Update on Sandia *Albany/FELIX* First-Order Stokes (FELIX-FO) Solver

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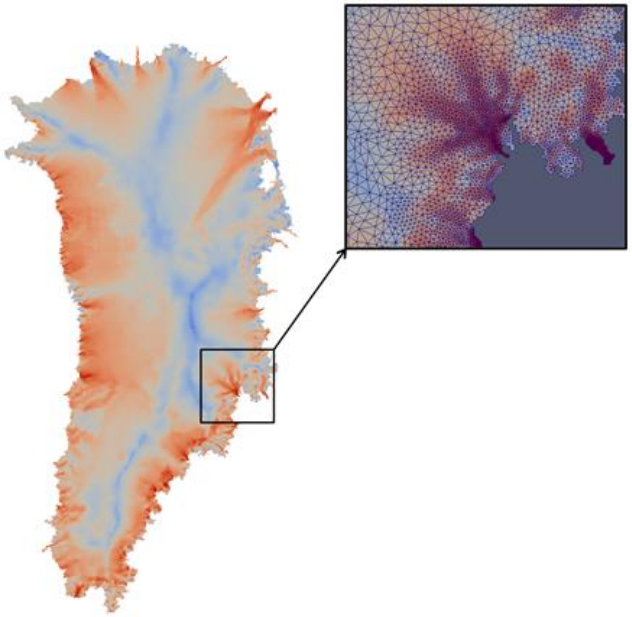
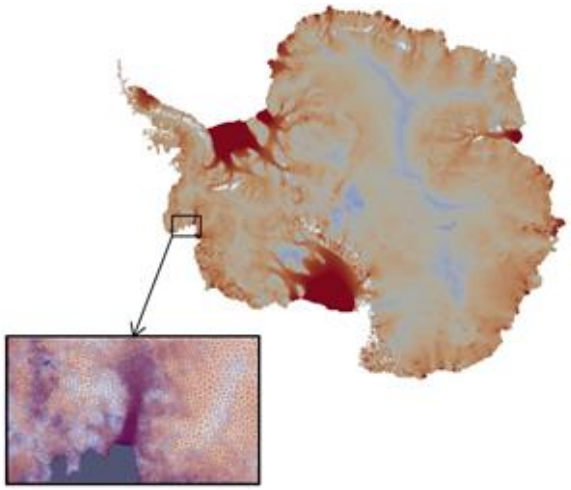


In collaboration with Mauro Perego, Andy Salinger, Ray Tuminaro, Steve Price, Matt Hoffman, Mike Eldred, John Jakeman, Irina Demeshko and Tobias Wiesner.



Thursday, November 5, 2015
PISCEES Project Meeting
Albuquerque, NM

Sandia National Laboratories

FY15 Progress Highlights

<u>Sandia's Role in the PISCEES Project:</u> to **develop** and **support** a robust and scalable unstructured grid finite element land ice solver based on the "First-Order" (FO) Stokes approximation→*Albany/FELIX**

***<u>Albany/FELIX, CISM-Albany, MPAS-Albany</u>* <u>Progress & Future Work</u> (this talk):**

- *Albany/FELIX* is ***verified***, ***scalable***, ***robust.***
- *Albany/FELIX is* ***portable*** to next-generation machines via *Kokkos*.
- We have written/are writing several ***journal articles*** on *Albany/FELIX.*
- We have looked at the effect of ***earth curvature*** using stereographic projection.
- *Albany/FELIX* is ***coupled*** to *MPAS* and *CISM*; mostly coupled to ACME (via *MPAS*).
  →We have developed a ***stable semi-implicit coupling method*** for thickness-FO Stokes (implemented in *MPAS-Albany*).
- Codes are ***running*** on *Hopper, Edison, Titan, Mira*.

*FELIX = Finite Elements for Land Ice eXperiments

<u>Additional Progress & Future Work</u> (other talks):

- ***Deterministic inversion*** (talk by M. Perego).
- ***Uncertainty quantification:*** Bayesian calibration, forward propagation of uncertainty (talk by J. Jakeman).

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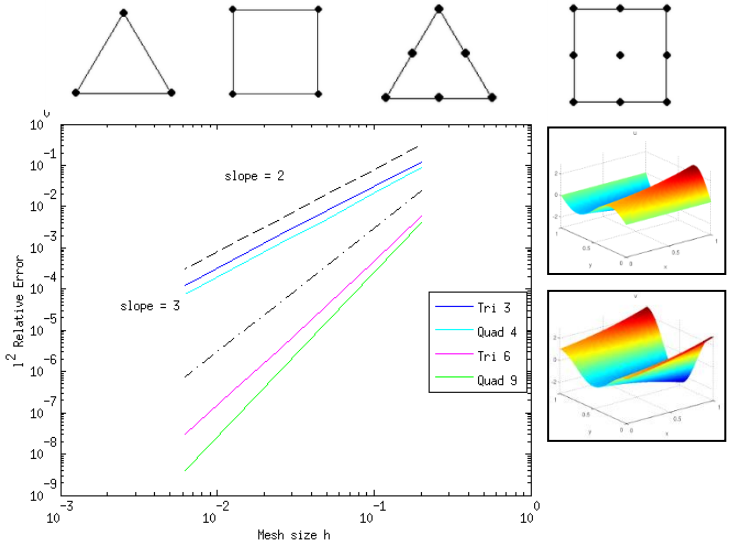
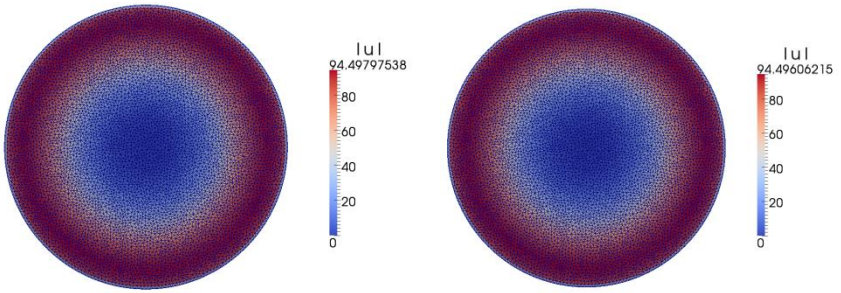
Verification of *Albany/FELIX*

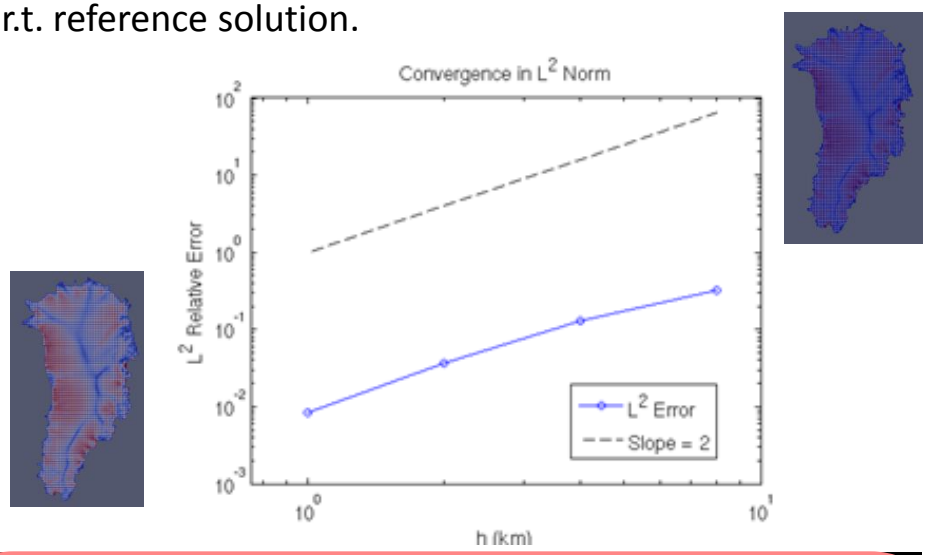
Stage 1: solution verification on 2D MMS problems.



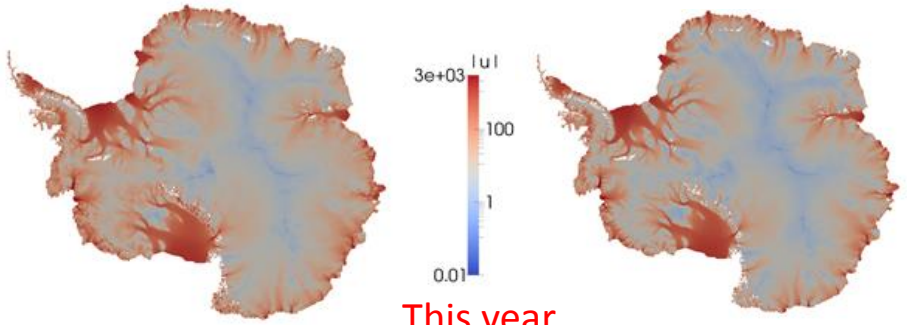
Stage 2: code-to-code comparisons on canonical ice sheet benchmarks (*Albany/FELIX* – left; *LifeV* – right).



Stage 3: full 3D mesh convergence study on Greenland w.r.t. reference solution.

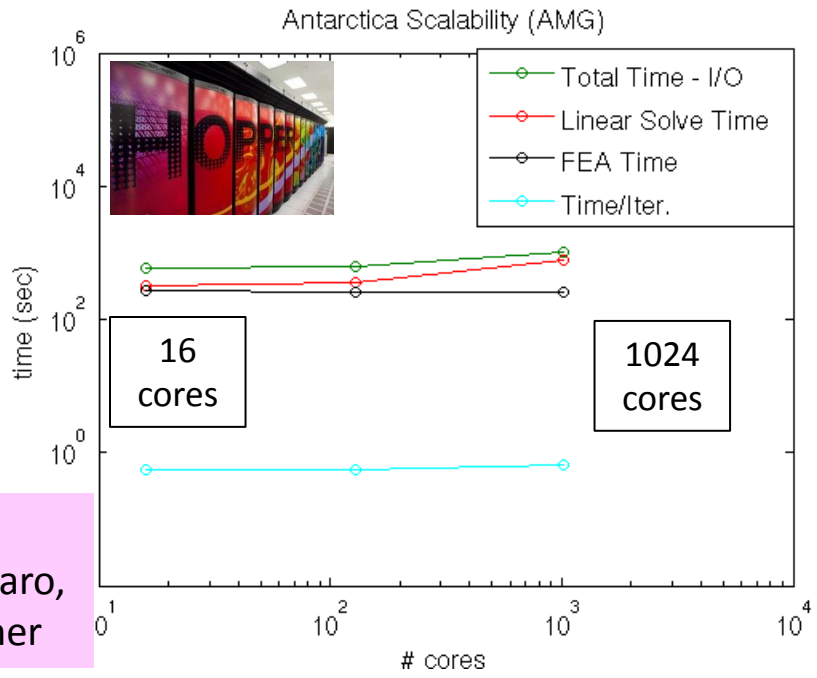


Stage 4: reasonable solutions for large-scale realistic GIS & AIS problems (*Albany/FELIX* – left; reference solution – right)



Scalability via Algebraic Multi-Grid Preconditioning with Semi-Coarsening

We achieve ***excellent scalability*** (even with ice shelves!) via new algebraic multi-grid (AMG) preconditioner with semi-coarsening.



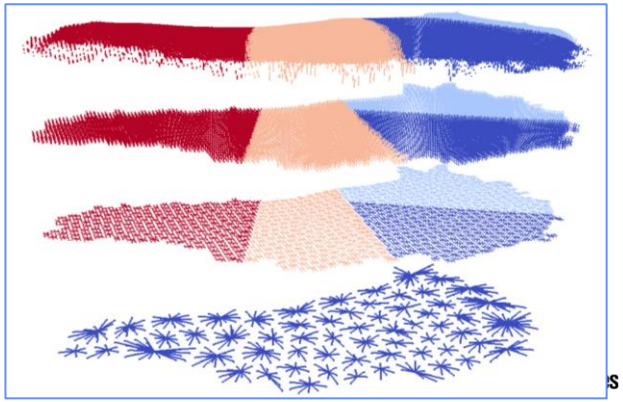
FY15 progress:

- Demonstration of good ***scalability/ performance*** of AMG solver on Antarctica: 30x faster than ILU solver!
- 3 ***papers*** featuring new AMG preconditioner.
- New AMG preconditioner has been implemented in ***MueLu*** (T. Wiesner).

with R. Tuminaro, T. Wiesner

Planned work:

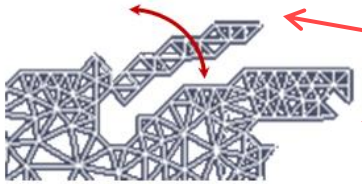
- Speeding up *MueLu* AMG preconditioner (*MueLu* solver slower than *ML*).
- Performance studies (optimizations?) on new architectures (template on 3rd dimension?) and/or with dynamical cores.



I. Tezaur, M. Perego, A. Salinger, R. Tuminaro, and S. Price, *GMD,* 2015.
I. Tezaur, R. Tuminaro, M. Perego, A. Salinger, S. Price, *Procedia CS,* 2015.
R. Tuminaro, M. Perego, I. Tezaur, A. Salinger, S. Price, *SISC*, 2015.

Improved Linear Solver Performance through Removal of Hinged Peninsulas

Islands/hinged peninsulas lead to **solver failures**



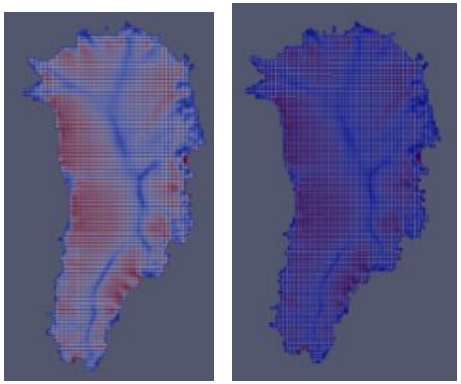
FY15 Progress:

- An algorithm has been developed to detect/remove ***hinged peninsulas*** & islands based on coloring & repeated use of connected component algorithms.
- Solves ***~2x faster*** with hinges removed.

Planned work:

- Integration of algorithm for hinge removal into dynamical cores?

with R. Tuminaro



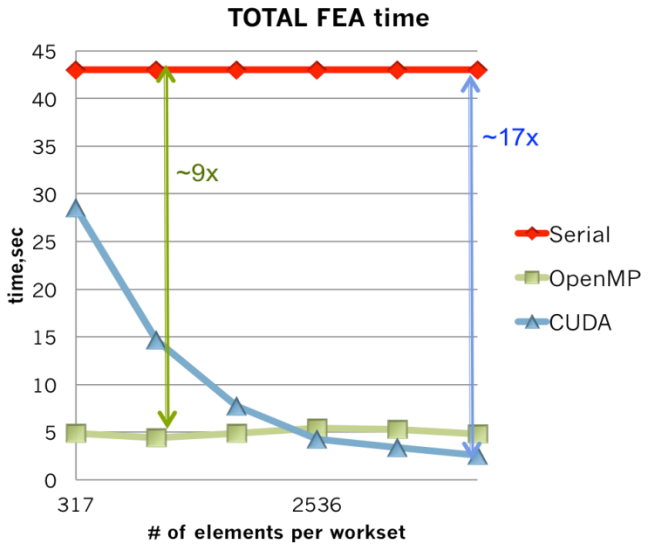
Greenland Problem

Resolu-tion	ILU – hinges	ILU – no hinges	ML – hinges	ML – no hinges
8km/5 layers	878 sec, 84 iter/solve	693 sec, 71 iter/solve	254 sec, 11 iter/solve	220 sec, 9 iter/solve
4km/10 layers	1953 sec, 160 iter/solve	1969 sec, 160 iter/solve	285 sec, 13 iter/solve	245 sec, 12 iter/solve
2km/20 layers	10942 sec, 710 iter/solve	5576 sec, 426 iter/solve	482 sec, 24 iter/solve	294 sec, 15 iter/solve
1km/40 layers	--	15716 sec, 881 iter/solve	668 sec, 34 iter/solve	378 sec, 20 iter/solve

Performance Portability via *Kokkos*

Performance portability achieved through ***Kokkos*** programming model/*Trilinos* library.

Kokkos abstractions allow device-specific memory layout and parallel kernel launch → same code can run on diverse devises with different memory models (multi-core, many-core, GPUs)



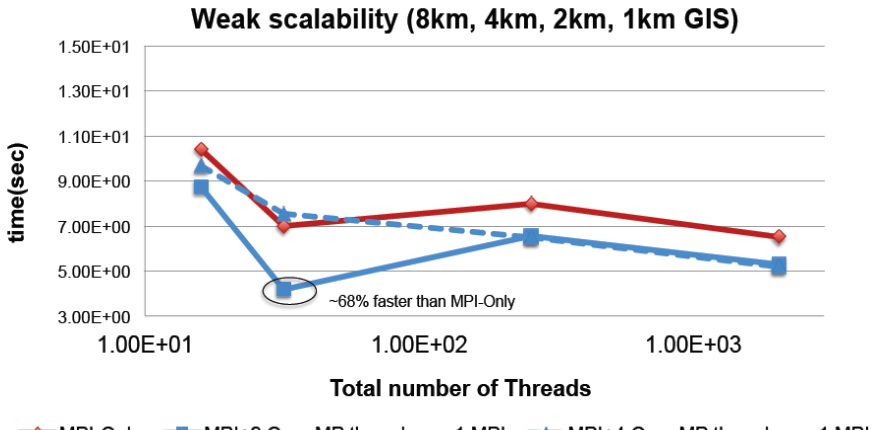
FY15 Progress:

- ***Finite element assembly (FEA)*** in *Albany* has been converted to *Kokkos.*
- Demonstrated performance portability with ***CUDA/OpenMP*** on Sandia clusters; with ***OpenMP*** on *Titan*.

with I. Demeshko

Planned work:

- Journal ***article*** in preparation (I. Demeshko).
- Running on **GPUs** of *Titan*: awaiting gcc-4.7.2 compiler support from Cray.



I. Demeshko, A. Salinger, W. Spotz, I. Tezaur, in prep for *J. HPC Appl.,* 2015.

FO Stokes Equations on Spherical Grids

Current ice sheet models are derived using ***planar geometries*** (reasonable, especially for Greenland)… The effect of Earth's ***curvature*** is largely unknown and may be nontrivial for Antarctica!

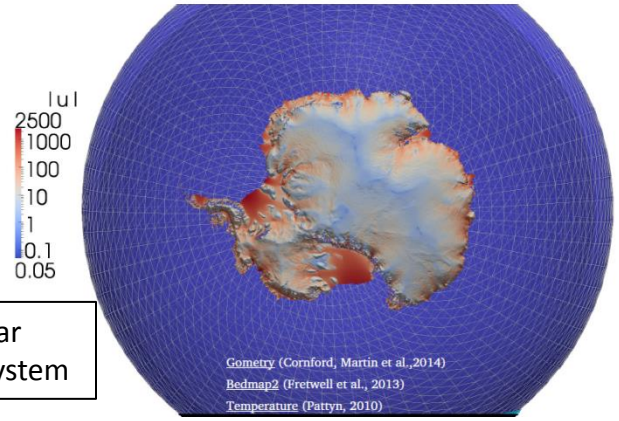
FY15 Progress:

- We have derived a FO Stokes model on sphere using ***stereographic projection*** and implemented it in *Albany/FELIX*.
- ***Preliminary results:*** curvature has some effect on Antarctica simulations.

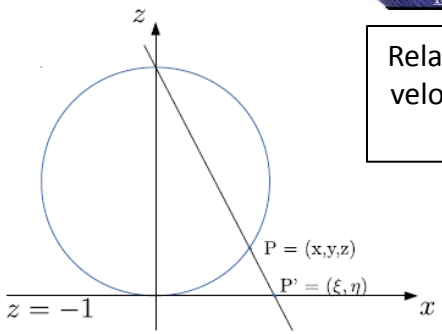
Planned work:

- Verification.
- Try transient simulations with dycores on curved geometry and investigate effect on quantities of interest (e.g., sea-level rise).
- Journal article.

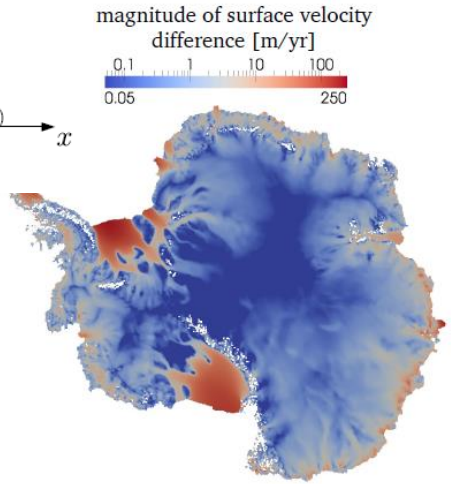
Surface velocity magnitude [m/yr], ice sheet thickness not at scale (100 X)



Curvilinear coordinate system



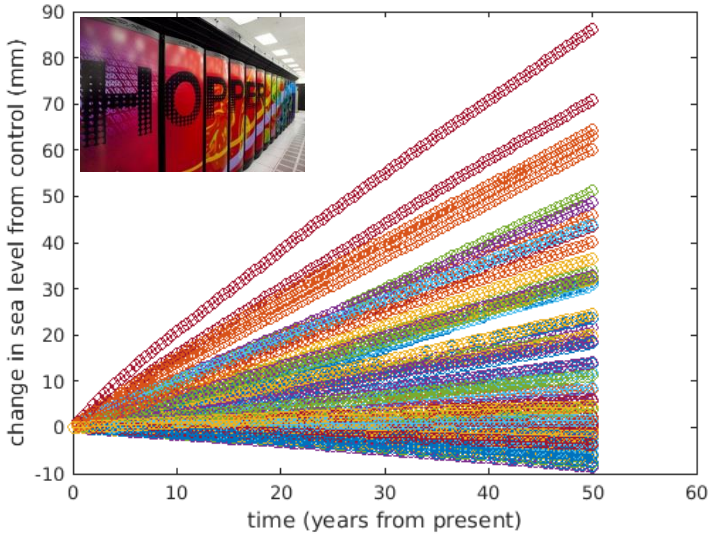
Relative difference in surface velocity magnitude is 10% in fast flow regions.



with
M. Perego

CISM-Albany Update

***CISM-Albany* dycore:** *Albany/FELIX* has been coupled to *CISM* for transient simulations.



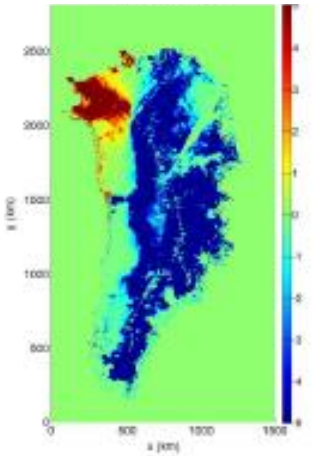
FY15 Progress:

- ***Floating ice*** & ***kinematic Dirichlet*** BCs have been implemented in *CISM-Albany* for realistic problems.
- *CISM-Albany* was used for 50 year ***UQ forward propagation*** study (see J. Jakeman's talk)

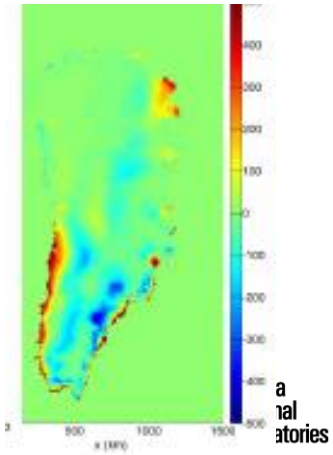
→ demonstrated ***robustness*** of *CISM-Albany*: all 66 forward UQ runs with highly perturbed β converged on *Hopper* out-of-the-box!

with S. Price, J. Jakeman

β perturbation



H perturbation



Planned work:

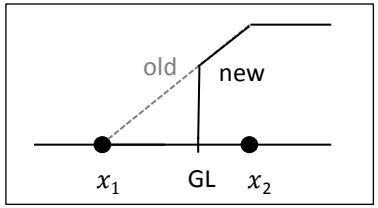
- Fine-resolution ***GIS validation test case*** towards science runs using *CISM-Albany* (with S. Price).
- ***Science paper*** using *CISM-Albany* (with S. Price).
- Improved ***UQ demonstration*** (with J. Jakeman).

MPAS-Albany Update: Semi-Implicit Thickness-FO Stokes Coupling

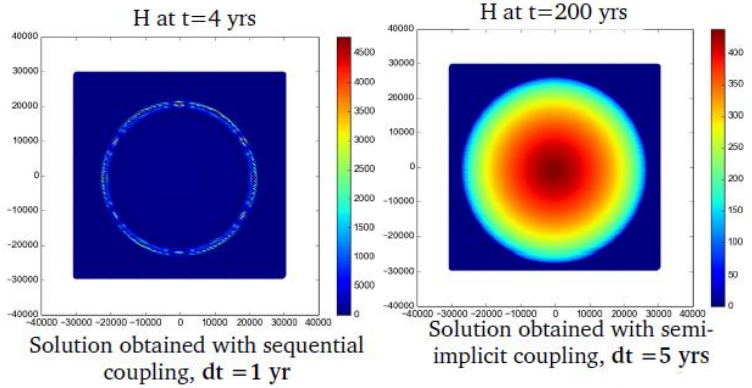
FY15 Progress:

- Improved ***interface*** between *MPAS* and *Albany*.
- Improved BCs (***nonlinear basal BCs**/ grounding line*** parametrization**).
- Developed and implemented ***semi-implicit*** thickness-FO Stokes*** discretization in *MPAS-Albany*: can use larger time steps (advective vs. diffusive CFL).

New GL parametrization



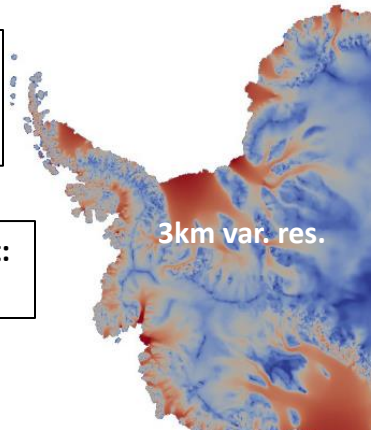
$$-\nabla\cdot\left(\mu\tilde{\mathbf{D}}\left(\mathbf{u}\right)\right)=-\rho g\nabla\left(b+H\right)\ \text{ in }\Omega_{H^n} \qquad \frac{H-H^n}{\Delta t}+\nabla\cdot\left(\bar{\mathbf{u}}\,H^n\right)=\theta^n$$



Planned work:

- Continue investigating robustness/efficiency/ accuracy of the semi-implicit method and grounding line parametrization.
- Coupled science simulations under ACME.

Dome test case: sequential approach unstable with dt = 1yr; semi-implicit approach stable with dt = 5yrs.



AIS prelim. result: *~4.5x speed-up*

w/ M. Perego, S. Price, M. Hoffman

* $\beta = C|\boldsymbol{u}|^{m-1},\ m=\frac{1}{n}$.

** Using high-order quadrature.

*** $\boldsymbol{u}$ computed in *Albany/FELIX* with implicit solve; *MPAS* uses velocity to march in time explicitly.

Summary of Ongoing/Planned Work for FY16

***Albany/FELIX*:**

- *MueLu* speed-ups; optimizations for new architectures?
- Continue porting to new architecture machines (e.g., GPUs on *Titan*), and performance-portability paper.
- Testing under LIVV.
- Finish optimization capabilities (see next talk by M. Perego).
- Coupling with hydrology model (with L. Bertagna; see next talk by M. Perego).
- Improved Bayesian calibration UQ demonstration (see J. Jakeman's talk).

CISM-Albany:

- Greenland validation test case.
- Science runs using *CISM-Albany*, and science paper
- Grounding line parametrization.
- Improved forward propagation UQ demonstration (see J. Jakeman's talk).
- Testing under LIVV.
- Linear solver performance studies/optimizations? Integration of hinge removal algorithm?

MPAS-Albany:

- Coupled science simulations under ACME.
- Continue investigating robustness/efficiency/accuracy of the semi-implicit method and grounding line parametrization.
- Testing under LIVV.
- Linear solver performance studies/optimizations? Integration of hinge removal algorithm?