Large scale mantle dynamics modeling

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To model the geodynamic evolution of plate convergence, subduction and collision and to allow for a connection to various types of observational data, geophysical, geodetical and geological, we developed a 4D (space-time) numerical mantle convection code. The model is based on a spherical 4D Eulerian fem model, with quadratic elements, on top of which we constructed a 4D Lagrangian particle in cell(PIC) method. We use the PIC method to transport material properties and to incorporate a viscoelastic rheology. Since capturing small scale processes associated with localization phenomena require a high resolution, we spend a considerable effort on implementing solvers suitable to solve for models with over 100 million degrees of freedom. We implemented Additive Schwartz type ILU based methods in combination with a Krylov solver, GMRES. However we found that for problems with over 500 thousend degrees of freedom the convergence of the solver degraded severely. This observation is known from the literature [Saad, 2003] and results from the local character of the ILU preconditioner resulting in a poor approximation of the inverse of A for large A. The size of A for which ILU is no longer usable depends on the condition of A and on the amount of fill in allowed for the ILU preconditioner. We found that for our problems with over 5×10^5 degrees of freedom convergence became to slow to solve the system within an acceptable amount of walltime, one minute, even when allowing for considerable amount of fill in.

We also implemented MUMPS and found good scaling results for problems up to 10^7 degrees of freedom for up to 32 CPU's. For problems with over 100 million degrees of freedom we implemented Algebraic Multigrid type methods (AMG) from the ML library [Sala, 2006]. Since multigrid methods are most effective for single parameter problems, we rebuild our model to use the SIMPLE method in the Stokes solver [Patankar, 1980]. We present scaling results from these solvers for 4D spherical models. When dealing with problems of this size efficient data storage becomes essential. We describe a general purpose interface that allows for the distributed, compressed storage of large datasets in VTK XML format, using compression routines from the PNG library.

We rely on the meshing application developed by van Thienen to provide high resolution 3D spherical meshes (see poster "Finite element meshing of three-dimensional faulted domains")

[*Saad*, 2003] Saad, Y. (2003). Iterative methods for sparse linear systems.

[*Sala*, 2006] Sala. M (2006) An Object-Oriented Framework for the Development of Scalable Parallel Multilevel Preconditioners. ACM Transactions on Mathematical Software, 32 (3), 2006

[*Patankar*, 1980] Patankar, S. V.(1980) Numerical Heat Transfer and Fluid Flow, Hemisphere, Washington.