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How to make an Earth-like geodynamo model

Ulrich Christensen (1), Julien Aubert (2), and Gauthier Hulot (2)

(1) Max-Planck-Institute of Solar System Research, Katlenburg-Lindau, Germany (christensen@linmpi.mpg.de), (2) Institut de Physique du Globe de Paris, Paris, France (aubert@ipgp.fr)

For many published dynamo models an Earth-like magnetic field has been claimed. However, it has also been noted that as the Ekman number (viscosity) is lowered to less unrealistic values, the magnetic field tends to become less Earth-like. Here we define quantitative criteria for the degree of similarity between the field of a dynamo model and the geomagnetic field, concentrating on the agreement in field morphology. Main criterion is (1) the ratio between the axial dipole component and non axial dipole parts of the field. In addition, we include (2) the ratio between equatorially symmetric and antisymmetric components and (3) between zonal and non-zonal components in the non-dipole field and (4) a measure for the degree of concentration of magnetic flux at the core surface into small patches. We test a large number of dynamo models that cover the accessible parameter space concerning their compliance with these criteria. We tentatively order models according to to magnetic Reynolds number Rm and magnetic Ekman number Em (ratio between rotation period and magnetic diffusion time). Requirements for an Earth-like field morphology are that Em $\leq 10^{-4}$ and that Rm falls into a limited range that depends on Em and ranges between 140 and 450 at Em=10^{-4} and increases to 1000-5000 when extrapolated to the Earth value Em=5×10^{-9}. Earth-like models seem to exist in a contiguous swath of parameter space that links the present high-Ekman number models with the geodynamo. Hence the models are probably generically similar to the true geodynamo. The thermal boundary condition (fixed temperature or fixed flux) and the distribution of sources and sinks of buoyancy has a secondary influence on the field morphology. The computationally least expensive Earth-like models can be constructed at Em $\approx 3x10^{-4}$ for compositionally driven convection.