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Quantitative investigation of physical properties of mantle plumes in 3D numerical models

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Numerical calculations have been carried out to investigate the physical properties of plumes in mantle convection depending on the Rayleigh number. Boussinesq approximation was applied in a three-dimensional Cartesian domain filled with isoviscous, purely bottom-heated fluid. In order to monitor the dynamical behavior of plumes an automatic plume detecting routine (PDR) was developed based on the temperature difference between the plume and its surroundings.

It was established that by increasing the Rayleigh number (Ra) the average cross-sectional area of an individual plume decreases (appr. $\sim$Ra$^{-2/3}$), the vertical velocity in plumes increases ($\sim$Ra$^{2/3}$), while the average temperature in plumes is independent of Ra. The number of plumes forming in the box increases ($\sim$Ra$^{1/3}$) which is in accordance with the scale analysis using the energy balance and the conservation of momentum. Furthermore, the Rayleigh number influences the temporal behavior of the average surface heat flow (Nusselt number – Nu) and the heat advected by plumes. The characteristic time period of the fluctuation in Nu seems to be proportional to the conduction time for the thermal boundary layer. The characteristic time of the fluctuation of advection in the plumes scales approximately inversely with the vertical velocity. A strong correlation ($>$0.8) of the advected heat in plumes was observed at different depths of the model, and a weak correlation (0.3-0.4) between the Nusselt number and the heat advected by plumes was revealed in spite of strong smoothing in the top thermal boundary layer. The time shift used to achieve maximum correlation reassures that the heat in plumes is transported by advection and in the top thermal boundary layer mainly by conduction.