The Generation of the Earth’s Magnetic Field: The Strong-Field Regime (Ref IAP-17-99)

Newcastle University, School of Mathematics, Statistics and Physics
In partnership with University of Glasgow, School of Mathematics and Statistics

Supervisory Team
- Dr Céline Guervilly, Newcastle University
- Dr Radostin Simitev, University of Glasgow
- Dr Graeme Sarson, Newcastle University
- Dr Robert Teed, University of Glasgow

Key Words
1. Geomagnetic field
2. Dynamics of the Earth’s core
3. Deep Earth interior
4. Convection
5. Dynamo

Overview

The geomagnetic field and the Earth’s core
The geomagnetic field is produced deep inside the Earth, in the liquid outer core. Motions of liquid iron in the core are driven by thermal and compositional convection due to the cooling of the planet. These motions generate the magnetic field by a process called the geodynamo.

Importance of the geomagnetic field
The geomagnetic field provides the Earth with an electromagnetic shield that protects us from harmful radiation. Fluctuations or weakening of the geomagnetic field can damage space satellites and ground-based power grids. For example, there is a large area over the South Atlantic where the geomagnetic field is weak (the South Atlantic anomaly). Most satellite failures occur when satellites pass through the South Atlantic anomaly. The core flow is currently increasing the size of the South Atlantic anomaly, and so, understanding the geodynamo is crucial to predicting the hazards of its future evolution.

The nature of the core flow
Little is actually known about the flows inside the core due to the lack of direct observations. We can make estimates of the flow near the boundary between the outer core and the mantle from measurements of the changes of the magnetic field. This gives a flow speed of about 10-20km/yr, which is sufficient to change the field significantly over hundreds of years. However, we cannot observe the flow in the interior of the core directly, and this has motivated the development of numerical models that aim to describe the main...
features of these flows (e.g. Christensen & Wicht 2015). The core flow is expected to be very turbulent, meaning that a wide range of lengthscales (from 1000km to 1mm) and timescales (from millions of years to days) are involved in the dynamics. Resolving this vast spectrum of scales is extremely challenging numerically, so current models of the core can only compute mildly turbulent flows and rather slowly rotating systems.

Scientific challenge and aim of the project

Current numerical models suggest that the geomagnetic field is produced by motions on small scales of only about 100 m. This result is inconsistent with both theoretical predictions and geophysical observations, which indicate that the motions responsible for the geodynamo occur on much larger spatial scales (e.g. Jones 2000, Jackson et al. 2000). A key mechanism is thus missing from the current models to lead to the formation of flows on large spatial scale. A possible scenario is that this key mechanism originates from the feedback of the magnetic forces acting on the flow. The aim of this project is to explore this scenario in detail with numerical simulations.

![Numerical simulation of the dynamics in the Earth's core and generation of a magnetic field via a dynamo process.](image)

Project outline and objectives

Magnetocoercion models, where the convective flows interact with an imposed magnetic field, show that the flows adopt a large spatial scale (comparable to the core radius, ~100-1000km) under the influence of a strong magnetic field (“strong-field” regime) (Chandrasekhar 1961). By contrast, in dynamo models (where the magnetic field is generated by the flow rather than externally imposed), the magnetic field only has a mild influence on the convection (“weak-field” regime), despite possessing a strong intensity (e.g. Hori et al. 2010, Busse & Simitiev 2011, Soderlund et al. 2012). To explain the discrepancy between results of magnetocoercion and dynamo studies, we need to determine how a strong-field regime can be reached in dynamo simulations. The main objectives of the project are:

1. to determine the conditions leading to drastic modifications of the structure of the convective flow by magnetic fields in magnetocoercion models,
2. to reach the strong-field regime in a self-sustained dynamo simulation starting from the strong-field regime in magnetocoercion,
3. to extrapolate the results (intensity of the field, secular variation of the field) to Earth’s core conditions.

Methodology

We will use existing numerical codes for simulation of convectively-driven dynamos in spherical geometry independently developed at Newcastle and Glasgow. The student will modify the codes to study magnetocoercion, either by imposing a magnetic field in the volume or by enforcing a magnetic field at the boundaries (e.g. Sarson et al. 1997, Teed et al. 2015). Simulations using the magnetocoercion codes will be run on the high performance computing facilities available at Newcastle and Glasgow Universities. An exploration of the parameter space (intensity of the imposed field, vigour of the convection) will be carried out to establish a strong-field regime and large-scale convective flows. The imposed magnetic field will then be switched off to determine whether the strong-field regime can be maintained in dynamo simulations.

Timeline

Year 1: Literature survey on the dynamics of the deep Earth’s interior, rotating convection, magnetocoercion and dynamo theory. Develop familiarity with the numerical model to be used in the research and high performance computing. Modify the numerical model for magnetocoercion study.

Year 2: Perform the magnetocoercion simulations. Present results at international conferences. Publish magnetocoercion results.

Year 3: Determine the most promising cases to be used as initial condition for the dynamo model and perform the dynamo simulations. Present results at international conferences. Write draft of paper about the dynamo results.

Year 4 (6 months): Finish paper on dynamo results. Write and defend thesis.

Training & Skills

The student will develop a multi-disciplinary expertise in deep Earth research and applied mathematics. In particular, the project provides specialist training in
mathematical and numerical aspects of geophysics, fluid dynamics, and magnetohydrodynamics, with a strong emphasis on high performance computing. The student will have the opportunity to attend training workshops in computational modelling. Training in a wide range of generic skills (e.g. presentation skills, scientific writing skills) is provided by the Faculty of Science, Agriculture and Engineering at Newcastle University via the Postgraduate Researcher Development Programme (PGRDP) and additional accredited researcher-development courses are available at Glasgow. The School of Mathematics and Statistics at Glasgow provides year-long taught PhD modules in core topics of Applied Mathematics as a part of the Scottish Mathematical Sciences Training Centre (SMSTC). These SMSTC courses are available via video-conferencing and can be attended remotely. The student will also benefit from cross-disciplinary training provided as part of IAPETUS. The student will participate in weekly meetings of the astrophysical and geophysical fluid dynamics research group of the Schools of Mathematics at Newcastle and at Glasgow. The student will be encouraged to attend and present their work at national and international conferences and to develop collaborations in and outside Newcastle and Glasgow.

References & Further Reading


Further Information

Dr Céline Guervilly, celine.guervilly@newcastle.ac.uk, 0191 208 7209, http://www.ncl.ac.uk/maths/staff/profile/celineguervilly.html