SMALL-SCALE MOTION IN THE CORE OF THE EARTH

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SUMMARY

In 1996, St Pierre (1996) reported numerical simulations of a buoyant blob migrating across the earth's outer core and subject to the combined effects of rotation and an azimuthal magnetic field. He noted that the blob rapidly fragments into a series of plate-like structures. Quite independently, Davidson (1995, 1997) observed a similar behaviour in the context of low-R_m turbulence (without a Coriolis force) and showed that this phenomenon has its roots in the destruction of angular momentum by the Lorentz force. The purpose of this paper is to pull together these earlier studies and, in particular, to determine whether or not St Pierre's platelets are likely to be a generic feature of small-scale motion in the core of the earth.

Classical theories of the geo-dynamo rest on the assumption that there are two scales of motion in the core. For example, α-Ω dynamos rely on large-scale differential rotation sweeping out an azimuthal field, B_θ, from the observed dipole field, and then on small-scale motion (waves or turbulence) reinforcing the dipole field via the α-effect acting on B_θ. However, the validity of such a picture has recently been questioned, partially because small-scale turbulence is highly dissipative and so α-Ω (or α-α) dynamos are not particularly efficient mechanisms for maintaining the earth's magnetic field. (See, for example, Malkus, 1994). Moreover, recent large-scale numerical simulations, which do not model the small scales, suggest that a dynamo might operate through the action of large-scale motion alone. All of this suggests that the α-effect, if it operates at all, is most active at the intermediate to large scales, and not at the small scales, as classically assumed.

It seems natural, therefore, to examine the small-scale dynamics in order to determine just how dissipative it is, and to assess the validity, or otherwise, of the use of sub-grid models in some of the large-scale simulations. Moreover, recent numerical experiments (St Pierre, 1996) show that small buoyant eddies in the outer core rapidly fragment into plate-like structures aligned with the local **B-Ω** plane, a phenomenon anticipated by Braginsky (1964), Braginsky and Meytlis (1990), and Braginsky and Roberts (1995). It is clearly desirable to understand why this phenomenon occurs and to determine if it is likely to be a generic feature of all small-scale turbulence.

Our starting point is the study of low-R_m turbulence by Davidson (1995, 1997), in which the Coriolis force is absent. It is shown there that the disintegration of eddies into platelets is inevitable whenever the axis of rotation of the eddy is non-parallel to the local magnetic field. Moreover, Davidson shows that this behaviour can be predicted from a simple argument related to the angular momentum of the vortex. The main purpose of this paper is to extend the earlier analysis of Davidson by incorporating the Coriolis force, thus forming a bridge to the work of Braginsky (1964), Braginsky and Meytlis (1990), St Pierre (1996), Shimizu and Loper (1997) and Loper (2001). We conclude that the small scales are both highly dissipative and highly anisotropic.

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