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Effects of T- and p-dependent thermal expansivity on the layering of mantle convection and the fate of subducted slabs

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Recent high-pressure experiments provide precise thermal properties of the mantle materials under the pressure less than 30 GPa. Katsuta et al (2004) revealed temperature and pressure dependence of thermal expansivity of the ringwoodite, which is a main mineral of the transition zone. We have investigated influences of thermal expansivity on mantle convection using numerical modeling. We especially focus on its effects on the layering of the mantle convection when the mantle convection interacts with phase transitions. We examine the effects on (I) the basic character of mantle convection with constant viscosity, and (II) the interaction of a subducted slab with the transition zone. Phase transitions are set at the depth of 410 km and 660 km except three models with no phase transitions in Series (I). The results are summarized as follows.

(I) Effects on the mantle convection with constant viscosity
In Series (I), we examine pure effects of thermal expansivity. The physical properties including the viscosity are therefore set to be constant. The dimension of the model box is set to be 8000 km x 2000 km. The style of temperature and pressure dependence of thermal expansivity changes which thermal boundary layer (top or bottom) drives primarily the convection. When the phase transition is introduced, temperature and pressure dependence affects on the layering of the convection. If the temperature dependence of thermal expansivity is introduced, buoyancy of hot plumes is increased because of larger thermal expansivity due to the high temperature. In this case, two-layer convection is broken into the single layer more frequently than in the case with constant thermal expansivity.

(II) Effects on the subducted plate in the transitions zone
In Series (II), we construct models with a subducting plate generated self-consistently in the mantle convection system. We employ a 2-D model in a box with 8000 km x 1320 km. To produce plate-like motion with asymmetric subduction, we employ rheology with hysteresis-dependent yielding. Arrhenius-type temperature and pressure dependence is also considered. We assume intrinsic viscosity contrast to increase by 1 and 10 times between the upper and lower mantle. The viscosity totally changes by 1.5 to 30 times across the 660 km boundary because the latent heat of the phase transition changes the temperature. The Clapeyron slope for the 660 km phase transition is varied from -1 to -3 MPa/K. The slab penetrates into the lower mantle when the Clapeyron slope is -2 MPa/K with constant thermal expansivity and no intrinsic viscosity contrast. The temperature and pressure dependence of the thermal expansivity reduces the negative buoyancy of the slab so that it enhances the effect of the phase transition. This effect is equivalent to about +1 MPa/K reduction of a critical Clapeyron slope. The viscosity jump at the 660 km boundary also acts as a barrier for the stiff slab with shallow dip angle. A horizontally-lying slab is produced even in the case with the Clapeyron slope of -1 MPa/K if both the temperature- and pressure-dependent thermal expansivity and the viscosity jump are introduced.