Numerical experiments on stagnation and avalanche of subducting slabs: Important roles of trench migration and its temporal change

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We conducted numerical simulations of thermal convection of highly viscous fluids in a 2-D spherical annulus in order to study what mechanisms control the dynamic behaviors of subducting slabs such as the formation of ``stagnant slabs'' in the mantle transition zone (MTZ) and their avalanche into the lower mantle. Two series of experiments are carried out, by applying the different histories of migrating motion of ``trench'' where the slab of cold fluids descends from the top surface, together 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 the first series of experiments where the migration rate of trench is kept constant with time, our model successfully reproduces the diverse morphology of subducting slabs depending on the delicate combinations of control parameters, including five fundamental types named penetration (P), accumulation (A), flotation (F), long-term stagnation (LS) and short-term stagnation (SS). In addition to the above fundamental types, we found two distinctive types of slab behaviors (named pS and cS) where the slabs are stagnated at the base of MTZ after they experience the penetration or collapse into the lower mantle and yield the snapshot behaviors very close to those of SS at some time instances. In the second series of experiments where we imposed a step-like change in the trench retreat velocity with time, we found that a deceleration of trench retreat enhances the collapse of the horizontally-lying or stagnant slabs (SS, cS, pS and LS types in the first series of experiments) into the lower mantle whose style and course strongly depend on the slab shapes at the time instance of the sudden stop of the trench retreat. In these experiments, we obtained wider variations of slab behaviors than in the cases with continuous trench retreat, such as the avalanche of stagnant slabs from its hinge and the flattening of slabs below the 660 km discontinuity without any discontinuous changes in mantle properties at the depth. Our results suggest that the formation and avalanche of stagnant slabs are strongly related to the trench retreat, particularly through its temporal changes. In other words, the variations in the shapes of subducting slabs in nature are most likely to reflect the difference in the history of trench migration.

Keywords: numerical simulation, mantle convection, stagnant slab, trench retreat, subduction zone