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New 2D adaptive mesh refinement algorithm based on conservative finite-differences with staggered grid

T. Gerya, T. Duretz, and D.A. May

Swiss Federal Institute of Technology, Department of earth Science, Zurich, Switzerland (taras.gerya@erdw.ethz.ch, +41 1 632 10 80)

We present new 2D adaptive mesh refinement (AMR) algorithm based on stress-conservative finite-differences formulated for non-uniform rectangular staggered grid. The refinement approach is based on a repetitive cell splitting organized via a quad-tree construction (every parent cell is split into 4 daughter cells of equal size). Irrespective of the level of resolution every cell has 5 staggered nodes (2 horizontal velocities, 2 vertical velocities and 1 pressure) for which respective governing equations, boundary conditions and interpolation equations are formulated. The connectivity of the grid is achieved via cross-indexing of grid cells and basic nodal points located in their corners: four corner nodes are indexed for every cell and up to 4 surrounding cells are indexed for every node. The accuracy of the approach depends critically on the formulation of the stencil used at the "hanging" velocity nodes located at the boundaries between different levels of resolution. Most accurate results are obtained for the scheme based on the volume flux balance across the resolution boundary combined with stress-based interpolation of velocity orthogonal to the boundary. We tested this new approach with a number of 2D variable viscosity analytical solutions. Our tests demonstrate that the adaptive staggered grid formulation has convergence properties similar to those obtained in case of a standard, non-adaptive staggered grid formulation. This convergence is also achieved when resolution boundary crosses sharp viscosity contrast interfaces. The convergence rates measured are found to be insensitive to scenarios when the transition in grid resolution crosses sharp viscosity contrast interfaces. We compared various grid refinement strategies based on distribution of different field variables such as viscosity, density and velocity. According to these tests the refinement allows for significant (0.5-1 order of magnitude) increase in the computational accuracy at the same computational costs for the models with sharp and large viscosity contrasts that makes our approach applicable for geodynamic problems involving strong rheological variations.