Dynamic interaction between mantle convection and water transportation in subduction zones

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The effects of water on subduction dynamics, e.g., plate migration rate, slab geometry, stress field, and back arc spreading, are investigated by using a 2-D self-consistent model for lithosphere subduction and whole mantle convection. We solve water transportation coupled with hydrous mineral phase changes. Mantle flows and water transportation are interactive through constitutive and state equations for hydrous rocks. Our model has successfully reproduced the water distribution in a mantle wedge and along the slab with sufficient resolution comparable to that of previous models that focus on the mantle wedge structure. As a result, low density owing to hydration reduces subduction rates, back arc spreading, and slab stagnation on the phase boundary at 660-km depth, whereas low viscosity owing to hydration enhances rapid subduction, trench migration, and slab stagnation. We attribute these results to mechanisms that cause the hydrous buoyancy of subducting plates to reduce the slab pull force and the accompanying tensile stress on overlying lithosphere. In addition, hydrous weakening diminishes the mechanical coupling of the subducted slab with the wedge mantle and overriding lithosphere. Thus, water is capable of generating two opposite situations in the stress field of the overlying lithosphere and the subduction rate. Water is therefore expected to be an important mechanism for generating broad styles of the subduction structure and kinematics, as observed in actual subduction zones such as Tonga and Mariana, comparable to other tectonic forces such as overlying plate motion. Water in the mantle is thus a key to a better understanding of the whole mantle-scale slab dynamics as well as island arc volcanic processes.

Keywords: water transportation, free convection, subduction dynamics, plate velocity, stagnant slab, trench migration

