Subject offered for a contract starting October 2017

SUBJECT TITTLE:

Centennial time scale fluctuations of the geomagnetic field: Observations, processes, and models

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IPGP- Geomagnetism – UMR7154

Financing: Doctoral contract with or without teaching assignment

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Presentation of the subject: (1 or 2 pages)

Estimating the secular variation of the Earth's magnetic field over the past 150 years is made possible by observations collected in a network of dedicated observatories. Analysis of these data points to a general decline in the strength of the field: the geomagnetic dipole, the main contributor to the field intensity at the Earth's surface, has lost approximately 10 % of its strength since 1850 and the advent of direct geomagnetic intensity measurements. This decrease is partly connected with the evolution of a series of mid-to-low latitude reverse flux patches at the top of Earth's core, whose signature at Earth's surface takes at present-day the form of a broad region of low geomagnetic intensity centered on the South Atlantic Ocean, termed the South Atlantic Anomaly (SAA). From a theoretical standpoint, the birth and growth of reverse flux patches is likely to be connected with the phenomenon of flux expulsion, whereby toroidal magnetic field lines in Earth's core are carried upward by buoyancy, before diffusive processes kick in and give rise to the formation of a pair of patches (of opposite polarity) at the core surface – a similar mechanism is thought to be at the origin of sunspots.

Prior to 1850, little is known about the fluctuations of the dipole (not to mention the evolution of the SAA), simply because intensity data are lacking - the catalog of historical data for the 1600-1850 period consists mostly of directional data collected by mariners. In view of better constraining the fluctuations of the geomagnetic dipole during the historical period (1600 AD-2000 AD), and in order to place constraints on the physical processes at their origin, a promising approach appears to be that complementing the existing historical database with high-quality, well-dated indirect observations on the geomagnetic field provided by archeomagnetism.

The overarching goal of this PhD project is to further our understanding of the evolution of the geomagnetic field strength and morphology over the historical period through careful data acquisition and theoretical analyses. Following a holistic approach, the PhD candidate will begin by acquiring new well-targeted data (details below), which he or she will include in a dataset comprising the finest archeomagnetic measurements for the period of interest. This dataset will next be used in order to construct time-dependent models of the geomagnetic field over the historical period. The inverse method will consist of a regularized least-squares method, and uncertainties will be taken care of following a generic ensemble approach. Predictions from these models will be compared with predictions based on the widely known *gufm1* historical model of Jackson et al. (2000), in order to assess the compatibility of the selected archeomagnetic dataset with the historical dataset *gufm1* rests upon. Depending on the outcome of this comparison, an extra step may be taken, and models constructed based on the joint use of the archeomagnetic and historical datasets.

The models proposed so far for the historical period rely on a fundamental hypothesis made for the evolution of the axial dipole moment prior to 1840. A "classical" assumption (Barraclough, 1974) is that the decay of the dipole during the 17th and 18th century is similar to that seen over the past 150 years, which served as a basis for *gufm1* (Jackson et al., 2000). Other assumptions favored a rather flat evolution of the geocentric axial dipole field moment between 1600 and 1840 (Gubbins et al., 2006; Finlay, 2008). In fact, the only way to discriminate between the possible behaviors is to use the results from archeomagnetism, a discipline combining geomagnetism and archeology. Archeomagnetism aims at analyzing the thermoremanent magnetization carried by baked clay artifacts from archeological sites (bricks, tiles, pottery, kiln walls) in order to extract information on the past field evolution (intensity and direction depending on the nature of the studied material). Precisely dated archeointensity data obtained from France by Genevey et al. (2009) may argue for an oscillatory variation of the geomagnetic dipole intensity in the past centuries, with a minimum towards the end of the 18th century followed by an increase towards 1840. Data from Brazil tend to corroborate this evolution (Hartmann et al., 2010, 2011) but this remains to be confirmed by data acquisition in regions remote from mainland France, a task for which our group is perfectly positioned through our continuing work on creating and enriching archeomagnetic intensity databases (e.g. Genevey et al., 2008; 2009; 2016; Gallet et al. 2014; 2015). A significant part of the project will therefore focus on the acquisition of new high-quality archeointensity data with ages ranging from the 16th to the 19th century from different regions worldwide. This work will benefit from the experimental procedure developed for the Triaxe magnetometer (Le Goff and Gallet, 2004), a unique instrument allowing magnetization measurements directly at high temperatures, whose pertinence and reliability have been demonstrated through several comparative studies using more classical intensity techniques. Furthermore, according to sampling opportunities offered by our network of collaboration with French archeologists, we also envisage the acquisition of new archeodirectional data from France.

We will use the new data, together with the most reliable data from the archeomagnetic database to construct a collection of time-dependent models of the geomagnetic field for the 1600-2000 time window, in the form of Gauss coefficients varying over that period. The time-dependency of these models will be parameterized using a standard approach based on splines, and a regularization in time will ensue, in order to improve the conditioning of the inverse problem at hand (e.g. Jackson et al., 2000). In space, regularization will rest on the so-called dynamo norm, i.e. on those statistical properties of Gauss coefficients estimated from the numerical integration of numerical models of the geodynamo (e.g. Fournier et al., 2011; Sanchez et al., 2016). Uncertainties will be taken into account following a Monte Carlo approach, giving rise to an ensemble of models. Predictions from these models will be compared against predictions from *gufm1*, and the compatibility (and complementarity) of the associated datasets will be assessed. If sensible, a series of time-dependent models combining both datasets will be constructed.

In parallel to this data-driven effort, we expect the successful candidate to carry out a detailed analysis of the flux expulsion mechanism, whose understanding has arguably remained elusive so far. This analysis will be based on kinematic models and 3-D first-principles simulations of the geodynamo. The theoretical insight gained from this work will allow the student to make connections between dynamical features inferred from archeomagnetic and / or historical observations and their geophysical origin.

International collaborations: A collaboration with our colleague Christopher C. Finlay (Danish Technical University, Copenhagen) is planned. Chris Finlay has carried out a series of studies on the secular variation of the Earth's dipole (see e.g. Finlay, 2008; Finlay et al., 2016), and is a leading figure in geomagnetic field modelling. The successful candidate will have the opportunity to visit him in Copenhagen over the course of the project, while we hope that his constraints will allow Chris to visit us for a month or two within the next 3 years. In addition, Andy Jackson (ETH Zürich) already agreed to provide guidance and his expertise when we start dealing with the historical database he put together.

National collaborations are also planned, in particular with Agnès Genevey (Laboratoire d'Archéologie Moléculaire et Structurale, UPMC) in the domain of archeomagnetism.

We seek a highly motivated candidate with a background in geophysics, in particular geomagnetism and inverse problem theory. Experience in data acquisition and / or scientific computing is a plus.

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