A Performance Portable, High-Resolution Global Atmosphere Model

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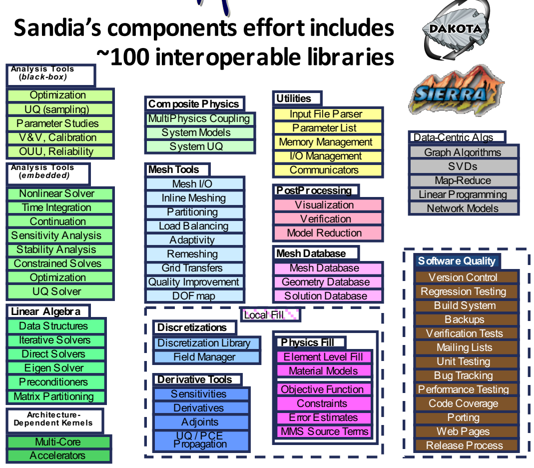
Objectives

Develop a ***next-generation*** atmosphere model by leveraging Albany, a C++, parallel, implicit, unstructured-grid finite element code from Sandia National Laboratories that demonstrates ***agile components*** and enables rapid prototyping. Unique features include embedded ***uncertainty quantification***, and ***performance portability***.

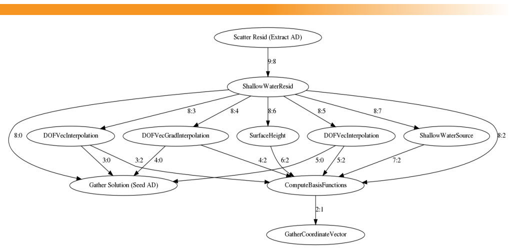
Component-Based Strategy

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

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



Graph of Finite Element Assembly Kernels



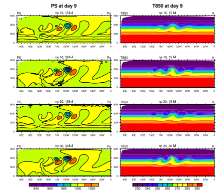
Dependency graph of finite element assembly kernels for the Shallow Water equations. By use of operator overloading-based automatic differentiation (AD), the same code base is used for implicit and explicit calculations. Most kernels shown here are general-purpose finite element calculations provided by Albany.

Extensions to Albany

To develop Aeras, we added the following extensions to Albany:

- Shell elements, spectral elements, efficient explicit time-stepping, additional explicit time-stepping methods, ***concurrent samples***, embedded UQ for transient problems, and spherical coordinate system transformations

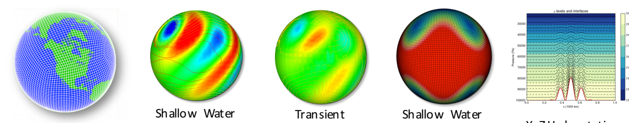
Capabilities



3D Hydrostatic Baroclinic Instability

Aeras capabilities include:

- Shallow water, X-Z hydrostatic, and 3D hydrostatic models
- Spectral element discretization on the cubed sphere
- Hybrid η vertical discretization
- Hyperviscosity stabilization
- Explicit and implicit time-stepping techniques, with advanced solvers
- Embedded uncertainty quantification
- Performance portability



Cubed Sphere | Shallow Water Test Case 5 | Transient Sensitivities | Shallow Water Test Case 6 | X-Z Hydrostatic

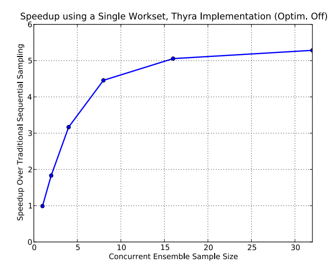
Concurrent Samples

Idea:

Execute multiple models concurrently, making loop over samples the inner loop (using Scalar template parameter)

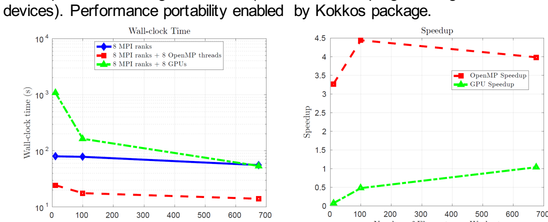
Advantages:

- Improved memory access patterns
- Increased work for fine-grained parallelism
- Increased message size for MPI
- Fewer messages for MPI

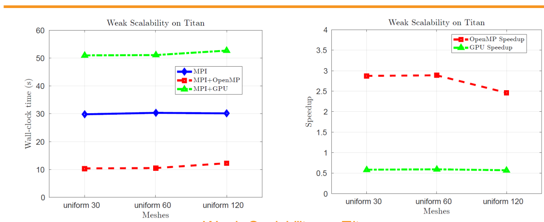


Performance Portability

All numerical experiments are conducted using a ***single code base*** that supports both OpenMP threading and GPUs (as well as other programming models & devices). Performance portability enabled by Kokkos package.



Workset Scalability on Shannon



Weak Scalability on Titan

Note: GPUs in Albany with Kokkos was implemented using unified virtual memory (UVM) which is known to impose performance overheads that will be significantly reduced by future hardware improvements.

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