Machine Learning for the geodynamo inverse problem

Physics-informed Neural Network

Romain Claveau

28 mai 2025

1 Context

The geodynamo is a physical process behind the Earth's sustained magnetic field, stemming from complex fluid motions of the electrically conducting liquid metal within the outer core. Because these processes occur at extreme depth and conditions, which are entirely out-of-reach of direct observations or experimental replicas, our understanding of the geodynamo relies heavily on numerical simulations.

However, the Earth's physical parameters are also out-of-reach of numerical simulations as its outer core operates at low viscosity (as measured by $\mathrm{Ek} \simeq 10^{-15}$ and $\mathrm{Pm} \simeq 10^{-6}$). Also, the Earth's dynamo features a small ratio of the kinetic to magnetic energy (as measured by $\mathrm{Al}^2 \simeq 10^{-4}$). So, reproducing Earth-like conditions requires to reach an asymptotic regime, which afterwards could be extrapolated to the Earth.

We recall the definitions of the Ekman number (Ek), the magnetic Prandlt number (Pm) and the Alfvén number (Al):

$$\mathrm{Ek} = \frac{\tau_\Omega}{\tau_\nu} \quad ; \quad \mathrm{Pm} = \frac{\tau_\eta}{\tau_\nu} \quad ; \quad \mathrm{Al} = \frac{\tau_A}{\tau_U} \tag{1}$$

where τ_Ω the inverse rotation rate, τ_ν the viscous diffusion time, τ_η the magnetic diffusion time, τ_A the Alfvén time and τ_U the convective overturn time.

As a result, in addition to numerical simulations of the geodynamo, we rely on the induction equation relating the outer core motions and the magnetic field, to infers the flow through magnetic observations by solving the geodynamo inverse problem.

2 The geodynamo inverse problem