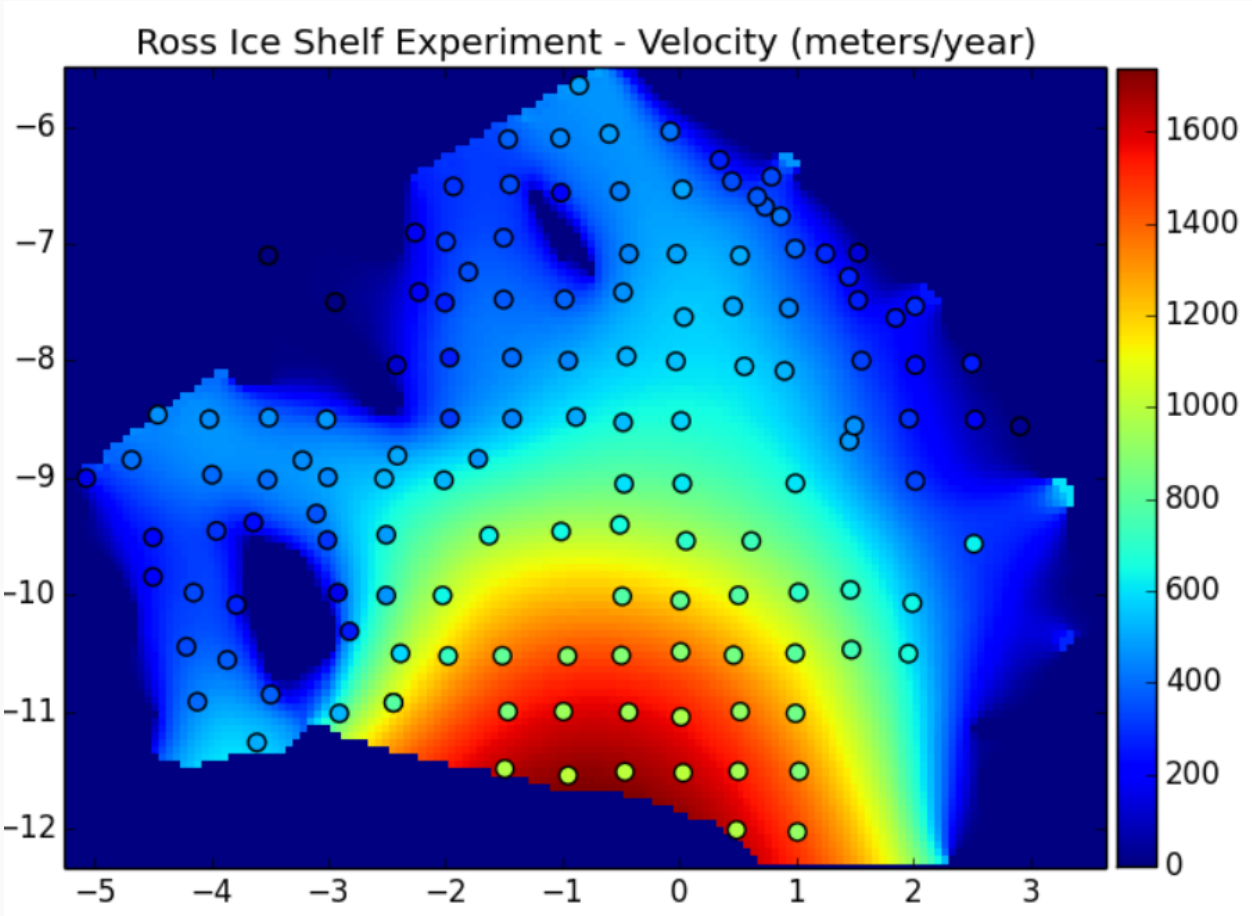
- Time-dependent analytic solution for shallow-ice dynamics; used to test Glissade SIA with explicit transport scheme
- Using a second-order upstream gradient to remove checkerboard noise in thickness field



rms error = 11 m

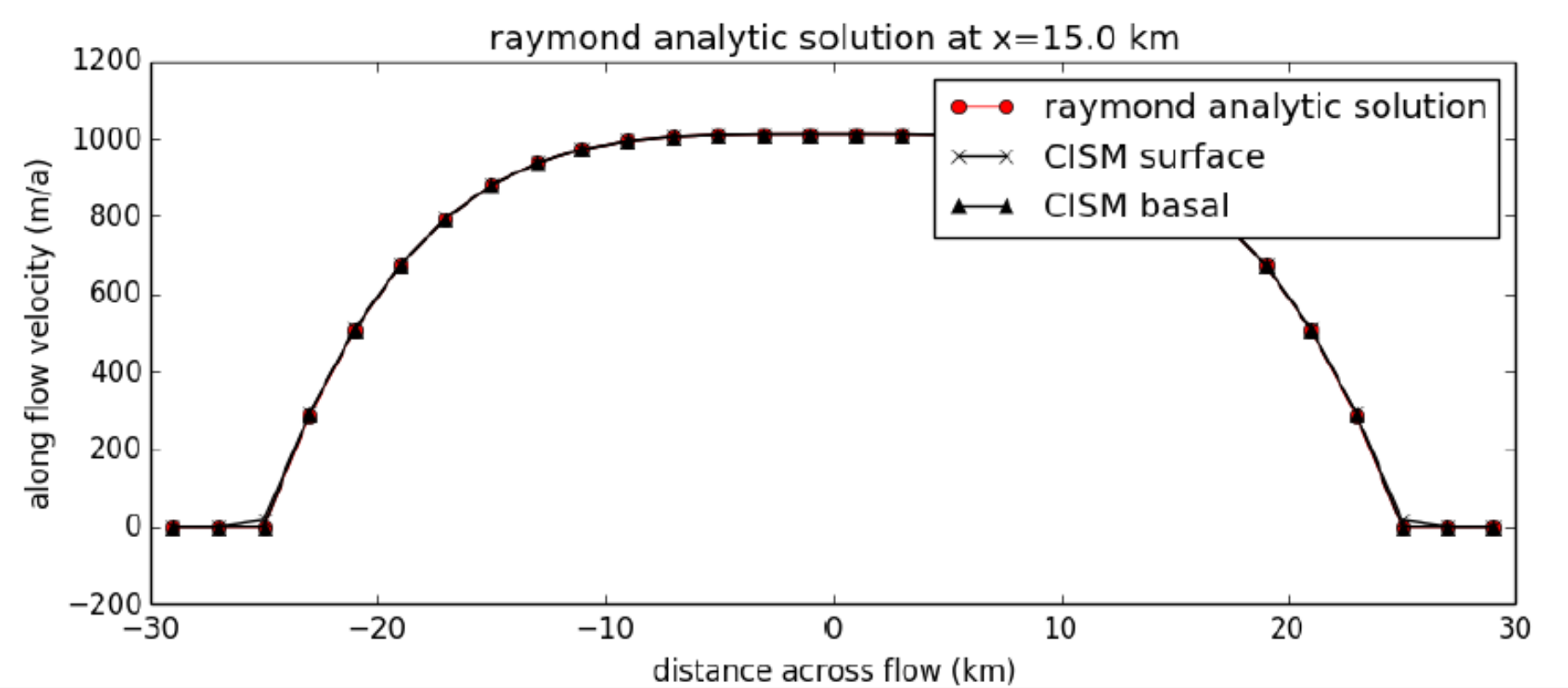
CISM2: Ross Ice Shelf test

- Observation/model comparison for shallow-shelf dynamics
- Accurate results for SSA, L1L2 and Blatter-Pattyn solvers



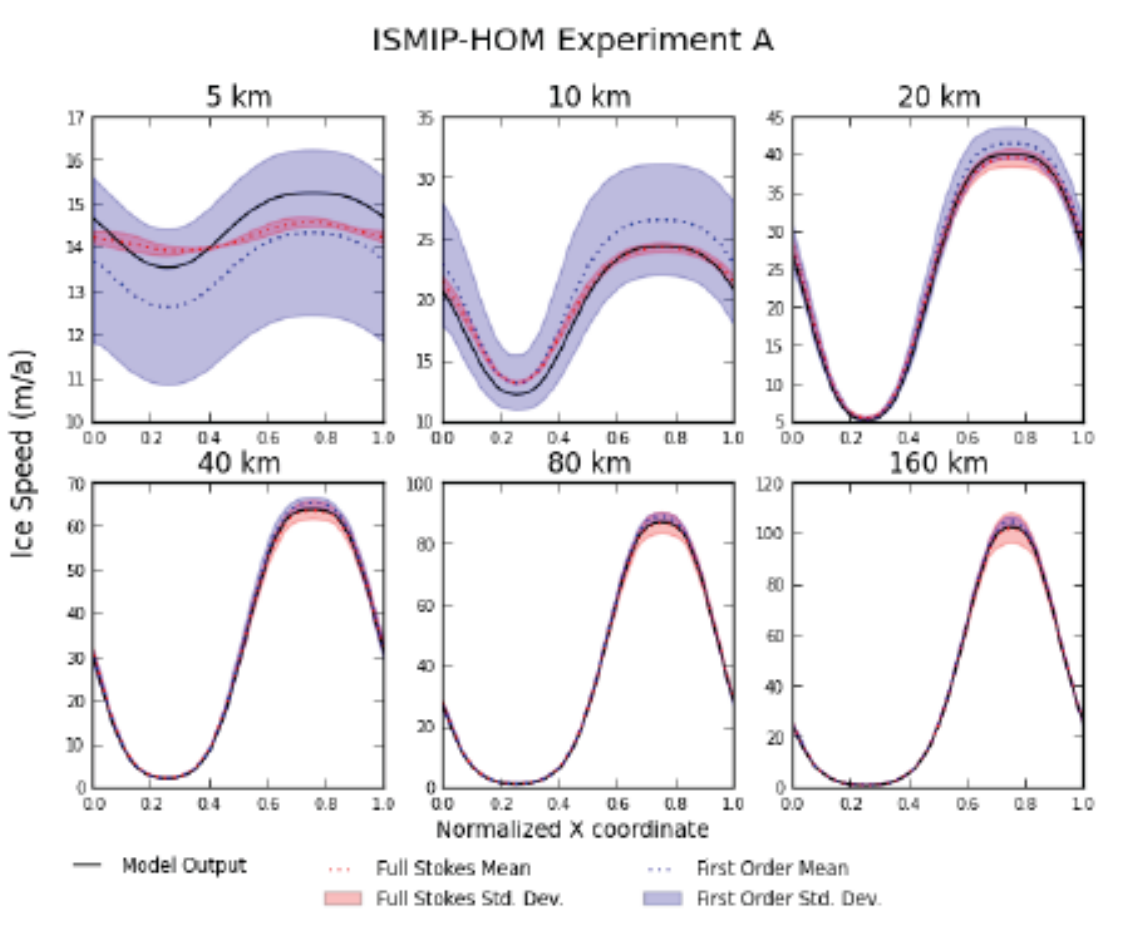
CISM2: Raymond ice stream test

- Tests model's ability to resolve sharp shear margins
- Glissade higher-order solver closely matches the Raymond (2000) analytic solution



CISM2: ISMIP-HOM tests

- Compare higher-order model results to community benchmarks (Pattyn et al. 2008) for problems with small-scale variations in topography and basal traction
- Glissade's Blatter-Pattyn solver agrees well with benchmarks



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

CISM2: Glint coupling interface

- Glimmer code supported coupling to climate models using a **positive-degree-day scheme** (temperature and precipitation from climate model); this code remains in CISM2
- CISM2 adds support for a **surface-mass-balance scheme**
  - SMB and surface temperature received from climate model in multiple elevation classes, downscaled to local topography
  - Ice sheet fractional area and surface elevation returned to climate model, along with calving and runoff fluxes
- We plan to include CISM2 in **CESM2** (2016 release)
  - Diagnostic ice sheets (1-way coupling) by default
  - 2-way ice-sheet/climate coupling supported for **ISMIP6** (Ice Sheet Model Intercomparison Project for CMIP6)
  - Bill Sacks will say more about CISM/CESM coupling

Recent development (CISM 2.1)

- **Enthalpy-based thermodynamics** (code developed at CU)
- **Grounding-line parameterization**
  - Smoother, more accurate transition between grounded and floating ice, as required to model marine ice sheets (e.g., MISMIP test cases)
- **Depth-integrated viscosity solver** (Goldberg 2011)
  - About as fast as L1L2, but more accurate and robust for some problems

We hope to have these ready for CESM2.

DOE ice sheet model development

PISCEES: Predicting Ice Sheet and Climate Evolution at Extreme Scales, 2012-2017, PIs Steve Price and Esmond Ng

- Continued **BISICLES** development (external dycore for CISM)
- **FELIX**: hierarchy of finite-element-based velocity solvers on an unstructured mesh
- **MPAS Land Ice**: New ice sheet model in the framework of the Model for Prediction Across Scales
  - Uses Felix solvers
  - Other dynamics and physics adapted from CISM to the unstructured MPAS mesh
  - Ice sheet component of DOE Accelerated Climate Model for Energy (**ACME**)
- New codes subject to DOE code-sharing policies; not for immediate public release

Summary

- CISM2 is freely available to the community at http://oceans11.lanl.gov/cism/
- CISM2 has been coupled to CESM and will be used for CMIP6 climate simulations
- The model has been extensively verified for standard test cases and is now being used for more realistic problems (e.g., Greenland ice sheet)
    - More development is needed to support robust simulations of the Antarctic ice sheet
- New users and developers are welcome!