§8. Magnetic Island Evolution in the Presence of ITG Turbulence

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Turbulence is known to drive and sustain magnetic islands of width equal to multiples of the Larmor radius [1]. The nature of the drive is studied here by means of numerical simulations of a fluid electrostatic model in 2D (single helicity) sheared-slab geometry. The electrostatic model eliminates the coalescence of short wavelength islands as a mechanism for sustaining longer wavelength islands [1]. In quiescent islands the polarization current, which depends on the propagation velocity of the island through the plasma, plays a critical role in determining the growth or decay of island chains[2]. For turbulent islands, the unforced propagation velocity is significantly changed by strong zonal flow [3].

The simulations show, however, that the turbulent fluctuations in the current density are much larger and faster than those in the zonal flow, and that they dominate the steady-state perturbed current density. In order to distinguish the roles of the zonal flow from the direct action of the fluctuations on the islands, a new diagnostic is implemented. This new diagnostic separates the effects of all the sources of parallel current. These are the curvature (which drives Pfirsch-Schlüter currents) and the divergences of the viscous and Reynolds stresses (the latter driving polarization currents). The new diagnostic also enables the contributions from short and long wavelengths to be separated for each term. It shows that in the absence of curvature, the drive is dominated by the contributions to the polarization current from the short wavelength fluctuations, while the long-wavelength fluctuations play a stabilizing role. In the presence of unfavorable curvature, by contrast, the effects of the short- and long-wavelength contributions of the polarization current reverse roles but nearly cancel, leaving the Pfirsch-Schlüter current as the dominant drive [3].

We based our choice of island width on the following considerations. For small islands, the electrostatic approximation becomes questionable since the jitter in the island propagation velocity caused by its interaction with turbulent eddies can be expected to become significant. In the opposite limit of large islands, we expect the effects of profile flattening, which are omitted from our simulations, to be significant. One of these effects is to reduce the intensity or even quench the turbulence so that in the large island regime, we expect steady-state effects to dominate. Such steady-state effects include the polarization current examined in our previous paper as well as effects related to the current profile. For the chosen width of $W = 3.5\rho_s$, however, Fig. 8 of Ref. [1] shows that the fluctuations in the velocity of the X- and O-points are small, while Ref. [2] shows that the profile flattening is weak and the steady-state polarization current is stabilizing. For such intermediate widths, the fixed gradient electrostatic model used in our simulations is justified.

In all the cases we have simulated, we find that the internal dynamics acts to drive island growth (Fig. 1). In the absence of curvature, the drive is dominated by the contributions to the polarization current from the short wavelength turbulent fluctuations. That is, the island is driven by the polarization currents induced by its interaction with short-scale eddies. The contribution to the polarization current from the zonal flow is healing but subdominant. In the presence of unfavorable curvature, by contrast, we find that the internal drive is dominated by the contribution from the Pfirsch-Schlüter current, which is such as to drive growth.

We have found that the turbulence significantly enhances the drag force opposing any departure of the propagation velocity of the island from its natural value. The turbulent diffusion of momentum across the separatrix of a magnetic island in the Gyro-Bohm unit is

$$\mu_{\rm tur} \approx 0.2\rho_i^2 v_{Ti}/L_n$$

for ITG turbulence with $\eta_i = 2.5$. That is $\mu_{\rm tur} \approx 0.2/(1.6\times10^4) \approx 1.3\times10^{-5} L_n v_A$ in the MHD normalization. Our choice of viscosity in the previous paper [2], $\mu_{\rm tur} = 0.1\rho_i^2 v_{Ti}/L_n$, is close to the turbulent diffusion obtained here. These results may depend on the width of magnetic island. The study of this dependence is retained for future studies.

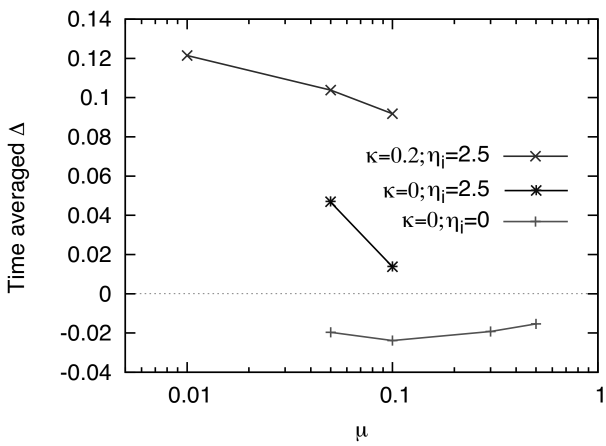

Fig. 1: Time averaged internal drive for freely propagating island, $\bar{\Delta}(u_{\rm free})$, with ITG turbulence and curvature ($\eta_i = 2.5$ and $\kappa = 0.2$), with ITG turb ulence and no curvature ($\eta_i = 2.5$ and $\kappa = 0$), and without ITG turbulen ce $\eta_i = \kappa = 0$.

1) A. Ishizawa and N. Nakajima. Phys. Plasmas **17**, 072308, (2010).

2) A. Ishizawa, F. L. Waelbroeck, et.al., Phys. Plasmas **19**, 072312 (2012).

3) A. Ishizawa and F. L. Waelbroeck, Phys. Plasmas **20**, 122301 (2013).