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Scaling of vorticity generation due to density stratification: Implications for the Earth

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Differential flow is one of the key components needed to maintain a magnetic dynamo, therefore it is important to understand the processes that generate differential flows in rotating bodies. In a rotating density-stratified fluid, local vorticity generation occurs as fluid parcels move radially, expanding or contracting with respect to the background density stratification. The convergence of this vorticity forms zonal flow structures as a function of the radius and the slope of the background density profile. While this effect is thought to be of importance in bodies that are quickly rotating and highly turbulent with large density stratifications such as Jupiter, it is mainly neglected in bodies such as the Earth's outer core, where the density change is small. Simulations of thermal convection in the 2D rotating equatorial plane are conducted to determine the parameter regime where local vorticity generation plays a significant role in organizing the fluid flow. Three regimes are found: a dipolar regime, where the flow is not organized by the rotation, a transitional flow regime, and a differential flow regime, where the flow is strongly organized into zonal flow with multiple jets with radius. A scaling law is determined based on the convective Rossby number and the density contrast across the equatorial plane, providing a simple way to determine in which regime a given body lies. While a giant planet such as Jupiter lies firmly in the differential flow regime as expected, the Earth's outer core is also found to lie in the differential flow regime indicating that, even in the Earth's outer core, where the density contrast is small, vorticity contributions via fluid movement through the density stratification may be non-negligible.