A database of synthetic observations for geomagnetic data assimilation practice

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Data assimilation aims at producing an optimal estimate of the state of the dynamical system one is interested in by combining two sources of information: physical laws (in the form of a numerical model) and observations. A mandatory step during the development of a data assimilation framework involves a validation phase using synthetic data. In this well-controlled environment, the true dynamical trajectory of the system is known (it results from the integration of the numerical model), and it is used to generate synthetic observations. Those are subsequently used to assess the efficacy, and to highlight possible shortcomings, of the chosen methodology.

Data assimilation has recently come to the fore in geomagnetism (e.g. Fournier et al., 2010), a surge motivated by our increased ability to observe the geomagnetic field (thanks to dedicated satellite missions), and by the concurrent progress in the numerical description of core dynamics. Open questions are related to the type of physical models one should resort to, and to the choice of a suitable algorithm, able to integrate the highly heterogeneous geomagnetic record at our disposal, and to deal with the non-linearities of the problem at hand (e.g. Aubert & Fournier, 2011; Fournier et al., 2011).

We plan to construct a database of synthetic observations meant at reproducing the heterogeneity of the geomagnetic record; we aim at using this database to perform twin and fraternal experiments for algorithmic verification. We have integrated a high resolution numerical dynamo simulation and selected a portion of the dynamical trajectory spanning $10,000$ years. We report today on the dynamical properties of this simulation and outline plans to generate the associated millenial database.

The model

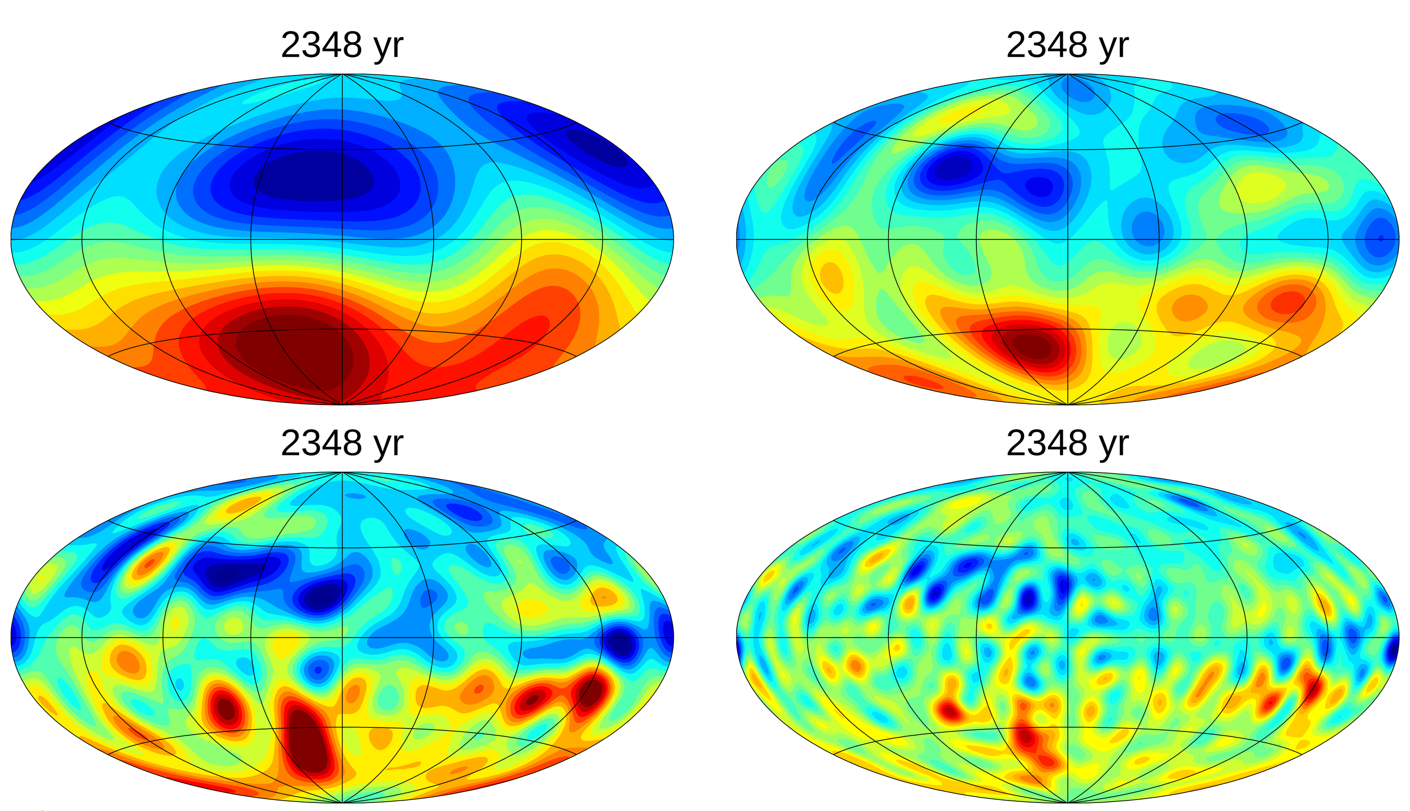

Fig. 1 A snapshot of the radial component of the field generated by the simulation at the surface of the shell, displayed for various truncations (from top to bottom, form left to right: $l = 3, 8, 13$ and 24).

Following the implementation of Dormy et al. (1998); Aubert et al. (2008), we solve for the conservation of mass, momentum, and energy of a convecting Boussinesq fluid in rapid rotation, in addition to the induction equation. We use the codensity formalism of Braginsky & Roberts (1995).

- Boundary conditions: flow: no-slip; field: insulating boundary condition at ICB and CMB; codensity: F_i (F_o) imposed at ICB (CMB).
- Thermo-chemical driving $f_i = \frac{F_i}{F_i + F_o} = 75\%$
- Input parameters
  $\mathrm{E} = 10^{-5}, \quad \mathrm{Pr} = 1, \quad \mathrm{Pm} = 0.4, \quad \mathrm{Ra} = \frac{g_o F}{4\pi\rho\nu\kappa\Omega} = 600,000$

Simulation properties

Number	meaning	value
Re	$\tau_\nu/\tau_{\mathrm{adv}}$	1600
Rm	$\tau_\eta/\tau_{\mathrm{adv}}$	640
Lu	τ_η/τ_A	614
Le	τ_Ω/τ_A	0.015
Λ	Elsasser	9.4
A	$\tau_A/\tau_{\mathrm{adv}}$	1

- Flow exhibits fair amount of z-invariance (see Fig. 3)
- CMB field is remarkably Earth-like (see Fig. 1), according to Christensen et al. (2010) (see also Fig. 2, right)
- No fast waves, A for the Earth is $\mathcal{O}\left(10^{-2}\right)$, and Lu $\sim \mathcal{O}\left(10^{4}\right)$.
- Bulk spectra almost flat up to $l \sim 30$, then sharp decrease (see Fig. 4).
- CMB non-dipole field spectra flat up to $l \sim 30$; SV spectra $\propto l$ up to $l \sim 100$ (Fig. 4)

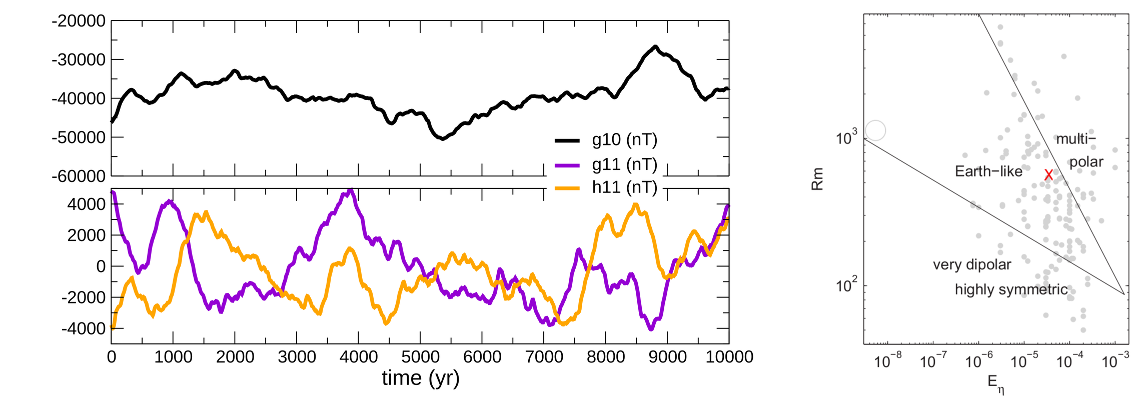

Fig. 2 Left: timeseries of dipole Gauss coefficients. Right: location in parameter space. Adapted from Christensen (2011), based on Christensen et al. (2010)

Flow and field properties: Snapshots

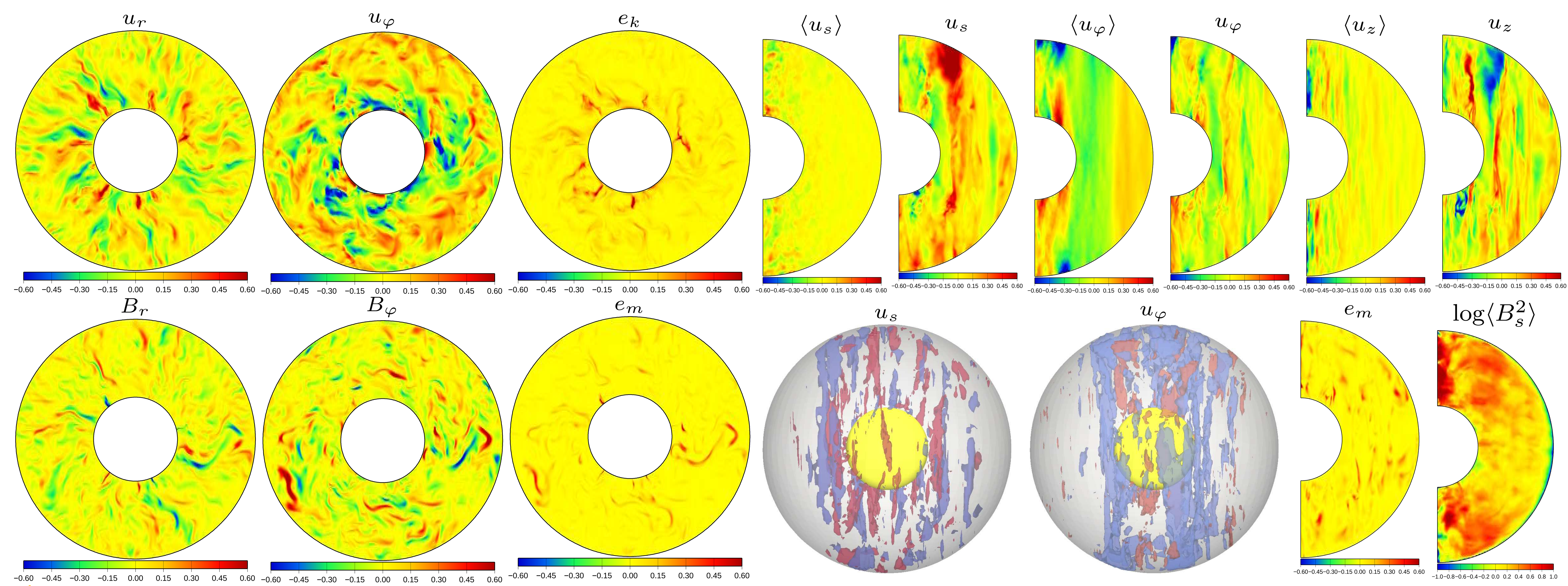

Fig. 3 An overview of the dynamical properties of the simulation. Plots are normalized. $\langle\cdot\rangle$: azimuthal average.

Flow and field properties: Spectra

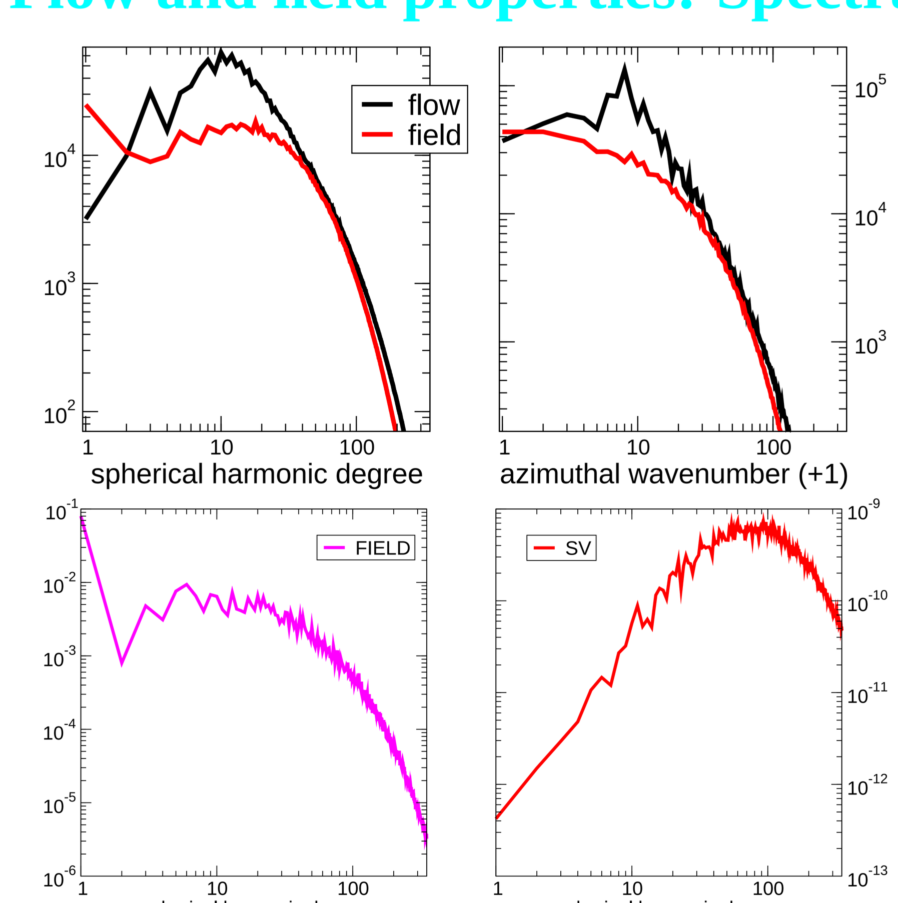

Fig. 4 Top: bulk kinetic and magnetic spectra (dimensionless). Bottom: Mauersberger-Lowes spectra (dimensionless).

Construction of the Holocene database

We will construct both a homogeneous and a heterogeneous catalog, the latter based on the temporal and spatial distribution shown in Fig. 5, after the compilation of Donadini et al. (2009); Korte & Constable (2011).

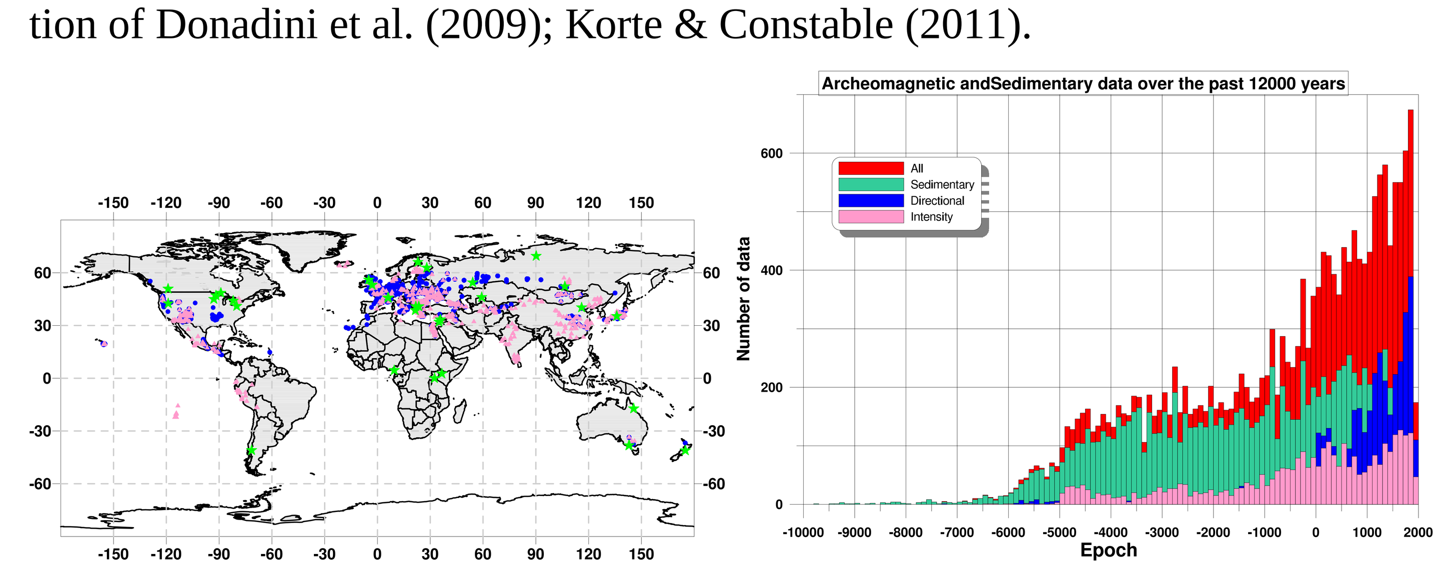

Fig. 5 Spatial (left) and temporal (right) distribution of observations to be used for the construction of the synthetic Holocene dataset.

What is next:

- the construction of the Holocene database
- the construction of a historical database based on a subset of the trajectory described here
- the calculation of a satellite database relying on a high-resolution simulation allowing for fast waves (Gillet et al., 2010b, 2011)
- the use of these nested databases to validate our assimilation tools based either on 3D-dynamo, or quasi-geostrophic, forward models
- the diffusion of these databases via a dedicated www portal

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