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Fluidity: A New Adaptive, Unstructured Mesh Geodynamics Model

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Fluidity is a sophisticated fluid dynamics package, which has been developed by the Applied Modelling and Computation Group (AMCG) at Imperial College London. It has many environmental applications, from nuclear reactor safety to simulations of ocean circulation. Fluidity has state-of-the-art features that place it at the forefront of computational fluid dynamics. The code:

1. *Dynamically optimizes the mesh*, providing increased resolution in areas of dynamic importance, thus allowing for accurate simulations across a range of length scales, within a single model.
2. Uses an *unstructured mesh*, which enables the representation of complex geometries. It also enhances mesh optimization using *anisotropic elements*, which are particularly useful for resolving one-dimensional flow features and material interfaces.
3. Uses *implicit solvers* thus allowing for large time-steps with minimal loss of accuracy. PETSc provides some of these, though multigrid preconditioning methods have been developed in-house.
4. Is optimized to run on parallel processors and has the ability to perform *parallel mesh adaptivity* – the subdomains used in parallel computing automatically adjust themselves to balance the computational load on each processor, as the mesh evolves.
5. Has a novel *interface-preserving advection scheme* for maintaining sharp interfaces between multiple materials / components.
6. Has an *automated test-bed* for verification of model developments.

Such attributes provide an extremely powerful base on which to build a new geodynamical model. Incorporating into Fluidity the necessary physics and numerical technology for geodynamical flows is an ongoing task, though progress, to date, includes:

1. Development and implementation of parallel, *scalable solvers for Stokes flow*, which can handle sharp, orders of magnitude variations in viscosity and, significantly, an anisotropic viscosity tensor.
2. Modification of the multi-material interface-preserving scheme to allow for tracking of *chemical heterogeneities* in mantle convection models.
3. Incorporation of a suite of *geodynamic benchmarks* into the automated test-bed.

These recent advances, which all work in combination with the parallel mesh-optimization technology, enable Fluidity to simulate geodynamical flows accurately and efficiently. Initial results will be presented from: (i) a range of 2-D and 3-D thermal convection benchmarks; kinematic and dynamic subduction zone simulations; (iii) Comparisons between model predictions and laboratory experiments of plume dynamics. These results all clearly demonstrate the benefits of adaptive, unstructured meshes for geodynamical flows.