Geophysical Research Abstracts
Vol. 14, EGU2012-10945, 2012
EGU General Assembly 2012

Revising the spectral method as applied to the mantle dynamics modeling.

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The spectral method is widely used for modeling instantaneous flow and stress field distribution in a spherical shell. This method provides a high accuracy semi-analytical solution of the Navier-Stokes and Poisson equations when the viscosity is only depth- (radial-) dependent. However, the distribution of viscosity in the real Earth is essentially three-dimensional. In this case, non-linear coupling of different spherical harmonic modes does not allow obtaining a straightforward semi-analytical solution. In this study, we present a numerical approach, built on substantially revised method originally proposed by Zhang and Christensen (1993) for solving the Navier-Stokes equation in a spectral domain in case if lateral variations of viscosity (LVV) are present. We demonstrate a number of numerical algorithms allowing to efficiently calculate instantaneous Stokes flow in a sphere taking into account the effects of LVV, self-gravitation and compressibility. In particular, the Newton-Raphson procedure applied to the shooting method shows the ability to solve the boundary value problem, necessary for cross-linking solutions on spheres. In contrast to the traditionally used propagator method, our approach suggests continuous integration over depth without introducing internal interfaces. The Clenshaw-based recursion algorithms for computing associated Legendre functions and the Horner's scheme for computing partial sums allow avoiding the problems in the Poles vicinity typical for the spherical harmonic methods and obtaining a fast and robust solution on a sphere for high degree and order.

Since the benchmarking technique of 3-D spherical codes is not developed substantially, we employ different approaches to test the proposed numerical algorithm. First, we show that the algorithm produces correct results for radially symmetric viscosity distribution. Second, an iterative scheme for the LVV case is validated by comparing the solution for the tetrahedral symmetric (l=3,m=2) steady-state compressible convective flow comprising temperature-dependent Newtonian viscosity, with the solution obtained from the CitcomS numerical code (Zhang et al, 2000; Tan et al., 2006) for the same problem. In addition we analyze sensitivity of the technique to the LVV for different patterns of 3-D viscosity distribution and various viscosity contrast values.

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