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Triaxial rotation of the inner and outer spheres driven by Boussinesq thermal convection in a rotating spherical shell

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The problem of Boussinesq thermal convection in a rotating spherical shell has been investigated in reference to the global thermal convection in astronomical bodies. While there are some MHD dynamo models allowing the inner sphere rotation, studies of thermal convection performed so far have assumed that both inner and outer spheres rotate with the same constant angular velocity (co-rotation). However, the spheres do not necessary co-rotate in the actual astronomical bodies, and it is a more natural situation that both the spheres rotate freely. Actually, recent seismological researches suggest that the inner core of the Earth rotates differentially against the mantle. In the present study, therefore, we construct a Boussinesq thermal convection model allowing triaxial rotation of both spheres due to the viscous torques of fluid. We compare the convection flow with those of the co-rotating system[1], and discuss characteristics of rotation of both spheres.

First, we consider the case where the inner sphere rotates due to the torque while the angular velocity of the outer sphere is fixed. We seek for the finite-amplitude solutions which bifurcate supercritically at the critical point with the Newton method. The ratio of the radii of the inner and outer spheres and the Prandtl number are fixed to 0.4 and 1, respectively, while the Taylor number is varied from 52^2 to 500^2. No-slip and fixed temperature boundary conditions are given on both spheres. The obtained solutions propagate in the azimuthal direction and have four-fold symmetry around the rotation axis. When the Taylor number is less than 100^2, the inner sphere rotates in the prograde direction with respect to the outer sphere. However, when the Taylor number is between 200^2 and 300^2, both spheres rotate with about same angular velocity, and when the Taylor number is larger than 400^2, the inner sphere rotates in the retrograde direction. The stable region of TW4s differs from that of the co-rotating system at most by one percent, and the pattern of TW4s is qualitatively the same.

Secondly, numerical time integrations are performed in the case where both spheres freely rotate due to the viscous torque of the fluid. The radius ratio, the Prandtl number and the Taylor number are set to be 0.4, 1 and 500^2, respectively, with the Rayleigh number being 30,000 (= 4.7 R_c) and 50,000 (= 7.8 R_c) where R_c is the critical Rayleigh number. No-slip and fixed temperature boundary conditions are applied on both spheres. The inertial moment of the inner sphere is set to be 0.22, assuming that the density of the inner sphere is the same as that of fluid, while the inertial moment of the outer sphere is assumed to be 100, which is similar to the value of the mantle of the Earth. When the Rayleigh number is 30,000, the convection pattern has the equatorial symmetry and only the axial components of the angular velocity of the inner and outer spheres have significant values, although the behavior of convection pattern appears to be chaotic. When the Rayleigh number is 50,000, however, the equatorially asymmetric convection pattern emerges and all the three components of the angular velocity of both the spheres have significant values.

Finally, we examine the transition Rayleigh number where the equatorially asymmetric convection patterns emerge in the range of the Taylor number between 500^2 and 5000^2. We find that the equatorially asymmetric convection patterns appear when the Rayleigh number is larger than $5R_c$ - $6R_c$.

[1] K.Kimura, S.Takehiro and M.Yamada, Phys. Fluids, Vol.23, 074101 (2011)

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