8th. World Congress on Computational Mechanics (WCCM8)
5th European Congress on Computational Methods in Applied Sciences and Engineering (ECCOMAS 2008)
June 30 –July 5, 2008
Venice, Italy

TOWARD SCALABLE ADAPTIVE MANTLE CONVECTION SIMULATION ON PETASCALE SUPERCOMPUTERS

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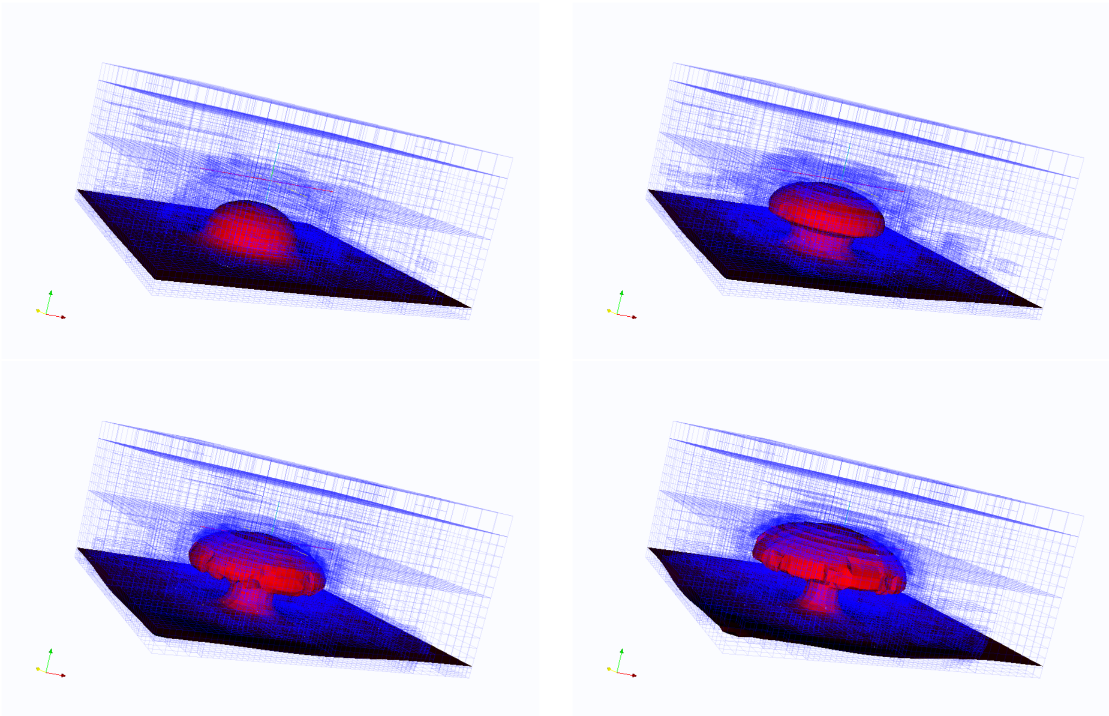
Key Words: *Mantle convection, petascale computing, parallel mesh adaptivity, algebraic multigrid, variable-viscosity Stokes solver.*

ABSTRACT

Mantle convection is the principal control on the thermal and geological evolution of the Earth. It is central to our understanding of the origin and evolution of tectonic deformation, the evolution of the thermal and compositional states of the mantle, and ultimately the evolution of the Earth as a whole. Mantle convection modeling involves solution of the mass, momentum, and energy equations for a viscous, creeping, incompressible non-Newtonian fluid at high Rayleigh ($O(10^9)$) and Peclet ($O(10^6)$) numbers, given appropriate initial and boundary conditions. Mantle convection is an important driver for petascale computing, due to the wide range of length and time scales involved. Our goal is to



conduct high resolution mantle convection simulations that can resolve thermal boundary layers and faulted plate boundaries, down to 1 km scales. Use of a uniform mesh at this resolution leads to multi-trillion element meshes, which are intractable even with petascale supercomputers. Thus parallel mesh adaptivity is essential.

To this end, we are developing `Rhea`, a new generation mantle convection code incorporating parallel adaptive mesh refinement/coarsening algorithms designed to scale to hundreds of thousands of processors. `Rhea`'s features include (or will include): (1) parallel octree-based mesh adaptivity algorithms, including support for dynamic coarsening, refinement, rebalancing, and repartitioning of the mesh; (2) a parallel variable-viscosity Stokes solver, based on Krylov solution of the (stabilized) Stokes system, with preconditioning carried out by F_p-type approximate block factorization and algebraic multigrid V-cycle approximation (via the `hypre` package) of the inverse of viscous and pressure Schur complement operators; (3) adjoint-based error estimators and refinement criteria; (4) integrated volume rendering and isosurface visualization; and (5) support for inverse as well as forward mantle convection solution.

We discuss parallel performance on *Ranger*, the 0.5 Petaflop 62,976-core Sun/AMD system at the Texas Advanced Computing Center (TACC) that went into production in February 2008. Preliminary results on *Ranger* for up to 8192 cores for the parallel adaptive advection-diffusion component indicate just 5% of the overall time is spent on all components related to adaptivity (the remainder is consumed by the advection-diffusion solver), while maintaining 90% parallel efficiency in scaling from 64 to 8192 cores. Moreover, the algorithmic scalability of the parallel variable-viscosity Stokes solver is also excellent: the number of MINRES iterations is almost insensitive to a 2048$\times$ increase in number of elements (from 131K to 336M velocity/pressure unknowns), three orders of magnitude variation in viscosity, four levels of mesh refinement, and a 2048$\times$ increase in number of processors.

The presentation, will describe the algorithm design and update the scalability results, with the goal of demonstrating scaling to tens of thousands of cores on the *Ranger* system.