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Plume generation as key to plate motion history

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The positions of hot spots and eruption locations of large igneous provinces at the Earth's surface correlate well with the two Large-Low-Shear-Velocity-Provinces (LLSVPs) at the Core-Mantle Boundary. Moreover the fit between the hot spots and the edges of the LLSVPs was interpreted in the concept of the Plume Generation Zones (PGZs) at these edges - zones of hot, possibly partially molten regions that may be associated with the seismically observed Ultra-Low-Velocity Zones near the Core-Mantle Boundary. Mantle convection modeling and seismic observations have revealed a number of possible features and dynamic processes occurring near these PGZs, including the arrival of slabs and the distinction between purely thermal or thermo-chemical boundary layers. In particular, the incorporation of global plate reconstructions as surface velocity boundary conditions increased the fit and comparability between model results and real Earth observations. Nevertheless, the positions of plume generation and surface impingement have been far from realistic in these global models. However, simplifications and uncertainties that are often used include unconstrained viscosity profiles, chemical heterogeneities and their properties as well as uncertainties in plate reconstructions, which have not yet been considered in a unified set of models.

In this work we show the extensive consequences of several of these simplifications on the distribution and shape of plume generation and rise. The correct adaption of material properties – especially the viscosity description – as well as consideration of thermo-chemical rather than purely thermal convection, and existing constraints on plate motion lead to a statistically significant fit between model results and real-earth observations. We show that a strong link exists between plate tectonics at the surface and plume generation at the Core-Mantle Boundary. Moreover, we illustrate how the model plumes form two clusters that are similarly arranged as observed hot spots, with each cluster centre overlying the centre of the corresponding LLSVP. This connection and clustering is not observed in models without prescribed plate velocities and shows a different pattern in a model with purely thermal convection. Finally, we demonstrate that modifications in the imposed plate reconstruction lead to characteristic changes in the shape of modeled LLSVPs and plume distribution. Thus, comparison between global mantle convection models and real Earth observations might enable us to improve existing plate reconstructions and to estimate their reliability.