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Sensitivity study of the thermal state in the lower mantle by 3-D convection with post-perovskite phase transition

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Numerical models have been systematically presented in order to study the possible influences of the post-perovskite (PPV) phase transition on the thermal state in the Earth's lower mantle. A time-dependent convection in a three-dimensional rectangular box of 3000 km height and aspect ratio 6x6x1 is considered. We employed an extended Boussinesq approximation, where the effects of latent heat exchange, adiabatic (de)compression and viscous dissipation are explicitly included. The viscosity of mantle materials is assumed to be exponentially dependent on temperature and depth. We take into account the temperature-dependence of thermal conductivity, which mimics the effects of radiative heat transfer expected to be dominant in a hotter part of the mantle. In addition to the endothermic phase transition at around 660 km depth, the transition between perovskite and PPV phases is modeled as a highly exothermic phase change located at about 200 km above the bottom surface. Spatial mesh divisions of up to 512x512x128 are utilized, by the help of newly developed algorithm for the Earth Simulator. We have varied (i) the rate of density change associated with the PPV transition which determines the intensity of latent heat exchange and (ii) the temperature at the core-mantle boundary (CMB) which determines the stability field of the PPV phase near the CMB through the relative positioning with the phase transition temperature there.

We found that the influence of the PPV phase transition is prominent only in the cases where (i) the transition is associated with a sufficiently large density jump and (ii) the CMB temperature is lower than the temperature of the PPV phase transition at the bottom surface. The former condition requires a sufficient amount of latent heat exchange during the phase transition, while the latter requires that the PPV phase transition takes place not only in cold but also in hot regions at depth. When the above conditions are met, the vertical temperature profile tends to be bent toward the equilibrium relations of the PPV phase transition owing to the buffering effect of latent heat exchange. Our results also indicate that, taken together with the thermodynamical nature of the PPV transition estimated so far from theoretical and experimental studies, the actual PPV transition is not likely to exert significant influences on the thermal state at depth because its density change is insignificantly small.

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