Magnetic Tubes in Overshooting Compressible Convection

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Abstract: A magnetic tube is introduced into turbulent compressible penetrative convection. After being strongly advected, most of the magnetic flux is stored in the overshoot region. With rotation there are meridional travelling waves.

We investigate the evolution of a strong toroidal magnetic field initially beneath the solar convection zone by simulating highly supercritical compressible convection with overshoot, see Hurlburt *et al.* (1986). Once the convection is well developed the magnetic field is added. The geometry is Cartesian, and we only consider two-dimensional solutions ($\partial/\partial y = 0$). The xz plane is convectively unstable for $0 \leq z \leq 1$, but stably stratified for $1 < z \leq 2$. We assume that solutions are periodic in x and discretize using 63^2 gridpoints. A similar model is described more fully by Brandenburg *et al.* (1990).

An initial magnetic field $B_y(x,z)\hat{\mathbf{y}} = B_0 \exp\left[-100\{(x-1)^2 + (z-1.25)^2\}\right]\hat{\mathbf{y}}$ represents the flux tube, which is advected and diffused according to the induction equation:

$$\rho\left[\partial/\partial t + (\mathbf{u}\cdot\nabla)\right](B_y/\rho) = \eta\nabla^2 B_y \ . \tag{1}$$

A magnetic pressure force is all that the Lorentz force yields, but this leads to an initial pressure discontinuity. Alternatively, the tube can be inserted such that the density or temperature is initially discontinuous, yet in each case sound waves rapidly smooth any steep gradients and there is a progression towards a final state in which most of the flux is stored in the overshoot region, see Figs. 2 and 3.

Including rotation makes the flow move poleward as a travelling wave. Inserted magnetic tubes also moves poleward, albeit rather slowly. This is suggestive of the latitudinal migration of magnetic features during the solar cycle. A detailed paper is in preparation.

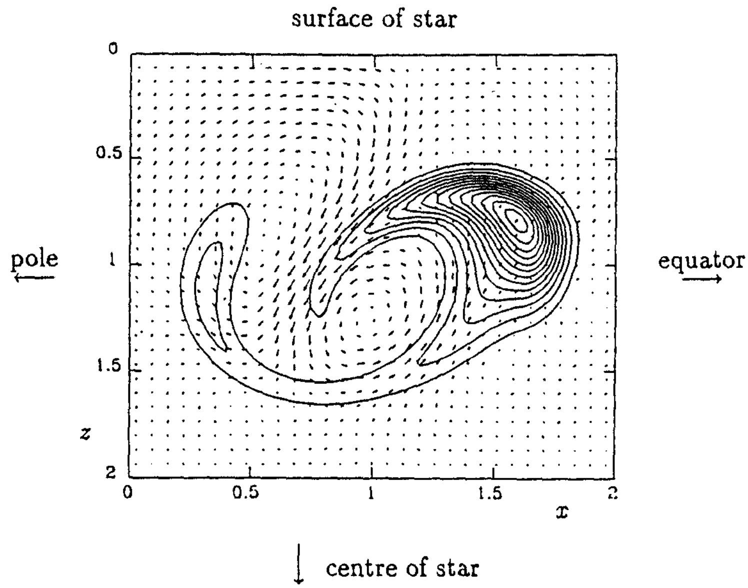

Fig. 1. Magnetic buoyancy makes the tube rise and expand. However, most of the tube's expansion is due to the decreasing density as it rises. Contours are of B_y, and arrows show the flow $\mathbf{u}$.

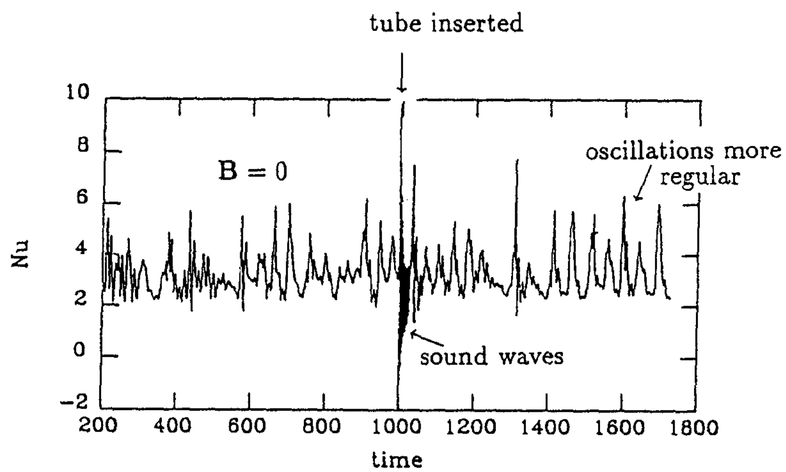

Fig. 2. A timeseries of the Nusselt number showing aperiodic oscillations with periods characteristic of internal gravity waves.

$t = 1427$ (squeeze)

$t = 1452$ (relax)

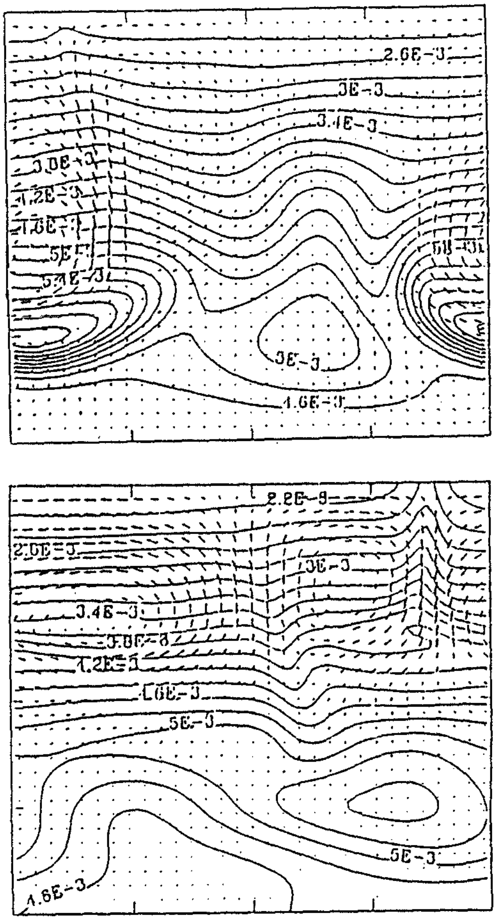

Fig. 3. Descending plumes compress the stored field, which then relaxes before the next compression. The frequency of compressions is compatible with that of gravity waves.

References

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Hurlburt, N.E., Toomre, J., Massaguer, J.M.: 1986, *Astrophys. J.* **311**, 563