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The flow helicity in quasi-ordered cellular convection

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Abstract. The helicity of cellular convective flows in a horizontal layer of compressible fluid (gas) heated from below and rotating about a vertical axis is studied using finite-difference numerical simulations. The medium is assumed to be polytropically stratified. An initial thermal perturbation is introduced so as to produce a system of Bénard-type hexagonal convection cells. The flow gradually becomes less ordered, and the mean helicity grows initially and decreases sharply after the substantial chaotisation of the flow. Given the Rayleigh and Prandtl numbers, the maximum value reached by the mean helicity increases with the decrease of the polytrope index and has a maximum at a certain rotational velocity of the layer.

Keywords. convection

The mean value, $\langle h \rangle$, of the velocity-field helicity $h = \mathbf{u} \cdot (\nabla \times \mathbf{u})$ is an important quantity governing the action of turbulent MHD dynamos, since it is related to the parameter α controlling the generation of large-scale magnetic fields (the α effect): $\alpha = -\tau/3\langle h \rangle$, where τ is the turbulence correlation time (Krause & Rädler 1980). Such estimates strongly depend on the assumptions about the structure of turbulence, being highly uncertain.

However, the convective motions of the solar plasma are relatively ordered, and representing them as an ensemble of turbulent pulsations is something of a stretch. A possible alternative is a "deterministic" approach that implies considering flows with well-defined structural elements. It gives hope of gaining more definite information on the helicity values.

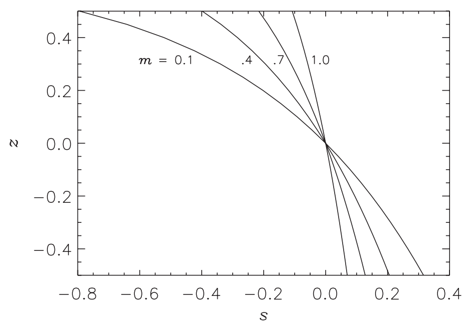

Figure 1. Static entropy profiles at different polytrope indices m.

Here, we numerically simulate relatively ordered cellular convective flows in a horizontal layer of compressible fluid (gas) rotating about the vertical axis z to investigate the dependence of the mean helicity on the stratification of the layer and its rotation rate. We use the *Pencil Code* software package (Brandenburg & Dobler 2001) based on a finite-difference approximation of sixth order in the spatial coordinates and third order in time. The computations were done in a box with horizontal sizes of 27.936×24.192 in units of the layer thickness H. The stratification of the layer was assumed to be polytropic, i.e., $p = K\rho^{\Gamma}, \quad m = 1/(\Gamma - 1)$, where p is the pressure, ρ is the density of the static atmosphere, Γ and m are the polytropic exponent and index, respectively, and K is a proportionality factor; in this case, the static z distribution of the entropy per unit mass has a logarithmic form (Fig. 1). The physical parameters of the problem are the Rayleigh and Prandtl numbers, $\mathrm{Ra} = (-g_z)H^3\Delta s/(c_p\nu\chi)$ and $\mathrm{Pr} = \nu/\chi$, where ν and χ are characteristic values of the kinematic viscosity and thermal diffusivity of the medium, Δs is the difference of the static entropy values at the bottom and top layer boundaries and c_p is the specific heat at constant pressure.

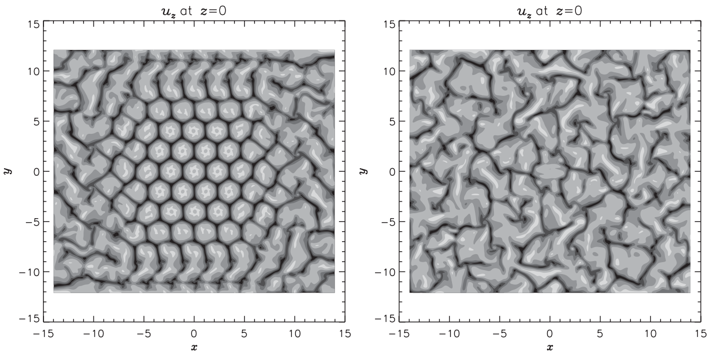

Figure 2. Distributions of the vertical velocity component in the horizontal midplane of the layer at two times; $m = 0.4$, $\Omega = 0.04$ [in units of $(-g_z/H)^{1/2}$], Ra = 20050, Pr = 1.

We assumed zero tangential stresses at all boundaries [previously, we used the horizontal-periodicity conditions (Getling 2012)]. A thermal perturbation of a special form was initially introduced to induce a flow in the form of hexagonal convection cells. Subsequently, the flow lost its regularity, and the evolution appeared as the inward propagation of the influence of the sidewalls (Fig. 2). As a rule, the maximum velocity over the box first reached a more or less wide plateau (at a certain level $u_{\rm pl}$) and then fluctuated randomly. The mean helicity grew until the time of the plateau end, after which varied chaotically.

The velocity $u_{\rm pl}$ and the maximum achieved value of $\langle h \rangle$ depend on the rotation rate of the layer and the polytrope index. While $u_{\rm pl}$ varies little with Ω, demonstrating a gradual decrease on the whole, the maximum value of $\langle h \rangle$ reaches a pronounced maximum at a certain Ω (Fig. 3). This indicates that the suppression of helicity by the rotation of the medium precedes the quenching of convection.

We summarise our findings as follows:

- Numerical simulations of convection in a rotating layer can reduce the uncertainties in the mean-helicity estimates.
- The mean helicity strongly depends on the degree of order in the flow. While, in a compressible medium, one sign of helicity dominates in cellular flows, the helicity varies chaotically in disordered convective flows.
- Given the stratification and parameters of the regime, a certain rotation rate is optimal for helicity generation in convective flows.

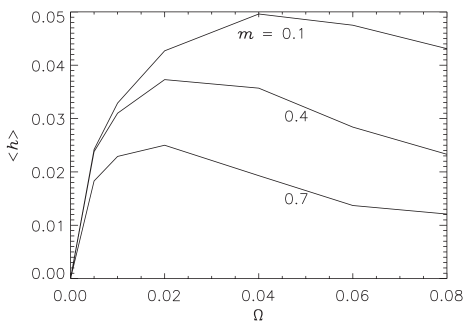

Figure 3. The maximum achieved value of $\langle h \rangle$ as a function of Ω at different m.

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