
DYNAMO BIFURCATIONS IN THE DIFFERENT DYNAMICAL REGIMES OBTAINED IN GEODYNAMO SIMULATIONS

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We investigate the nature of the dynamo bifurcation in a configuration applicable to the Earth's liquid outer core i.e. in a rotating spherical shell with thermally driven motions with no-slip boundaries. The control parameters have been varied significantly in order to deduce systematic behaviours which could improve our understanding of planetary dynamos. A huge amount of models has been performed. To interpret our dynamo results, a hydrodynamical study and a kinematic one have been carried out. In other words, the action of the magnetic field on the flow is highlighted by comparing dynamo runs with non-magnetic models having the same parameters. In addition, the kinematic dynamo threshold is systematically determined.

Different dynamical regimes are explored in non-magnetic models by varying the different dimensionless parameters. Close to the onset of convection, only the critical mode develops as columnar vortices aligned with the rotation axis, in the form of alternating cyclones and anticyclones arranged around the solid inner core. Inertia does not play a major role in this regime which is then dominated by the global rotation and viscous effects. At higher convective driving, kinetic energy is distributed on many convection modes and inertia is one of the dominant forces. By lowering the viscosity, large-scale zonal flows can develop in this turbulent regime even with no-slip boundaries.

Previous studies highlighted a dichotomy between non-reversing dipole-dominated dynamos and the reversing non-dipole-dominated multipolar solutions. Because of its importance for geophysical applications, strong dipolar fields have been preferred as initial conditions. This field collapses if the ratio of inertia to the Coriolis force exceeds a critical value. A strong initial field prevents zonal flows. By considering weaker fields, we show the existence of a supercritical multipolar branch whereas stronger fields give rise to dipolar solutions. A bistable regime exists where the magnetic topology depends on the initial magnetic field strength. By lowering viscous effects, the importance of zonal flows becomes more and more important and the result is the larger extension of the bistable regime. Large-scale zonal flows are typical of multipolar dynamos and plays a role in the field generation. Far above the dynamo threshold, the Lorentz force reduces zonal flows and a transition from a multipolar dynamo to a dipolar one is observed.

The dipolar branch has a subcritical behaviour in any hydrodynamical regimes.In the laminar regime, convection cells do not develop in the whole spherical volume. Strong initial fields extend convection cells toward the outer boundary where toroidal fields are advected which allows to sustain dynamo action. In the turbulent regime, zonal flows and small-scale motions develop and perturb dynamo action. Strong dipolar fields prevent zonal flows and decrease the flow speed. Dipolar field are then maintained in time only if this field is initially strong-enough.

We argue on the existence of different physical regimes for dipolar models. In the vicinity of the dynamo threshold, the action of the magnetic field on the flow is highlighted by comparing hydrodynamical models and dynamo ones. Lorentz force modifies the energy of the convective flow at small-scales in the laminar regime. The Lorentz force is balanced mainly by a modification of viscous effects whereas the dominant terms in the equation of motion are the Coriolis force, pressure gradients, buoyancy and viscosity. In the turbulent regime, the dipolar field reduces the energy of the convective flow at large-scales which suggests that Lorentz force is balanced by a modification of inertia.

Far above the dynamo threshold, Lorentz force becomes dominant as it is expected in planets. In the turbulent regime, the magnetic field affects significantly the flow speed, the flow structure and the heat transfer efficiency. This physical regime seems to be relevant for studying geomagnetic processes. These arguments are in agreement with recent geodynamo studies.

References