Title: Influence of inner core radius on thermal convection in a rotating spherical shell near the critical Rayleigh number

Authors: Yuki Nishida[1], Yuto Katoh[1], Hiroaki Matsui[2], Masaki Matsushima[3], and Atsushi Kumamoto[1]
([1]Tohoku University, [2]University of California, Davis, [3]Tokyo Institute of Technology)

Abstract:

The Earth has an instinct geomagnetic field. Geomagnetic field is generated by a dynamo action of liquid iron alloy convection in the outer core. Recent thermochemical calculations suggest that the solid inner core was nucleated about 1 billion years ago and after that it has grown to the present size from thermochemical calculations [e.g., O'Rourke and Stevenson, 2016]. There is a probability that change of the convective-rigion geometry influenced on the outer core convection, but geodynamo has sustained over 3.5 billion years from paleomagnetic analyses [e.g., Biggin et al., 2015]. It is important to reveal properties of dynamo in a rotating spherical shell corresponding to the past Earth in the perspective of understanding MHD and elucidating the environment of the past Earth. Because there are a few studies, in which Heimpel et al. (2005) discussed dynamo onset in the various inner core radii, geodynamo different from the current inner core size has not been fully understood. In the present study, using a numerical dynamo code Calypso [Matsui et al., 2014], we carried out non-magnetic thermal and dynamo simulations in three different aspect ratios: $r_\mathrm{i}/r_\mathrm{o} = 0.15, 0.25,$ and 0.35 (the present value), where r_i and r_o are the inner core and outer core radii, respectively. In $r_\mathrm{i}/r_\mathrm{o} = 0.15$, there are weak dipolar and non-dipolar dynamo cases. In $r_\mathrm{i}/r_\mathrm{o} = 0.25$, there are string and weak dipolar dynamo cases. In $r_\mathrm{i}/r_\mathrm{o} = 0.35$, there are only strong dipolar dynamo cases. In order to quantify a convection structure, we calculated a length scale of flow in azimuthal direction [cf. King and Buffett, 2013]. As a result, it is revealed that in both cases of $r_\mathrm{i}/r_\mathrm{o} = 0.25$ and 0.35, the dominant length scale in MHD cases is the same as that in non-magnetic cases in the range of Rayleigh number where dynamo is not sustained, $1.0\,Ra_\mathrm{crit} < Ra < 1.9\,Ra_\mathrm{crit}$ in $r_\mathrm{i}/r_\mathrm{o} = 0.25$ and $1.0\,Ra_\mathrm{crit} < Ra < 1.3\,Ra_\mathrm{crit}$ in $r_\mathrm{i}/r_\mathrm{o} = 0.35$. Ra is the Rayleigh number and Ra_crit is the critical Rayleigh number. It is also found that the scale of structure in non-magnetic cases gets larger than that in the Ra range of non-sustained dynamo cases, but that in MHD cases is comparable to non-sustained dynamo cases in the range of Rayleigh number where dynamo start to be sustained, in both cases of aspect ratios, $2.2\,Ra_\mathrm{crit} < Ra < 2.8\,Ra_\mathrm{crit}$ in $r_\mathrm{i}/r_\mathrm{o} = 0.25$ and $1.5\,Ra_\mathrm{crit} < Ra < 2.0\,Ra_\mathrm{crit}$ in $r_\mathrm{i}/r_\mathrm{o} = 0.35$. It is specifically shown that the dominant mode in thermal convection is changed from $m = 2$ to $m = 1$ in $r_\mathrm{i}/r_\mathrm{o} = 0.25$ and from $m = 4$ to $m = 3$ in $r_\mathrm{i}/r_\mathrm{o} = 0.35$ with Ra increasing. On the other hand, it is also shown that the dominant mode in dynamo cases convection remains for $m = 2$ in $r_\mathrm{i}/r_\mathrm{o} = 0.25$ and $m = 4$ in $r_\mathrm{i}/r_\mathrm{o} = 0.35$. These results show that the mode of maximum growth rate depends on Ra and initial magnetic field. In order to understand the structure of convection, it is needed to investigate what modes are easy to grow. In Ra at the onset of dynamo action, maximum growth mode is $m = 1$ and 3 in $r_\mathrm{i}/r_\mathrm{o} = 0.25$ and 0.35. In brief, maximum growth mode in MHD cases is larger than that in magneto-convection model.