A comparison between top-down and bottom-up type convective flows in a rotating spherical shell with stress-free boundaries

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The terrestrial bodies that maintain their intrinsic magnetic fields have dynamos in the fluid cores, in which convection is developed by a certain kind of compositional/thermal buoyancy sources. In the Earth´s core, compositional buoyancy is given by light element ejection into the outer core caused by inner core growth. In other words, compositional convection occurs as a "bottom-up" type convection. In other celestial bodies, iron ejection due to solidification of iron could occur at different depth, strongly depending on temperature-pressure conditions and bulk sulfur content within the core. When iron solidification occurs at or around the core-mantle boundary, the solid iron falls downward like snow drop, that is, so-called "iron snow". The iron snow can remelt, and then the fluid motion is driven as "top-down" type convection. In this study, basic features of the flows driven by these two types of buoyancy are investigated.
For this purpose, onsets of top-down and bottom-up compositional convection in a rotating spherical shell are studied as a linear stability problem. We consider the Boussinesq fluid contained in the rotating spherical shell, of which radius ratio is 0.2. The linearized governing equations, that is, conservation equations of the momentum and mass, and the transport equation of composition, are solved as an eigenvalue problem. The adopted values of the Ekman number, *Ek* range from 10^{-4} to 10^{-3}. Boundary conditions are stress-free and impermeable for the velocity field, and fixed flux for composition. It is found that the critical Rayleigh numbers *Rac* shows an Ekman-number-dependence of $Ra_c \propto Ek^{-1.26}$ for the top-down case and $Ra_c \propto Ek^{-1.09}$ for the bottom-up one. The flows at the onsets for both the types have columnar convection owing to the effect of rotation. Motion in the top-down case is dominated by the convection outside the tangent cylinder, which is an imaginary cylinder co-axial with the rotation axis touching the inner sphere at the equator. On the other hand, the axially elongated flow structure around the surface of the tangent cylinder is formed in the bottom-up case as well as columnar flows outside the tangent cylinder. In decreasing the Ekman number, it repeats that the structure inside the cylinder appears and vanishes, and depends on the transition of critical horizontal wavenumber.

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