Investigation of magnetic field modelling using modern computational techniques

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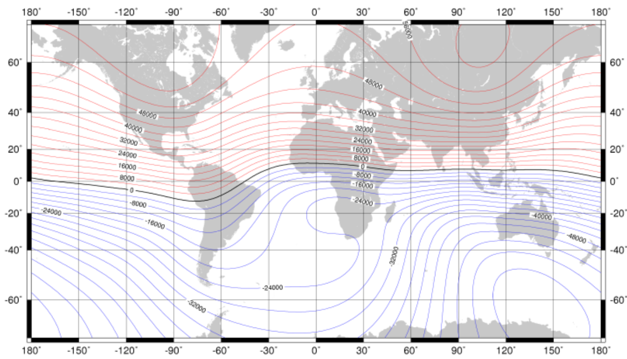
Project background

Although the Earth's magnetic field is approximately dipolar (like a bar magnetic), in detail has a large non-dipole element to it (see figure). It also changes continuously with time, requiring new models to be constructed annually from physical measurements across the globe. Magnetic field modelling using satellite and observatory data is a relatively complicated process in which millions of measurements made at different points in space and time are amalgamated together and used to solve for a smaller number (typically a few thousand) so-called Gauss coefficients. There are trade-offs to be made at each stage of the process – from selection of data in a limited local-time window and severe decimation of the data through to ignoring signals from high degree crustal fields and ionospheric effects. The final solution is computed by a linear inversion using an iterative L2 inversion technique, seeking a minimum L1-norm solution.



The strength of the downward component of the Earth's magnetic field in 2010.0, derived from satellite and ground observatory data.

With advances in satellite technology raising the volume of measurements and a strong desire in the geomagnetism user community for more detailed magnetic field models, it is time to examine new techniques in computational mathematics for solving large and dense problems such as this. Solving for geomagnetic field Gauss coefficients is not quite a classic 'big data' problem but does have some interesting properties that can exploit high performance computing. While newer computers allow the inverse problem to be solved more quickly in a *linear* fashion, we wish to examine theoretical and computational methods that have evolved in the past decade to allow *parallel* solving code to be developed. This will allow us to tackle much larger problems looking for many additional 'geophysical' signals in a more efficient and rapid manner.

This project will have two parts: (1) examine and apply the advances in parallel and distributed inverse problem solving using optimisation algorithms developed by Peter Richtarik and his group at the University of Edinburgh and with it raise the number and types of geophysical signals that can be resolved; and (2) investigate alternative methods for posing the inverse problem in geomagnetism.

The results will be used by the British Geological Survey to improve their magnetic field models and to allow new geophysical understanding of the different sources of the magnetic field that we can measure at and above the Earth's surface.

Key research questions

1) The first part of the project will be to analyse the types of inverse or optimisation solutions that can be applied to geomagnetic field modelling using Gauss coefficients (a natural manner in which to represent the magnetic field). In particular, the student will examine how to model the inverse problem as optimization problem, and will propose efficient solution techniques scalable to parallel and distributed HPC environments. Once this has been understood, vastly larger problems ("comprehensive modelling") can be approached, whereby more data and more geomagnetic signals (from the core to the magnetosphere) can be analysed (e.g. Sabaka et al., 2013).
2) The second part of the project is to investigate other models and methods for solving these problems. This will be a more theoretical approach to the problem of solving the inversion directly for an L1 norm or a different suitable objective, rather than by the current iterative method. It might be possible that alternative mathematical formulations of the basic problem are more amenable to efficient computation, or lead to better-behaved and/or more interpretable solution. The student would need to get acquainted with the advances in mathematical programming techniques and modelling in the recent decade.

Methodology

Year 1

- Key reading around the subject
- Familiarisation with methodology and software for producing field models
- Develop and apply code to produce geomagnetic field models from magnetic ground and satellite data, and analyse the results
- First year report on progress for the University of Edinburgh and presentation to BGS geomagnetism team

Year 2

- Develop and apply code to produce regional core surface flow models from magnetic data, including imposing constraints designed to reduce ambiguity
- Compare results with current models
- Presentation at international science meetings e.g. EGU/AGU
- If appropriate, paper to peer-reviewed journal
- Second year report on progress

Year 3-4

- Further development of software for producing magnetic field models/core flows
- Interpretation of results, and testing against other models from international teams working with the Swarm satellite data
- Presentation at international science meetings e.g. IAGA/EGU/AGU
- One or more papers to peer-reviewed journals
- Thesis

Training

A comprehensive training programme will be provided comprising both specialist scientific training and generic transferable and professional skills. The student will learn optimisation, geophysical inverse theory, and how to process and model large magnetic field datasets, and programming in HPC environments.

Requirements

The project will suit a student with a background in geophysics, physics or mathematics. Skills to be developed include methods of data selection, and computational methods such as geophysical inversion and methods suitable for handling large data sets.

Background reading

Sabaka, T. J., L. Tøffner-Clausen, and N. Olsen, Use of the Comprehensive Inversion method for Swarm satellite data analysis, Earth Planets Space, Vol. 65 (No. 11), pp. 1201-1222, 2013, doi:10.5047/eps.2013.09.007

Vol. 65 (11) Swarm Special Issue of Earth, Planets and Space, 2013, http://www.terrapub.co.jp/journals/EPS/frame/65.html.

30 word max project summary

This project will develop techniques to better model and understand the magnetic field using modern approaches to data inversion, optimisation and high performance computing.