

Nonlinear behaviour of the Yousef shear dynamo

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Summary

We present preliminary results from a nonlinear simulation of the shear dynamo investigated in the linear regime by Yousef *et al.*, which show that large scale flows typically come to dominate the dynamics.

Turbulent motions of plasma within the Sun are believed to be responsible for the generation and sustainment of its magnetic field via dynamo action. It is well understood how small scale magnetic fields can be induced by the small scale turbulence. A less understood phenomenon, however, is the ability of the field to display larger structure on the scale of the Sun itself. Mean field dynamo theory which utilises non-zero net helicity via the α -effect has long been used to explain the generation of the large scale fields, although there is recent evidence suggesting that the theory suffers from considerable inaccuracies in the solar regime where turbulence is generated by convection [11]. However, if the α -effect is not a plausible model, then how else is large-scale structure to be obtained?

Starting with the work of Yousef *et al.* ([1]), several authors [2, 3, 4] have demonstrated an apparently different mechanism. They investigated forced *non-helical* motion in a long domain in the presence of a uniform shear. They found that magnetic fields with long-range order (and extended lifetimes) can be induced, though the large-scale structures move irregularly and are hard to identify with cyclic behaviour common to the solar field. Their work implemented non-helical forcing in order to eliminate the α -effect as an amplification mechanism as well as a large aspect ratio to allow for large scale structure to develop whilst conserving computational resolution. A number of theoretical mechanisms have been suggested to explain the ability of shear to generate large-scale fields: an enhanced α via greater correlation of small-scale motions by the shear [5]; an interaction with the fluctuating α -effect [6, 7, 8]; or an enhancement of the shear-current effect [9, 10]. The enhancement of dynamo action due to shear without an α -effect has also been observed in models incorporating convection [12, 13]. Recently, [14] showed that it was possible to produce large-scale field with periodic behaviour using a shear dynamo mechanism although this was not a fully 3D simulation.

Our work, reported in [15], is an extension of the original ‘shear dynamo’ calculation. The work of [1, 2] was performed for the kinematic case only so we have investigated the natural extension of the model by including the Lorentz forces due to the magnetic field. This allows us to determine how the velocity and magnetic fields equilibrate and whether the large scale structures persist into the nonlinear regime. Our preliminary findings are that when the dynamo generated field becomes large enough to influence the flow, there is indeed a period of time when similar large scale structures continue to exist, with equilibrated amplitudes. However at later times - the interval apparently depending on the strength of the imposed shear and on the magnetic Prandtl number- large flows develop in the direction of the original shear, and the large scale structures are destroyed (see the Figure). I will discuss the force balances giving rise to this phenomenon, and will hope to present further calculations for more general shear flow profiles to see if the simple uniform shear treated here gives typical results.

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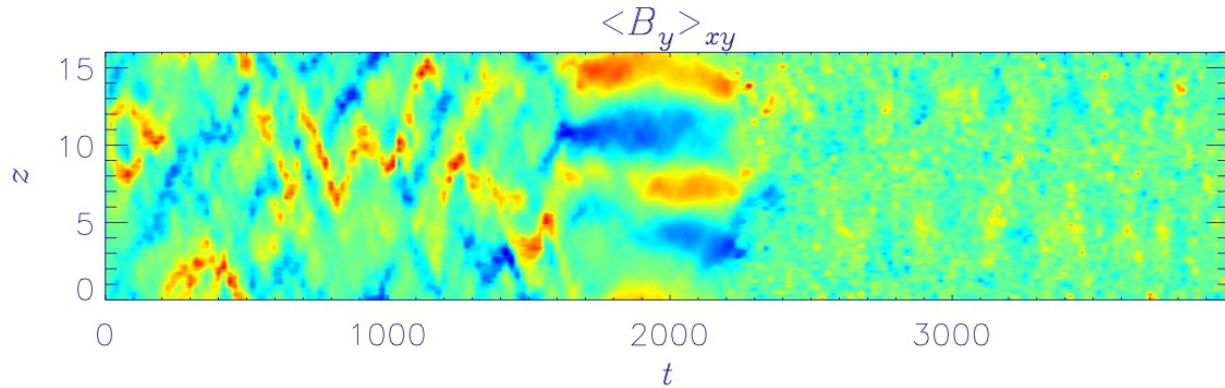


Fig. 1: Plot of the average magnetic field in the direction of the shear, averaged over the x and y directions, as a function of z (the coordinate in the direction of the longest box length) and time, for a moderate shear (from [15]). The left hand portion shows the linear behaviour, the centre portion the nonlinear equilibration with large scale structures, and the right hand portion the regime with large induced shear and no large scale structure.

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