Geomagnetic dipole reversals

Jon Rotvig

Institut für Geophysik, ETH, Hönggerberg, Zürich, Schweiz

The main magnetic field of the Earth is generated by convection in the liquid iron core located between a radius of 1280 km and 3485 km. The solidification of iron at the inner radius releases latent heat and light elements that together with secular cooling and radioactive sources maintain core convection. These motions of electrically conducting iron constitute the geodynamo. The induction of magnetic field has been present throughout most of Earth's history and the magnetic field provides an important shield against the solar wind.

The 3D, rapidly rotating, and highly non-linear magnetohydrodynamic geodynamo problem is commonly solved by means of numerical simulations. The first self-consistent geodynamo model was reported in Glatzmaier and Roberts (1995). Their model was also the first one to display reversals of the core-mantle dipole. Although the dipole component of the magnetic field prefers alignment with the rotation axis, it is not stable but typically changes orientation at a rate 1-5 times per million years according to paleomagnetic data. A computer model example may be seen in Figure 1. The first systematic study of geomagnetic reversals in numerical dynamos appeared only recently (Kutzner and Christensen, 2002). Prior to this work, searching for solutions with reversals was a matter of guesswork. We now know that a necessary condition is a sufficiently weak Lorentz force relatively to the other forces. In addition, the driving of the system must be sufficiently strong. This general scheme has been shown robust to a variety of driving mechanisms.

However, the fundamental question, ``Why does the dipole reverse at all?", is still not clearly understood. In the present work, I suggest a filtering method of the magnetic induction term in order to localize the processes responsible for reversals. The rapid rotation of the spherical shell introduces regions with relatively separated fluid dynamics. The tangent cylinder (TC) is defined as the cylinder along the rotation axis that touches the inner core. As long as the driving is not too strong the TC separates the dynamics. Based on results obtained in a highly supercritical 2.5D model, Sarson and Jones (1999) suggested rising plumes inside the TC as reversal triggers. However, as I have shown recently, there is no direct correlation between the onset of reversals and the onset of convection inside the TC. Nevertheless, filtering out the flow in the induction term in a narrow band at mid-radius inside the TC in the northern hemisphere shuts down reversals. The same applies to a narrow equatorial region immediately outside the TC. It is the combined effects of these two regions that is causing the reversals (given the imposed driving mechanism). Somewhat surprisingly, the effect of convection at mid-radius inside the TC is asymmetric in the two hemispheres: In the southern hemisphere this flow component seems to stabilize the core-mantle dipole rather than triggering reversals.

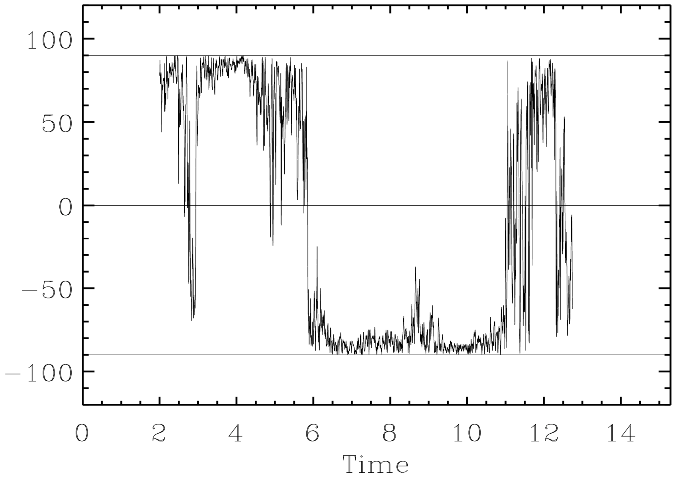

Figure 1. A convection-driven reversing geodynamo simulation at moderate Ekman number (ratio between viscous and Coriolis forces). The panel shows a time series of the position of the magnetic north-pole at the Earth's surface. The pole position is given by the latitude that varies between [-90°,90°]. We observe 2 reversals and several excursions. Time is measured in units of ~50000 years.

REFERENCES

Glatzmaier, G.A. & Roberts, P.H. (1995): A 3D convective dynamo solution with rotating and finitely conducting inner core and mantle. Phys. Earth Planet. Int. 91: 63-75.

Kutzner, C. & Christensen, U.R. (2002): From stable dipolar towards reversing numerical dynamos. Phys. Earth Planet. Int. 131: 29-45.

Sarson, G. & Jones, C.A. (1999): A convection-driven geodynamo reversal model. Phys. Earth Planet. Int. 111: 3-20.