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Assimilation of geomagnetic observations: Foundations and challenges

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Today, our understanding of core dynamics has arguably reached adolescence, and so has its prognostic numerical modeling. In addition, the quality of the magnetic observation of the earth has increased dramatically over the past ten years, thanks to various satellite missions (Ørsted, CHAMP, SAC-C), which led in particular to a finer description of the geomagnetic secular variation. At this stage, it seems natural to wonder whether progresses made at the observational and modeling levels can be coupled in synergy by data assimilation, the process through which all the information available on a system is used as accurately as possible in order to estimate the state of that system (Talagrand, *J. Met. Soc. Jap.*, 1997).

Unlike its more mature atmospheric and oceanic cousins, geomagnetic data assimilation is still in its infancy. Consequently, we first recall the foundations of data assimilation, as established by our colleagues working on the outer fluid envelopes of the earth, and see how they transpose to the earth's core. We then illustrate these basic concepts by considering a simple one-dimensional, nonlinear, and sparsely observed magneto-hydrodynamic toy model, upon which we apply a variational data assimilation scheme.

Variational data assimilation aims at minimizing an objective function (a component of which contains the distance between model predictions and observations), by computing its sensitivity to its control variables (initial state, model parameters, boundary

values); the calculation of this sensitivity is done in practice by integrating the so-called adjoint model. Adjoint calculations performed with this toy model show that it should be possible to benefit from current (and upcoming) high-quality geomagnetic data to re-assimilate past observations and improve historical magnetic field models, within a dynamically consistent framework (Fournier et al., *Nonlin. Processes Geophys.*, 2007).

The road going from a one-dimensional toy model to a fully operational, three-dimensional numerical model of earth's core dynamics -assimilating routinely geomagnetic observations- is long and paved with tremendous challenges. Some are related to the wide range of timescales of the processes at work, and the computational burden associated with the set-up of such a three-dimensional system. We discuss strategies that can be adopted to bypass some problems, relying in particular on recent work by Liu et al. (*JGR B*, 2007), and Kuang et al. (*Comm. Comp. Phys.*, 2008).

Finally, we make a case for a quasi-geostrophic model of core dynamics specifically geared towards the description of the annual to secular variability of the core magnetic field (which corresponds by far to the best documented part of the geomagnetic record), and show synthetic assimilation experiments performed using this model and its adjoint.