On Quantifying Entrainment Dynamics in Drift–Zonal Flow Turbulence

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Turbulence entrainment, or **spreading**, is the process by which turbulent regions expand into laminar regions, and so propagate fluctuation activity as well as heat, particles, etc. Entrainment is a fundamental process, with the turbulent wake being the clearest, simplest example [1]. In MFE, turbulence spreading [2] is relevant to non-locality phenomena, avalanching and to the turbulent broadening of heat load distributions in H-mode plasmas. Turbulence spreading has been widely studied, particularly by simulations. These investigations led to the production of numerous color visualizations. Here, we extend previous work [3] on 2D turbulence and 2D MHD and present the results of a quantitative basic study of spreading dynamics for locally forced drift–zonal flow turbulence. Special attention is focused on the fluctuation potential enstrophy flux. The aim is to elucidate basic physics. Spatially localized forcing is a key feature of these numerical experiments.

There are two key physics considerations in this problem. First is that turbulence propagates by BOTH wave energy density flux as well as by eddy mixing and scattering. Here, the “waves” are drift waves and the “eddies” are as in 2D turbulence. These two spreading channels work in synergy, with relative contribution in proportion to the Kubo number. Of course, $Ku\sim 1$ is the relevant regime, which presents a challenge to sorting out relative contributions. The second issue is that since zonal flows cannot propagate - as $v_r = 0$, due to symmetry,- energy coupled to zonal flows cannot spread. Thus, zonal flow damping and nonlinear decay have exert key controls on turbulence spreading. In particular, understanding the return of energy from the ZF to the turbulence is of prime importance.

Here, we explore the flux of potential enstrophy in the parameter space of zonal flow drag damping and localized turbulence forcing strength. For weak drag and low forcing, the spreading flux is small, reminiscent of the “Dimits shift” regime, where all energy is coupled to stationary zonal flows. As forcing strength increases, the spreading flux rises rapidly, suggesting that the zonal flow loses energy. Both the wave energy density flux and the fluctuation potential enstrophy flux exhibit qualitatively similar trends, though differences in detail do appear.

The challenge, then, is to quantify the return of energy from the zonal flow to the turbulence. This is done by calculating the Reynolds power density in time. Reynolds power density is a measure of the rate of energy transfer between turbulence and zonal flow. We then track the faction of the Reynolds power density which is positive, indicating decay of zonal flow energy. Note that since zonal flow persists, the Reynolds power fluctuates in time between negative and positive values. We show the positive fraction **increases** with forcing strength and **decreases** with increasing drag. Both trends are physically plausible.

Ongoing work is focused on modelling the Reynolds power density, and on studying the interaction of spreading and avalanching. We also are concerned with zonal flow drift and migration.

References

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