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New Insights into Plume Buoyancy Fluxes and Dynamic Topography from Numerical Modelling

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Mantle plumes are hot upwellings that transport heat from the core to the base of the lithosphere, and sample lowermost-mantle chemical structure. Plume buoyancy flux is a crucial parameter measuring the mass and heat mantle upwellings bring to the surface. However, the calculation of the global plume buoyancy fluxes is still in contention. Hotspot swells (topographically high regions with elevations of up to 2~3 km and widths of up to ~1500 km) are diagnostic surface expressions of mantle plumes.

Traditional approaches to calculate the swell buoyancy flux are based on two assumptions: (1) the asthenosphere moves at the same speed as the overriding plate; (2) hotspot swells are fully isostatically compensated, in other words, the seafloor is uplifted due to the isostatic effect of replacing ”normal” asthenosphere with hot plume material. However, at least some plumes (e.g., Iceland) can move faster than the corresponding plate motion. Also, hotspot swells are partly dynamically compensated as plume material is injected into the upper mantle. With increasingly accurate observational constraints for dynamic seafloor topography, it is time to update plume buoyancy fluxes globally and build a scaling law between the surface dynamic topography and plume buoyancy flux.

Here, we conduct thermomechanical models to study plume-lithosphere interaction and hotspot swell support. We use the finite-element code ASPECT in a high-resolution, regional, 3D Cartesian framework. We consider composite diffusion-dislocation creep rheology and a free-surface boundary at the top. We systematically investigate the effects of plume excess temperature, plume radius, plate velocity and age, and mantle rheological parameters. From these results for plume spreading beneath moving plates, the buoyancy fluxes of individual plumes, as well as the relevant plume temperatures and radii are quantitatively constrained. We find that: (1) for a fixed plume radius, higher plume excess temperature results in higher but not necessarily wider swell; (2) plume buoyancy flux is linearly proportional to swell height × width^2; (3) both faster plate velocities and older plates result in a lower swell height; (4) Lower upper mantle viscosity results in a wider but lower swell provided at a fixed plume buoyancy flux.

We demonstrate that previous swell-geometry-based estimates underscore the true buoyancy fluxes of the underlying plume upwelling. We update the plume-flux catalogue by building a scaling law for buoyancy flux as a function of swell geometry in order to estimate global heat and material fluxes carried by plumes.