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.

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PISCEES Project Meeting
Albuquerque, NM
FY15 Progress Highlights

Sandia’s Role in the PISCEES Project: 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*

Albany/FELIX, CISM-Albany, MPAS-Albany Progress & Future Work (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.

Additional Progress & Future Work (other talks):

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

*FELIX = Finite Elements for Land Ice eXperiments
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).

This year
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).

**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.

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?

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

Greenland Problem

with R. Tuminaro
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 devices 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.

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

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.

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 $\beta$ converged on Hopper out-of-the-box!

**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).

\[
-\nabla \cdot \left( \mu \nabla (u) \right) = -\rho g \nabla (b + H) \quad \text{in} \ \Omega_H^n, \quad \frac{H - H^n}{\Delta t} + \nabla \cdot (\bar{u} H^n) = \theta^n
\]

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

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

** Using high-order quadrature.

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

\[H \text{ at } t=4 \text{ yrs}\]

\[H \text{ at } t=200 \text{ yrs}\]

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

AIS prelim. result: \(~4.5x\) speed-up

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