Effects of dynamical boundary condition on banded structure produced by convection in a rotating spherical shell

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Surface flows of Jupiter and Saturn are characterized by the broad prograde zonal jets around the equator and the narrow alternating zonal jets in mid- and high-latitudes. ``Shallow'' models can produce narrow alternating jet sin mid- and high-latitudes, while the equatorial jets are not necessarily prograde. On the other hand, ``deep'' models, can produce equatorial prograde flows easily, while it seems to be difficult to generate alternating jets in mid- and high-latitudes. Heimpel and Aurnou (2007) proposed thermal convection in rapidly rotating thin spherical shell models and show that the equatorial prograde zonal jets and alternating zonal jets in mid- and high-latitudes can be produced simultaneously when the Rayleigh number is sufficiently large and convection becomes active even inside the tangent cylinder. However, they assume eight-fold symmetry in the longitudinal direction and calculate fluid motion only in the one-eighth sector of the whole spherical shell. Such artificial limitation of the computational domain may influence on the structure of the global flow field. For example, zonal flows may not develop efficiently due to the sufficient upward cascade of two-dimensional turbulence, or stability of mean zonal flows may change with the domain size in the longitudinal direction.
On these accounts, we performed long time numerical experiment of thermal convection in the whole thin spherical shell domain, where the experimental setup is same as that of Heimpel and Aurnou (2007). The result shows that the banded structure disappears and one broad eastward zonal jet appears in mid- and high- latitudes of each hemisphere, suggesting that the solution of Heimpel and Aurnou (2007) is not a statistically steady state but a transient state.
However, this solution where the inverse cascade efficiently operates presumably depend on the stress free dynamical boundary condition on the inner and outer spheres. Therefore, in this study, we change the stress free condition to the no-slip condition at the inner sphere to examine effects of dynamical boundary condition on the emergence of surface banded structure. The no-slip condition at the lower boundary may be more realistic for the application of the gas giant planets, since MHD drag is thought to operate in the transition between the neutral and electrically conducting layers.
We consider Boussinesq fluid in a spherical shell rotating with constant angular velocity. The non-dimensionalized governing equations consist of equations of continuity, motion, and temperature. The non-dimensional parameters appearing in the governing equations, the Prandtl number, the Ekman number, the modified Rayleigh number, and the radius ratio, are fixed to 0.1, 3×10^{-6}, 0.05, and 0.85, respectively. The thermal boundary condition is fixed temperature. Free-slip condition is adopted at the top boundary, while no-slip condition is applied at the bottom boundary. The initial condition of the velocity field is state of rest and that of the temperature field is conductive state with random temperature perturbations.
After time integration for about 12000 rotation period, a strong equatorial prograde surface zonal jet and weak alternating banded zonal jets emerge. In contrast to the case of free-slip condition at both boundaries, this banded structure in mid- and high-latitudes is maintained until about 19000 rotation periods. The reason why the banded structure does not disappear is considered to be

inhibition of inverse cascade caused by the Ekman friction which dissipates large scale flow efficiently.

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Reference:

- Heimpel, M., & Aurnou, J., Icarus, 187, 540--557, April 2007.

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