Rapid Development of an Ice Sheet Climate Application using the Components-Based Approach

Sandia National Laboratories
A.G. Salinger, I. Kalashnikova, M. Perego, R.S. Tuminaro, M.S. Eldred and J.D. Jakeman
Sandia National Laboratories, New Mexico, 87185

Objectives

Develop: robust and scalable unstructured-grid finite element ice sheet code:

- Stand-alone steady-state model for initialization and calibration
- Dynamic model when linked to Los Alamos National Laboratories (LANLs) MPAS framework for advection
- Future land ice component of Department of Energy (DOE) earth system model

Support: DOE climate missions, such as providing Sea Level Rise predictions

Leverage: software and expertise from SciDAC Institutes (FASTMath, QUEST, SUPER) and hardware from DOE Leadership Class Facilities

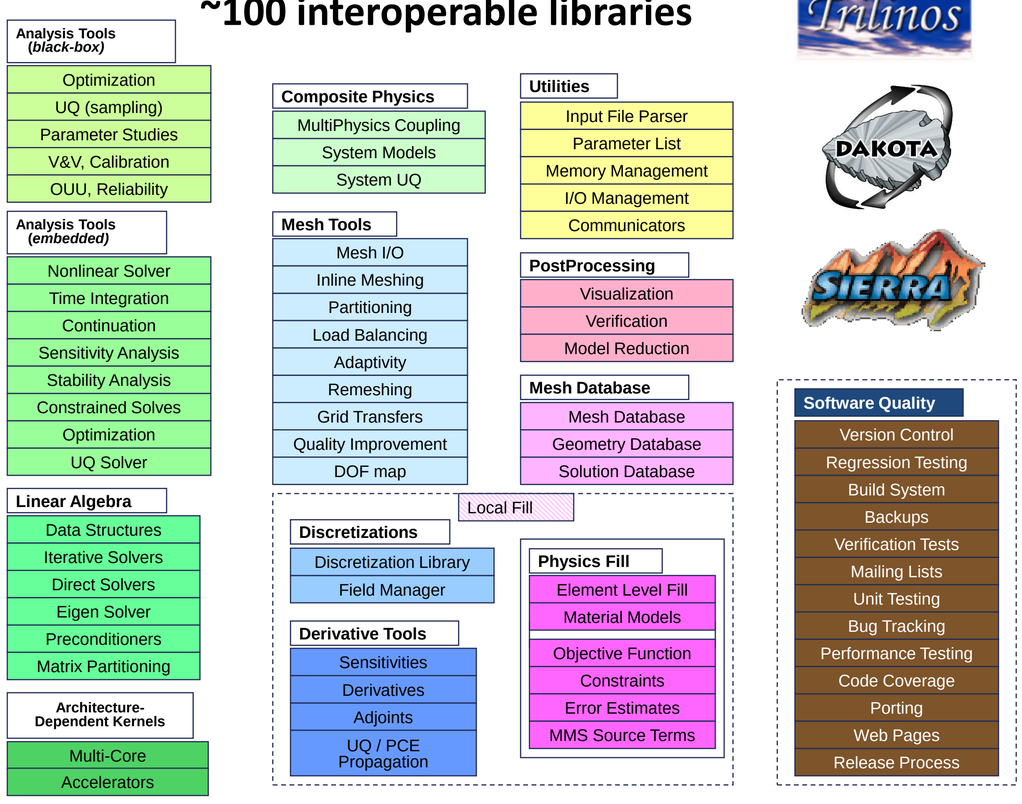
Funding: *"PISCEES" SciDAC Application Partnership (DOE's BER + ASCR divisions)*
PI*: Lipscomb [LANL]; collaboration with ORNL, LANL, LBNL, UT, FSU, SC, MIT, and NCAR*

Component-Based Strategy

Component-based approach enables **rapid** development of new **production** codes embedded with **transformational** capabilities

"Components" = ☑ Libraries ☑ Interfaces ☑ Software Quality Tools ☑ Demonstration Applications

Sandia's components effort includes ~100 interoperable libraries



Ice Sheet Model

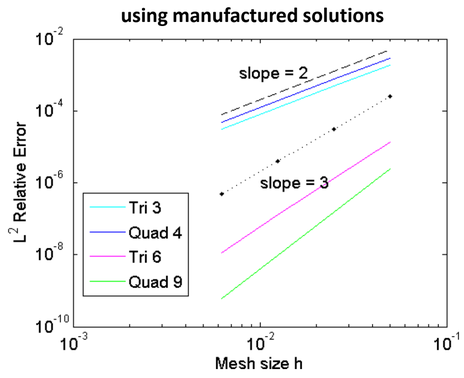
We are using the component-based approach to rapidly develop an Ice Sheet code meeting the above objectives

Nonlinear Stokes' Model for Ice Sheet Stresses

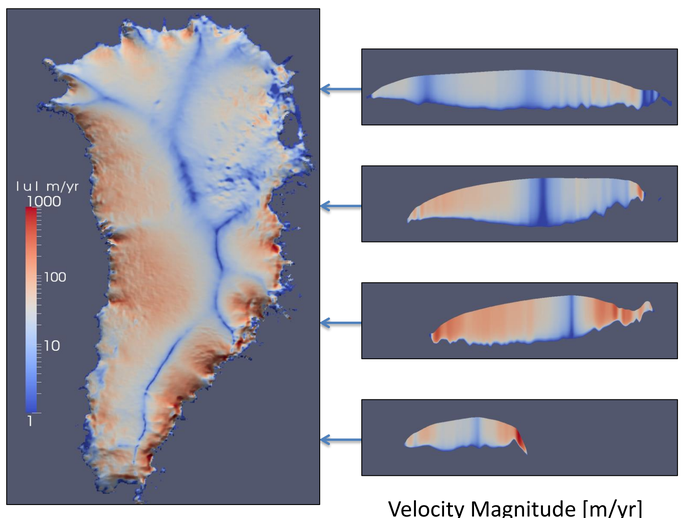
$$-\nabla\cdot(2\mu\dot{\epsilon}_1) = -\rho g\frac{\partial s}{\partial x}$$
$$-\nabla\cdot(2\mu\dot{\epsilon}_2) = -\rho g\frac{\partial s}{\partial y}$$

Model is discretized with the **Finite Element Method,** using **Automatic Differentiation** and dozens of other components for the **Nonlinear Solution** and **Analysis**

Solution Verification
using manufactured solutions



Results: Greenland



Surface Velocity Magnitude [m/yr]

Velocity Magnitude [m/yr] in x-z planes. (Height "z" is stretched 100x.)

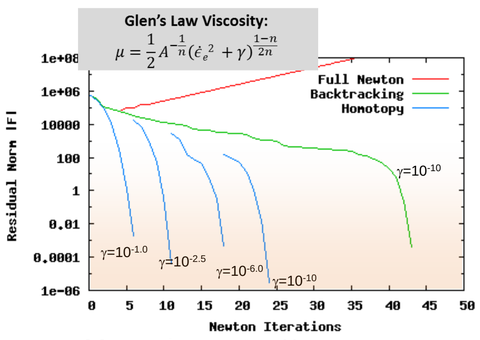
From **components** to **Greenland** simulation with real data*, verification, robustness, scalability, and UQ in **8 months** (~1FTE)

5 km resolution
640K hex elements
1.44M Unknowns

*Data courtesy of J. Bamber and J. Griggs (Univ. of Bristol) as part of the Ice2Sea project

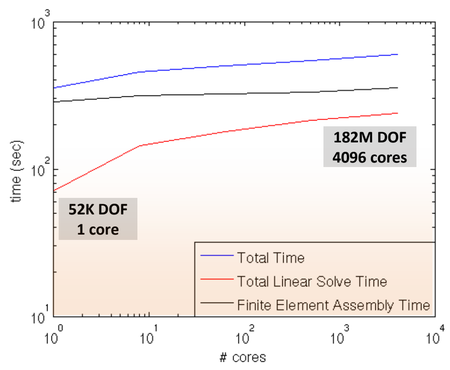
Scalability and Robustness

Increased Robustness via Homotopy Continuation



- Most robust using Homotopy continuation, decreasing γ to 10^{-10}

Preliminary Scalability Study



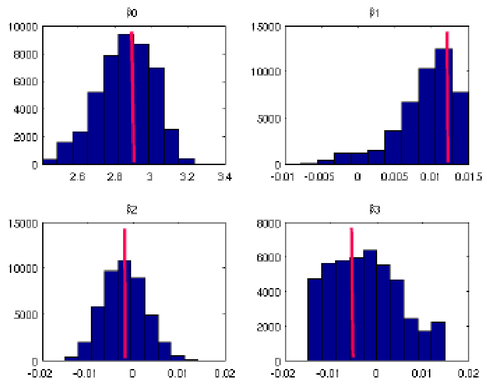
- Weak Scaling: 1, 8, 64, 512 and 4096 cores of **Hopper** (NERSC)

UQ: Calibration and Propagation

Step 1: Model Initialization through Bayesian Calibration

What are the **model parameters** that render a given a set of **observations**?

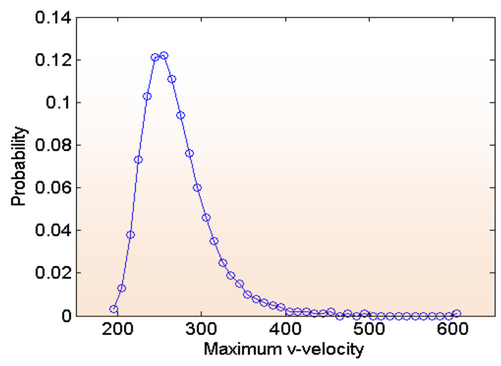
Basal sliding coefficient:
$\beta(x,y) = \beta_0 + \beta_1 x + \beta_2 y + \beta_3 r$



Step 2: Uncertainty Propagation

What is the impact of **uncertain parameters** in model on **quantities of interest**?

Basal sliding coefficient:
$\beta(x,y) \sim Normal(1, 0.2)$



Ongoing Work

- Coupling to MPAS for dynamic evolution
- Deterministic and stochastic initialization runs
- Coupling to full earth system model

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