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On the role of cross-helicity in β-plane magnetohydrodynamic turbulence

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In the sun, a thin layer known as the tachocline is considered especially important to the generation of the solar dynamo. Turbulent momentum transport in the tachocline, pertinent to the question of why the tachocline is able to exist, has been the recent object of considerable study by way of a simple magnetohydrodynamic (MHD) model on a β-plane. In particular, it has been shown that the presence of a sufficiently strong in-plane mean magnetic field (relative to the resistivity) leads to the inhibition of large-scale momentum transport and the destruction of zonal flow patterns [1]. However, previous work has not addressed the question of cross-helicity in this system, whose conservation is explicitly broken by the Coriolis (β) term.

In this work, we show that conservation of squared magnetic potential in this system leads to a global increase in the cross-helicity, which can be estimated in terms of the Rossby parameter, the mean magnetic field, the mean turbulent magnetic energy and dissipation parameters. We also present a basic closure of the system using weak turbulence theory which respects the nonzero cross-helicity and is valid for a strong mean field. We show that, within weak turbulence, the time-averaged cross-helicity spectrum exactly determines the time-averaged Reynolds-Maxwell stress spectrum — and thus the mean momentum transport properties. We show that this result also makes explicit the maxim that the turbulence is primarily magnetic at small scales and kinetic at large scales, with the separation scale being the magnetic Rhines scale $k_{MR} = \sqrt{\beta/b_0}$ [2]. As an unsurprising corollary, we also find that the flux of magnetic potential is completely quenched in weak turbulence. Finally, combining the relationship between the cross-helicity and the Reynolds-Maxwell stress with the estimate for the global cross-helicity yields an estimate for the partitioning between magnetic and kinetic turbulent energies.

We supplement our analytic results with stochastically-forced simulations of the system with a strong mean field. These confirm our estimate for the global cross-helicity and the claimed equivalence of the time-averaged cross-correlators. They also indicate that the transition between Alfvenic and Rossby-like turbulence occurs around the overlap between the magnetic Rhines scale and the forcing scale. We report that, in this transitional regime, the global cross-helicity is largest, and "near-zonal" flows with a wavelength equal to the box size appear.

Future avenues for research are suggested.

References

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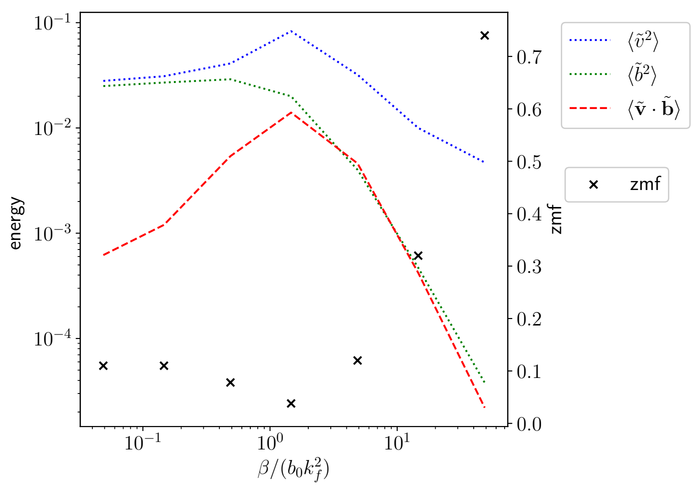

Figure 1: Plot of stationary turbulent energies, turbulent cross-helicity, and zmf obtained from simulation. The transition from Alfvénic to Rossby turbulence is presaged by an increase in the mean turbulent cross-helicity.