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9:30〜9:45

Energy transfer among the equatorially symmetric components of magnetic and flow fields during dipole reversals in geodynamo model

#Takumi Kera$^{1)}$,Hiroaki Matsui$^{2)}$,Masaki Matsushima$^{3)}$,Yuto Katoh$^{1)}$
$^{(1}$Dept. Geophys., Grad. Sch. Sci., Tohoku Univ.,$^{(2}$UC Davis,$^{(3}$Tokyo Tech

Paleomagnetic observations have revealed that the geomagnetic field has reversed its polarity a number of times. Numerical dynamo simulations have represented dipole reversals and provided insights into physical processes that give rise to the polarity reversals. Both paleomagnetic observations and numerical dynamos have inferred that the equatorial symmetry of the magnetic and velocity fields is related to polarity reversals. The tilt of the virtual geomagnetic dipole obtained by the paleomagnetic field observations during the past 150 Ma shows that geomagnetic field reversed polarity more frequently when the geomagnetic field was more symmetrical with respect to the equator (McFadden et al., 1991). Dynamo simulations revealed a strong inverse correlation between the stability and the equatorial symmetry of the magnetic field (Coe and Glatzmaier, 2006). Olson et al., (2004) proposed a process of magnetic polarity reversals in a dynamo model. In their model, the reversed magnetic field flux is produced locally in the convective plumes near the inner core boundary and transported from one hemisphere to the other hemisphere by the meridional circulation. This result suggests that anti-symmetric flow with respect to the equator plays a large role in reversals. This anti-symmetric flow is enhanced when the magnetic dipole is reversed. Nishikawa and Kusano (2008) explained this asymmetric velocity field enhancement by enhancement of energy transfer from magnetic field to asymmetric velocity field in polarity reversal phase by the Lorentz force. However, Nishikawa and Kusano (2008) set large magnetic Prandtl number (Pm=15), and there is no comparison of contribution between the amplitude of the Lorentz force and buoyancy. In the present research, we investigate how anti-symmetric flow is growing and maintained in the dynamo in which reversals occur with lower Pm.

We perform dynamo simulations using Calypso (Matsui et al., 2014) to represent dipole dominant dynamo with reversals. In the present study, we set the fixed heat flux, non-slip, and connecting the potential field at the inner and outer boundaries as the boundary conditions for temperature, velocity, and magnetic field, respectively. For the dimensionless numbers, we set dimensionless numbers to Ekman number E = 6x10^{-4}, Prandtl number Pr = 1, magnetic Prandtl number Pm = 5 and modified Rayleigh number Ra = 2000. We investigate the energy fluxes in terms of the symmetricity with respect to the equator in the stable polarity phase and in the polarity reversal phase, respectively.

When the dipole magnetic field sustains stably, the symmetric component is dominant for the velocity field, and magnetic field is dominated by the anti-symmetric components. On the other hand, during the reversal, flow fields are nearly anti-symmetric outside the tangent cylinder, while symmetrical and anti-symmetrical magnetic fields are comparable in amplitude. The energy conversion between components of different symmetry is also analysed.

We decompose the buoyancy fluxes for the symmetric and antisymmetric flow as $<$Ra T_s $\mathbf{u}_s$. $\mathbf{r}/r_o$$>$and $<$Ra T_a $\mathbf{u}_a$. $\mathbf{r}/r_o$$>$where subscripts s and a indicates symmetric and anti-symmetric components, respectively. We also decompose work of Lorentz force $<\mathbf{u}_s.\ (\mathbf{J}_s\ \hat{}\mathbf{B}_a)>$, $<\mathbf{u}_s.\ (\mathbf{J}_a\ \hat{}\mathbf{B}_s)>$, $<\mathbf{u}_a.\ (\mathbf{J}_s\ \hat{}\mathbf{B}_s)>$and $<\mathbf{u}_a.\ (\mathbf{J}_a\ \hat{}\mathbf{B}_a)>$. In the reversal phase, buoyancy flux to asymmetric velocity field $<$Ra T_a $\mathbf{u}_a$. $\mathbf{r}/r_o$$>$increases 1.05 times of that in the stable phase, while $<$Ra T_s $\mathbf{u}_s$. $\mathbf{r}/r_o$$>$decrease 0.98 times of that in the stable phase. This result may explain that asymmetric velocity field is enhanced in the reversal phase. Looking at the work of Lorentz force in the stable polarity phase, energy transfer from the symmetric velocity to the symmetric magnetic field $-<\mathbf{u}_s.\ (\mathbf{J}_a\ \hat{}\mathbf{B}_s)>$keeps 0.92 times of the symmetric velocity to the antisymmetric magnetic field $-<\mathbf{u}_s.\ (\mathbf{J}_s\ \hat{}\mathbf{B}_a)>$. In the reversal phase, only the energy transfer from the symmetric flow to antisymmetric magnetic field decreases from the stable dipolar phase, resulting that $-<\mathbf{u}_s.\ (\mathbf{J}_a\ \hat{}\mathbf{B}_s)>$is 1.12 times larger than $-<\mathbf{u}_s.\ (\mathbf{J}_s\ \hat{}\mathbf{B}_a)>$. This change can make the amplitude of the symmetric component of the magnetic field comparable to that of the anti-symmetric component during the reversal. In addition, conversion of asymmetric velocity to asymmetric magnetic field $<\mathbf{u}_a.\ (\mathbf{J}_s\ \hat{}\mathbf{B}_s)>$remains up to 90% of that in the stable phase, while the other terms decrease to nearly 60% from the stable phase. Consequently, asymmetric velocity field more contribute to generate antisymmetric magnetic field than in stable phase.