ÉCOLE DOCTORALE
SCIENCES DE LA TERRE ET DE L'ENVIRONNEMENT
ET PHYSIQUE DE L'UNIVERS, PARIS

Subject title: Full-sphere geodynamo simulations and their paleomagnetic implications

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The Earth's dynamo, the so-called geodynamo, is sustained by thermal-chemical convection in its liquid outer core. Cold and dense material sinks from the core-mantle boundary, where heat is extracted from the core by the overlying mantle, and light material and latent heat are released at the inner core boundary by the ongoing cristallization of the inner-core. At present-day, this cristallization is thought to be the major contributor to the power budget that is necessary to quench the geodynamo's thirst (e.g. Lister, 2003).

The current radius of the inner core (1221 km) amounts to approximately one third of the core radius (3485 km). The time in the past when the cristallization started is uncertain and controlled by the thermal evolution of the Earth as a whole over its geological history. A key parameter controlling the thermal state of the core as it cools is its thermal conductivity, k_T, estimates of which span almost one order of magnitude in the recent literature (e.g. Ohta et al., 2016; Zhang et al., 2020). This is not without consequences, as high values of k_T preclude a pre-inner core dynamo based on thermal convection alone, and demand additional sources of energy to be sought (e.g. Badro et al., 2016). In any event, the inner core is a relatively young structure of the Earth's interior, as recent estimates of its age range between 500 Ma and 1.3 Ga (Zhang et al., 2020, and references therein).

Yet, paleomagnetic analyses of ancient rocks indicate that the geodynamo has been operating for at least 3.4 Gyr, producing a magnetic field whose strength was large enough to be properly recorded (Tarduno et al., 2014). This implies that the geodynamo has been a full sphere fluid dynamo for most of its life. Some of the most intriguing paleomagnetic features, such that the hyperreversing regime recently put forward by e.g. Bazhenov et al. (2016); Gallet et al. (2019), could have been the product of such a full-sphere dynamo.

Full sphere dynamo action sustained by thermal convection alone has received little attention in a geophysical context, notwithstanding the work of Landeau et al. (2017) who compared a handful of simulations of dynamo action in the present-day, spherical shell geometry with a handful of simulations in the full-sphere geometry. Their conclusions are the following:

1. inner-core nucleation leaves no long-term trend in the paleointensity record
2. interestingly, the absence of an inner core enables a nondipolar and hemispherical dynamo regime that could have caused short-lasting paleomagnetic anomalies.

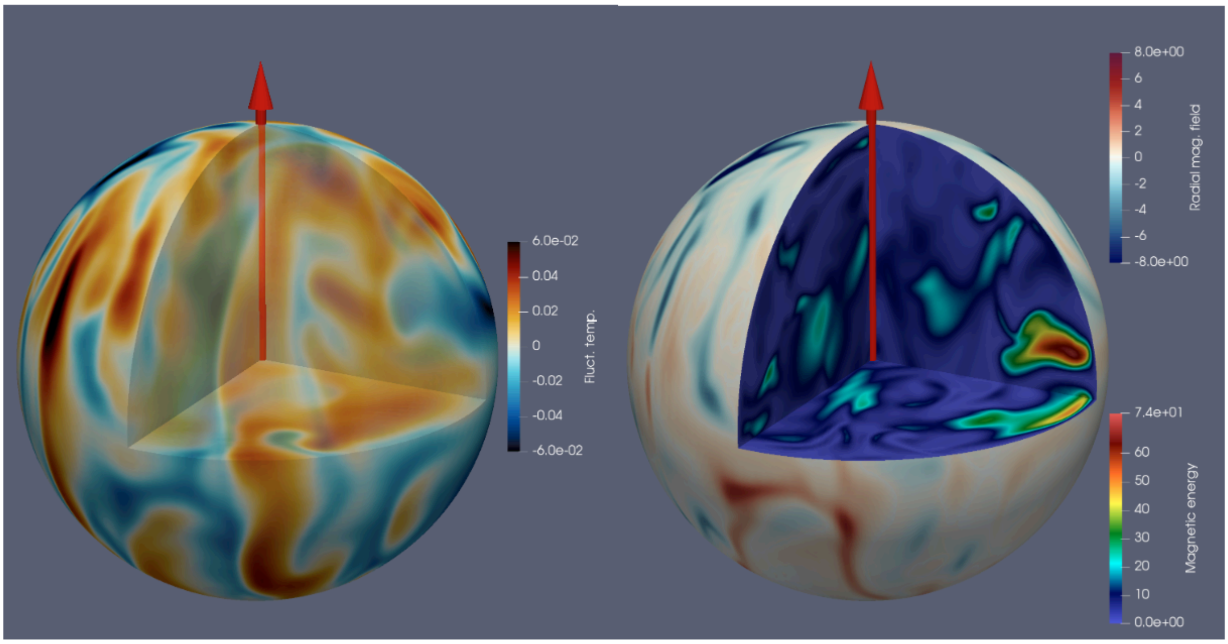

Figure 1: Preliminary full-sphere dynamo simulation. The red arrow is the axis of planetary rotation. Left: Temperature anomaly (see the cold downwelling in the equatorial plane. Right: Shown on the surface is the radial component of the dipole-dominated magnetic field. Shown in the bulk is the magnetic energy density, which appears to be concentrated in pockets in the vicinity of the core–mantle boundary.

These findings demand confirmation based on a more systematic analysis, as they may dramatically impact our interpretation of paleomagnetic intensity measurements. **The overarching goal of this PhD is to investigate the properties of thermally-driven dynamo action in a full sphere geometry through a systematic exploration of parameter space**. End products will include an extension of the scaling laws currently available for the spherical shell dynamo (e.g. Christensen, 2010) to the full-sphere dynamo, the determination of the boundaries between dipole-dominated and multipolar dynamos, and an analysis of the reversing properties of such dynamos, in order to facilitate the interpretation of paleomagnetic data.

Simulations will rest on the open-source, pseudo-spectral MagIC code[1], whose main developer is co-advisor Thomas Gastine. MagIC is equipped with a full-sphere technology which makes it possible to run full-sphere simulations without being penalized by the unwanted concentration of grid points in the vicinity of the center of a sphere. An example of a preliminary full-sphere dynamo calculation is given in Figure 1. This high-performance, massively parallel code is routinely run on the local S-CAPAD cluster and national facilities. It was used by former PhD student Tobias Scwhaiger to investigate the force balance in the present-day geodynamo (Schwaiger et al., 2019) and is currently the workhorse for PhD student Théo Tassin's thesis on double-diffusive convection and dynamo action (Tassin et al., 2021).

This thesis work falls within the general framework of modeling the dynamics of geophysical and astrophysical fluids, in particular by studying instabilities and establishing scaling laws. It involves developing strong skills in physical and numerical modeling. **We seek an indidividual with a solid background in geo or astro-physics**. Experience with parallel programming and/or paleomagnetic data is a plus. Depending on the PhD student's interests, emphasis may be placed on some numerical aspects, or on the paleomagnetic interpretation of our findings, through interaction with paleomagnetists (at IPGP and beyond).

1 https://github.com/magic-sph/magic

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