# Study of the required Rayleigh number to sustain geodynamo with various inner core radius

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The Earth has an intrinsic magnetic field. Paleomagnetic studies suggest that the geomagnetic field has been sustained over 3.5 billion years [e.g., Biggin et al., 2015], and studies of the thermal history of the Earth suggest that the inner core grows to the current size in the last billion years [e.g., O'Rourke & Stevenson, 2016]. The magneto-fluid convection driven by thermal and compositional buoyancy in the outer core is thought to cause geodynamo. While characteristics of magneto-fluid convection have been investigated in detail for the present radius ratio $r_i/r_o$=0.35, there have been few simulations for the settings of $r_i/r_o < 0.35$, which correspond to the environment of the past Earth. It is important to investigate the dynamo process occurring under the settings of $r_i/r_o < 0.35$, so as to examine conditions of the past Earth. Using the numerical dynamo open source code Calypso [Matsui et al., 2014], we perform a series of numerical simulations of the thermal convection and dynamo with the smaller inner core settings than the present inner core. To investigate the characteristics of the convection for dynamo process, we focus on the dependence of dynamo properties on the Rayleigh number, *Ra*, which is a parameter related to buoyancy, or a driving force of convection. Only *Ra* is treated as a variable and the other control parameters, the Ekman number *E*, the Prandtl number *Pr*, and the magnetic Prandtl number *Pm* are fixed to be $E = 10^{-3}$, $Pr = 1$, and $Pm = 5$, respectively.

In previous dynamo simulations, the property of *Ra* around the onset of dynamo action has been revealed for various radius ratios [Heimpel et al., 2005]. The tendency of the dynamo action has also been investigated by previous studies in the present ratio $r_i/r_o = 0.35$ [Christensen and Aubert, 2006], but the behavior of dynamo with *Ra* has not been fully understood with the smaller inner core. We perform dynamo simulations with a range of $1.9\ Ra_{crit} < Ra < 9.7\ Ra_{crit}$, where $Ra_{crit}$ is the critical Rayleigh number, and with the aspect ratio $r_i/r_o = 0.15$, 0.25, and 0.35, to quantitatively understand the tendencies with the smaller inner core. The results with $r_i/r_o = 0.25$ show that the sustained dipolar dominant dynamo occurs just above the onset of the dynamo action. In the case with larger *Ra* than that for the dipolar regime, non-dipolar components of the magnetic field is sustained. Finally, dynamo failed in the case with $Ra > 8.1\ Ra_{crit}$. The simulation results reveal that the magnetic energy density is largest at the dynamo onset, and becomes smaller at larger *Ra*. This implies that dynamo is not likely to be sustained in intense convection under the assumed setting. The results of $r_i/r_o = 0.25$ and 0.35 imply that the revealed tendency revealed by the present study can be applied to $r_i/r_o = 0.15$. Comparing the simulation results in the same $Ra/Ra_{crit}$(= 3.6), the magnetic dipole moment becomes smaller with the smaller inner core. This suggests a possibility that the convection favorable for the dipolar dominant dynamo is difficult to occur with the smaller inner core. We also find that the *Ra* range of the dipolar dominant cases becomes narrower with the smaller inner core, implying that *Ra* was very selective at the past Earth. To interpret the simulation results with the real physical quantities, the average temperature difference between the core-mantle boundary and the inner core boundary, $\Delta T$, is estimated. $\Delta T$ in $r_i/r_o = 0.25$ is larger than that in $r_i/r_o = 0.35$, so required buoyancy to sustain a dipolar dominant dynamo is larger with the smaller inner core.

Keywords: geodynamo, the past Earth, the inner core size