Performance and Stewardship of E3SM ice-sheet model MALI

Jerry Watkins[1], Oscar Antepara[2], Luca Bertagna[1], Max Carlson[1], Trevor Hillebrand[3], Matt Hoffman[3], Jonathan Hu[1], Kim Liegeois[1], Mauro Perego[1], Stephen Price[3], Mark S. Shephard[4], Cameron W. Smith[4], Irina Tezaur[1], Sam Williams[2]

[1]Sandia National Laboratories
[2]Lawrence Berkeley National Laboratory
[3]Los Alamos National Laboratory
[4]Rensselaer Polytechnic Institute

Introduction

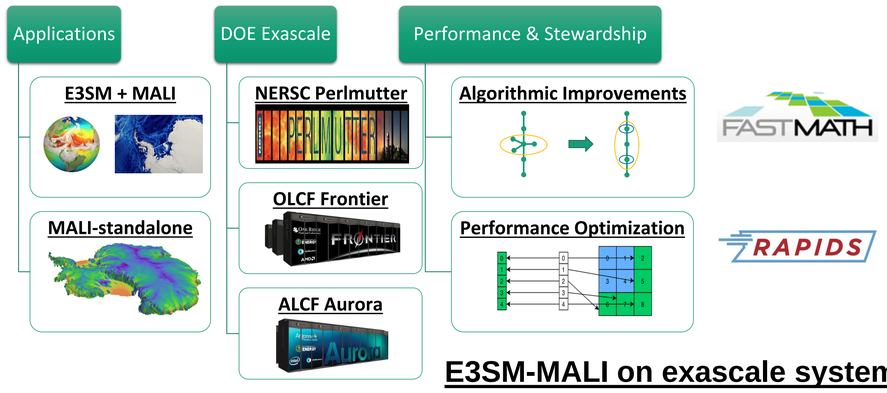
Motivation:

- Melting polar ice sheets (Greenland, Antarctica) are a major contributor to rising global mean sea level. Ice-sheet models are increasing in fidelity and resolution in order to capture accurate projections of future global mean sea level.

Problem:

- The growing complexity and resolution of ice-sheet models, combined with the need for large ensembles to capture uncertainties, demand fast and robust models that can efficiently run on upcoming architectures.

Goal:



E3SM-MALI on exascale systems

Software Stewardship

Software
MPAS-Albany (MALI): model
Albany: velocity solver
Omega_h: mesh adaptivity
Compass: workflow manager

Omega_h Integration

Challenge:

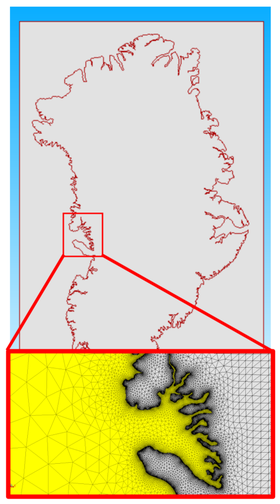
- Supporting an adaptive *mesh* in MALI requires integration of Omega_h and an initial mesh associated with a geometric model

Approach:

- Omega_h connectivity manager interface in Albany (mesh to dofs)
- Compass workflow to pass grounding line to Simmetrix mesh

Results:

- Omega_h-Albany (mesh-solver) Poisson regression test
- Compass Greenland ice-sheet grounding line (top). Simmetrix mesh (bottom).



Automated Testing & Tuning

Challenge:

- Sustainable computational throughput on DOE machines

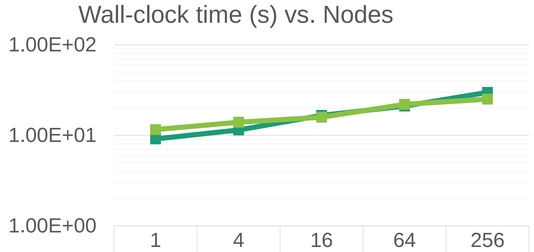
Approach:

- CDash software testing; GPTune solver tuning

Results:

- GPU solver on Perlmutter/Frontier

GPU Velocity Solver Weak Scalability
Wall-clock time (s) vs. Nodes



	1	4	16	64	256
Resolution (km)	16	8	4	2	1
Perlmutter	9.15	11.46	16.63	21.08	29.85
Frontier	11.58	13.97	15.85	22.03	25.15

Performance

Algorithmic improvements: Damped block Jacobi smoother

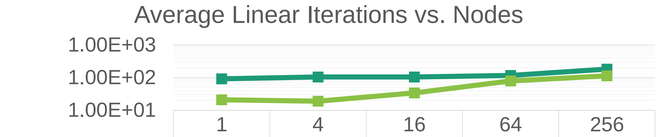
Challenge

- Improve linear solver convergence on GPU architectures

Approach

- Damped block Jacobi line smoother for anisotropic problem

Average Linear Iterations vs. Nodes



	1	4	16	64	256
Resolution (km)	16	8	4	2	1
Chebyshev	92	105	105	117	183
Block Jacobi	21	19	34	79	114
Improvement	4.4	5.5	3.1	1.5	1.6

Weak scaling solving for the ice velocity in Antarctic ice sheet at different resolutions

Results

- Up to **5.5x less linear iterations**, 1.9x speedup over Chebyshev smoother

Performance optimization: First-order Stokes residual kernel

Challenge

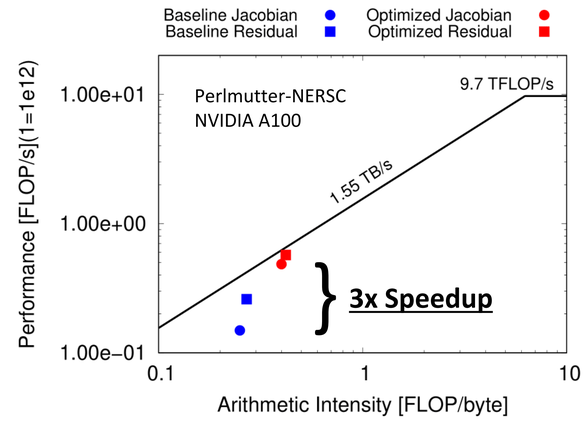
- Optimize single code (Kokkos/Sacado) for multiple architectures/data types

Approach

- Roofline analysis to identify potential optimizations in source code

Results

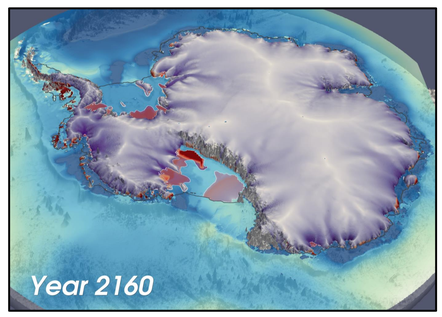
- Up to **3x speedup** in kernel over original code on Perlmutter/Frontier

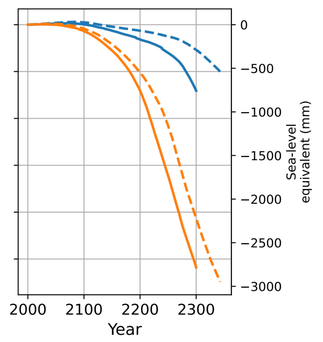


Impact

Antarctica ice-sheet production runs on Perlmutter (CPU/GPU)

- First production runs on Perlmutter-GPU





- 4km (solid) & 2km (dashed) ensembles with different global circulation models: CCSM4 (blue), HadGEM2 (orange)

E3SM-MALI on Perlmutter

- First test runs on Perlmutter with land-ice component on GPU

Future Work

- Kernel optimization to improve computational throughput
- Mesh adaptivity with first-order Stokes and thickness evolution
- Improve compass/spack integration/testing for exascale systems

Watkins et al. (2023) Performance portable ice-sheet modeling with MALI. *The International Journal of High Performance Computing Applications, 37(5), 600-625.*

FANSSIE
Framework for Antarctic System Science in E3SM
fanssie.github.io

E3SM Energy Exascale Earth System Model
e3sm.org

For additional information, contact:
Jerry Watkins
FAnSSIE performance lead

Sandia National Laboratories
jwatkin@sandia.gov

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