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Effects of core-mantle-boundary heat flow anomalies on a thermally stratified outer core

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Seismological observations, geomagnetic data and mineral physics calculations have all been used to infer the presence of a stably stratified layer at the top of Earth's fluid outer core. The outer core responds to the core-mantle-boundary as a rigid surface with a fixed heat flux imposed by the lower mantle because the timescales of core motion are much shorter than those of the overlying mantle. Seismic tomography shows two large regions of the lowermost mantle with anomalously low S-wave velocity, the Large Low Shear Velocity Provinces (LLSVPs), which are usually thought to be hotter than their surroundings, though perhaps chemically distinct, and so extract less heat from the core. Previous studies of convection in rotating spherical fluid shells have shown that lateral heat flow variations on the outer boundary will drive thermal winds and that boundary-driven flows are capable of penetrating deep into the fluid. These previous works have considered only weakly (or not at all) stratified fluids, so a key question is whether boundary forcing can penetrate into a strongly stratified layers and mix the layer into the bulk of the fluid.

We use numerical simulations of boundary driven flow in a rapidly rotating, thermally stratified spherical annulus with a Y22 spherical harmonic heat flux pattern imposed on outer boundary. We explore a broad range of thermal stratification strength (St), boundary anomalies strength (B) and Ekman number (E) and investigate the scale of penetration of flow into the fluid and whether strong thermal anomalies can induce radial flows such that the stratified layer is destroyed. For steady solutions, a clear transition is found between low St, which has virtually no influence on flow, and high St, which reduces velocities and confines flow to thin shear layers at the top of the core. We develop scaling laws for the dynamics, which we extrapolate to Earth's core parameters.