Component-Based Application Code Development, Part 2: Demonstration on a Land-Ice Model and Proposed Extension to Other Climate Components

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Background/Motivation

According to a 2012 report by the National Research Council, there is a critical need for a next generation of advanced climate models. The report calls for climate models to (1) take a more integrated path, (2) use a common software infrastructure, (3) add regional detail and new simulation capabilities, and (4) take new approaches for collaborating with their user community. Climate models have improved in recent years. However, much work is needed to make these models reliable and efficient on continental scales, to quantify uncertainties in the model's outputs, and to port the models to next-generation HPC architectures. Many legacy climate codes lack advanced analysis capabilities (e.g., sensitivity and adjoint calculations), and would need to be rewritten substantially in order to run accurately and efficiently on new architectures (e.g., GPUs).

Component-Based Code Development*

A promising approach for developing next-generation performance-portable solvers with advanced analysis capabilities.

Mature, modular libraries are combined using abstract interfaces and template-based generic programming, resulting in a final code that is verified, scalable, fast, robust, and has access to dozens of algorithmic and advanced analysis capabilities.


Scalability Through Leveraging of FASTMath Solvers & Expertise

The Albany/FELIX code has demonstrated scalability up to 1 billion unknowns and tens of thousands of cores thanks preconditioning methods developed using ASCR base math funding and added to Trilinos.

Uncertainty Quantification (UQ) with QUEST Collaborators

An Uncertainty Quantification (UQ) workflow is being developed for sea-level rise projections by leveraging software and expertise of QUEST collaborators.

End-to-end workflow for quantifying the uncertainty in the possible changes in sea level during the 21st century.

Proposed Direction for Future Work

Proposed direction is to look for ways to equip other climate components (e.g., atmosphere, sea-ice, ocean) and coupled ESMs with the advanced analysis and performance capabilities described in this poster by integrating into these models software libraries and algorithms developed by domain experts.

References


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The Albany/FELIX Land-Ice Solver Developed Under PISCEES

Sandia’s Role in the PISCEES Project: to develop and support a robust and scalable, unstructured grid, finite element land ice velocity solver “Albany/FELIX” (Finite Elements for Land ice exeriments)

Components = Trilinos and DAKOTA libraries

As part of the ACME DOE earth system model, the Albany/FELIX solver will enable actionable predictions of 21st century sea-level rise (including uncertainty).

Automatic Differentiation (AD) for Robustness & Advanced Analysis

Automatic Differentiation (AD) provides exact derivatives without time and effort of deriving and hand-coding.

The integration of AD into Albany/FELIX has enabled robust nonlinear solves, sensitivity analysis, adjoint-based optimization for ice sheet initialization (in place of ad hoc spin-ups and parameter tuning), and embedded uncertainty quantification (UQ).

Robust non-linear solver with AD and homotopy continuation

Adjusted-based POE constrained optimization for ice sheet initialization

Objectives: find ice sheet initial state that matches observations, matches present-day geometry and is in equilibrium with climate forcings.

Improvements in Time-Marching for Faster and More Stable Dynamic Simulations

The development of new semi-implicit momentum balance and thickness coupling techniques has led to more stable and efficient time-stepping schemes, expected to reduce substantially run-times for transient land-ice simulations.

Semi-implicit scheme: 2x speed-up for Antarctic Ice Sheet simulation

Classical scheme unstable with dt=1yr, improved stable scheme with dt=5yr.

Performance Portability via the Kokkos Trilinos Library & Programming Model

The Kokkos Trilinos library and programming model enables performance portability of kernels. With Kokkos, the same code can run on diverse devices with different memory models (e.g., multi-core, many-core, GPUs).

Kokkos abstractions allow device-specific memory layout and parallel kernel launch. The finite element assembly in Albany/FELIX has been written using Kokkos.

Proposed Success Story: PISCEES Land-Ice Model

PISCEES = “Predicting Ice Sheet Climate & Evolution at Extreme Scales”

PISCEES is a SciDAC Application Partnership between DOE’s BER & ASCR divisions (2012-2017) aimed to build a next-generation land-ice dynamical core to enable DOE climate missions. PISCEES is a multi-lab/multi-university project involving mathematicians, climate scientists, and computer scientists. PISCEES leverages software/expertise from SciDAC Institutes (FASTMath, QUEST, SUPER) and hardware from DOE Leadership Class Facilities.

Code Quality & Verification

Three-step code verification process to ensure code quality.

1. Solution verification on MMS problems.
3. Full 3D mesh convergence study on Greenland w.r.t. reference solution.

Additional code quality through common build system, test harness, release schedule/processes, documentation style.

Some specific ideas worth exploring:

• Embedded UQ for atmosphere.
• Non-linear solvers for sea-ice.
• Implicit/semi-implicit solvers for ocean.

Success rests strongly on a collaboration model for the development of climate technologies: climate modelers + computational scientists.