Numerical simulations on the formation and behaviors of slabs in 2-D spherical annulus

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We developed a numerical model of thermal convection of highly viscous fluid in a two-dimensional spherical annulus, aiming at (i) classifying the morphologies and dynamic behaviors of subducting slabs, (ii) comparing the shapes of slabs obtained in our simulation models with those estimated from seismic tomography to offer the constraints on the plate velocities and the properties of the 660 km discontinuity from fluid-dynamical viewpoints.
In this study, we consider a time-dependent convection of fluid under the extended Boussinesq approximation. The viscosity of mantle material is assumed to be exponentially dependent on temperature and pressure (or depth). We also have included the exothermic olivine to spinel phase transition at around 410 km depth and the endothermic post-spinel phase change at around 660 km depth. The plate subduction is modeled by downward flow of cold and viscous fluid along with a conduit which guides the descending slab from surface to the mantle transition zone. We take into account the effect of trench migration, by imposing the migration of the conduit with respect to the deep mantle.
We found that our model successfully reproduces the diverse morphology of subducting slabs which can be well compared with those of natural slabs, by carrying out calculations with systematically varying the velocities of subducting slabs and trench migration, the Clapeyron slope at around 660 km depth, and the viscosity jump between the upper and lower mantle. In particular, the dynamic behaviors of slabs around the mantle transition zone can be classified into five types depending on the combinations of varying parameters: (1) Penetrating, (2) Accumulating, (3) Floating, (4) Long-term Stagnation, and (5) Short-term Stagnation.
A careful comparison of the slab morphologies in our numerical experiments with those of natural slabs in selected subduction zones enabled us to estimate the rate of trench migration with respect to the deep mantle, given that both the duration of subduction and rate of two-plate convergence are properly known. This implies that the morphology of slabs can be used to settle a reference frame of motions of surface plates, which is of crucial importance in determining their absolute velocities from the relative ones. Such comparison could also offer fluid-dynamical constraint on the properties of the 660 km discontinuity.

Keywords: subducted slab, stagnant slab, mantle convection, numerical simulation