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Magnetic field stretching at the top of the Earth's core

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Abstract

Magnetic field stretching transfers kinetic energy to magnetic energy and by that maintains the dynamo against Ohmic dissipation. Stretching at the top of the outer core may play an important role in specific regions. High-latitudes intense flux patches may be concentrated by flow convergence. Reversed flux patches may emerge due to expulsion of toroidal field advected to the core-mantle boundary by fluid upwelling. Here we analyze snapshots from self-consistent 3D numerical dynamos to unravel the nature of field-flow interactions that induces stretching secular variation at the top of the core. Our results may shed light on the kinematic origin of intense geomagnetic flux patches and may provide insight to the convective state of the upper outer core.

1. Introduction

The geomagnetic field is generated by convective motions of an electrically conductive fluid in Earth's rapidly rotating liquid outer core. Temporal changes in the core field, termed secular variation (SV), are due to magnetic advection, stretching and diffusion.

It is under debate whether any stretching effects prevail at the top of the core. In this work we analyzed snapshots from numerical dynamos in order to study the role of stretching in the radial induction equation at the top of the core, focusing on its local behavior in regions of intense magnetic flux patches.

2. Methodology

We use the numerical dynamo code MagIC [1] that solves the full set of MHD equations in a spherical shell. The boundary conditions are rigid and insulating. Convection is set to be thermochemical within the co-density framework, with fixed co-density on the inner boundary and fixed heat flux on the outer boundary. Dynamo models are in the dipole-dominated nonreversing regime [2]. For each model 10 arbitrary snapshots are analyzed in terms of the field-flow interactions that yield the secular variation at the top of the shell.

In order to analyze the dynamo simulations, some statistical tools were developed: RMS ratio of stretching/advection (ζ/ξ) and poloidal/toroidal flow ($\wp/\tau$); correlations of radial vorticity and tangential divergence $corr(\delta_h, \omega_r)$, absolute radial magnetic field and downwelling $corr(B_r, \delta_h < 0)$ and absolute radial magnetic field and upwelling $corr(B_r, \delta_h > 0)$. These statistical measures are calculated globally as well as at regions of intense flux patches. In addition, the level of cancellation of various properties is also evaluated locally.

3. Results

Stretching has a larger influence on the secular variation than what may be expected from the relative strength of the poloidal flow. Locally, stretching may dominate the secular variation near high-latitudes intense flux patches where the radial field is nearly aligned with the toroidal flow and advection is less effective. In contrast, near low-latitudes reversed flux patches advection is as efficient as stretching. In both cases stretching locally intensifies the field.

References

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