Dependence of the dipole component dominancy on the Rayleigh number and inner core size in geodynamo simulations

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Geomagnetic field is generated by a dynamo action in the fluid outer core. Studies of the thermochemical evolutions of the Earth's core suggest that the solid inner core has been growing up for approximately one billion years [e.g., O'Rourke and Stevenson, 2016]. Results of numerical dynamo simulations with various aspect ratios (ratios of inner to outer core radii) indicates that the sustained magnetic field is categorized into dipolar-dominated or non-dipolar-dominated regime [e.g., Hori et al., 2010; Driscoll, 2016]. However, any dominant factors controlling the regime have not been fully understood. In the present study, we perform dynamo simulations with various inner core radii using a geodynamo code Calypso to investigate the characteristics of the generated magnetic field. We fix the Ekman, Prandtl, and magnetic Prandtl numbers to be $E = 10^{-3}$, $Pr = 1$, and $Pm = 5$, respectively, and change the Rayleigh number and the aspect ratio to be $r_i/r_o = 0.15$, 0.25, and 0.35. Then we examine the dominancy of the dipole component in two approaches; one is calculating the dipolarity, f_{dip}, which is the ratio of the amplitude of the axial dipole magnetic field to the total amplitude, and the other is comparing magnetic energy for the dipole component with extrapolated magnetic energy for $l = 1$ using an exponential function for odd degree components from $l = 3$ to $l = 19$. The magnetic energy for the dipole component is compared with that extrapolated from the fitting curve.

In $r_i/r_o = 0.25$ and 0.35 cases, f_{dip} is approximately 0.8 at $Ra/Ra_{crit} \fallingdotseq 2.0$ and gradually decreases to approximately 0.45 with increase of Ra/Ra_{crit} up to around 6.0, where Ra_{crit} is the critical Rayleigh number. By referring to the obtained fitting curve, we find that the magnetic energy for the dipole component is more than 5 times larger than the extrapolated value for $l = 1$ at $Ra/Ra_{crit} \fallingdotseq 2.0$ and decreases with increase of Ra/Ra_{crit} in both aspect ratios. The dependency of the dipole component dominancy on the Rayleigh number is similar in both aspect ratio cases. However, in the $r_i/r_o = 0.15$ case, f_{dip} is approximately 0.4 at $Ra/Ra_{crit} \fallingdotseq 8.0$ and decreases to approximately 0.1 with increase of Ra/Ra_{crit} up to around 15.6. At $Ra/Ra_{crit} = 8.1$ and 9.0, the amplitude of the dipole component is comparable to extrapolated value from the fitting curves. At $Ra/Ra_{crit} > 10.1$, the magnetic energy for $l = 1$ component is smaller than that for the $l = 2$ component. Consequently, the magnetic field obtained in the simulation results is non-dipolar. To summarize above, we categorize the present dynamo simulations as shown in Figure 1. Here we define strong/weak dipolar dynamo by a condition that the magnetic energy is larger/smaller than the kinetic energy. The axial dipolar component becomes small in all three ratio cases for larger Rayleigh numbers. Non-dipolar components become larger for the smaller inner core. In other words, for $r_i/r_o < 0.35$, it is likely that the dipolar magnetic field is dominant for larger inner core.

Keywords: Geodynamo, Inner core size, Rayleigh number, Dipole component dominancy

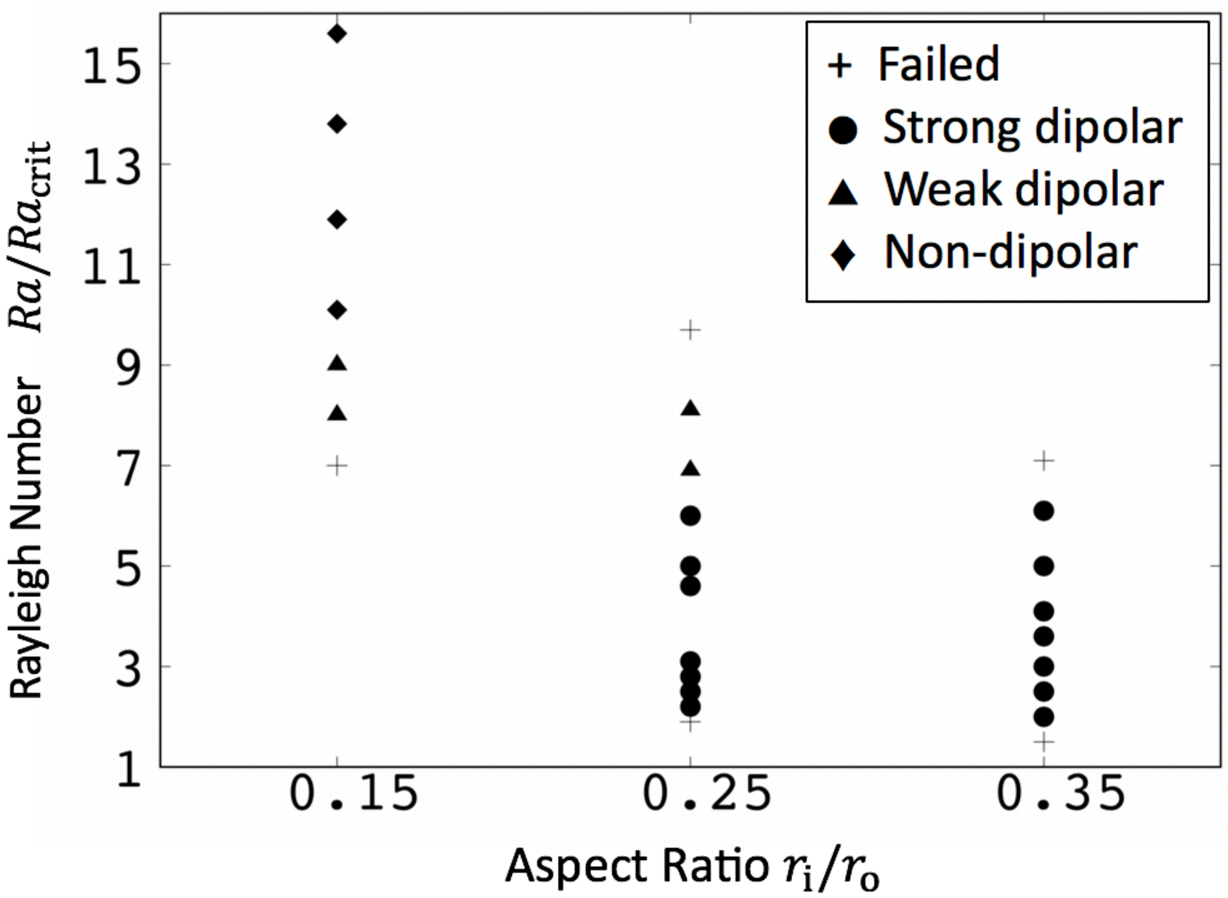

Figure 1 Dynamo regime in various aspect ratios. Cross, circle, triangle, and diamond symbols represent failed, strong dipolar, weak dipolar, and non-dipolar dynamo cases, respectively.