Water transport and mixing in the whole-mantle scale convection

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The subduction of oceanic plates transports sea water with the basaltic crust to the Earth’ s interior. High-pressures experiments reveal that nominally anhydrous minerals (NAMs) contain the water of a few thousands ppm in the weight fraction. On the other hand, numerical simulations show that the NAMs layer above the subducted slab plays an important role in water transport into the deep mantle. However, the details of the water circulation and distribution processes on the whole mantle has still not been understood well.
We perform numerical simulations of isoviscous mantle convection in a two-dimensional cylinder in which hydrous-mineral phase changes and the hydration-dehydration reaction are considered. We systematically examined the effects of parameters that control activity and mixing efficiency of the mantle convection, i.e., the Rayleigh number, the internal heating rate, and the water storage capacity of the lower mantle, on the water transport into the deep mantle.
The distribution and total amount of the water transported into the mantle strongly depends on the convection style. When the internal heating is absent, stable cellular flow dominates the mantle convection. The stable convection does not mix water well so that the water distributes only near the convection cell boundary. When the mantle has the internal heating, the mantle flow becomes strongly time-dependent by thermal boundary layer instabilities. Migration of the convection cell boundary enhances the mixing of the water into the whole mantle. In addition, mixing efficiency increases with the Rayleigh number, which is an index indicating convective vigor. When the water storage capacity of the lower mantle is much smaller than the NAMs, the ejected water forms the regional hydrous layer with high water content over the 660 km discontinuity near the downwellings. However, these hydrous regions are hindered from globally spreading to the mantle transition zone. The water content in most of the mantle rocks becomes equal to the smaller value among water storage capacities of the NAMs in the upper mantle and the lower mantle finally, though the upper mantle can accommodate more water. The amount of the water stored in the whole mantle rocks is, therefore, smaller than the summation of their capacities. As a result, the equilibrium of the water regassing and degassing is realized more rapidly than the whole mantle rocks are completely saturated.

