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Potential Vorticity Mixing in a Tangled Magnetic Field[1]

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Rossby/Drift-zonal flow turbulence frequently occurs in a background of a static stochastic (tangled) magnetic field. Tangled fields that coexist with an ordered mean field play a key role in turbulence in the solar tachocline[2], and in magnetic confinement devices. and in magnetic confinement devices. In the case of weak-field perturbations, quasi-linear theory predicts that the Reynolds and magnetic stresses will balance, as turbulence Alfvénizes for a larger mean magnetic field. However, even a modest mean magnetic field leads to large magnetic perturbations for large magnetic Reynolds number. Thus, the physically relevant case is that of a strong but disordered field. We present a novel double-average theory of potential vorticity (PV) mixing in the context of β-plane MHD, with a special focus on the physics of momentum transport in the stably stratified, quasi-2D solar tachocline. We present numerical calculations indicate that the Reynolds stress is modified well before Alfvénization i.e. before fluid and magnetic energies balance. Calculations indicate that mean-square fields strongly reduce Reynolds stress phase coherence and also induce a magnetic drag on zonal flows. The physics of transport reduction by tangled fields is elucidated and linked to effects in other channels. We propose a physical picture of the system as a resisto-elastic medium threaded by a tangled magnetic network. Reynold stress decoherence is identified as the main effect. Applications of the theory to momentum transport in the tachocline and other systems are discussed in detail. Related experiments[3] indicate that RMP fields can reduce fluctuation-driven Reynolds forces and so inhibit the initiation of the L-H transition. We present a theory of PV flux (Reynold force) decoherence and its implications for zonal flow evolution. Using the techniques discussed above, we calculate the decoherence of the PV flux due to stochastic magnetic field scattering. Decoherence requires the stochasticity-induced decorrelation rate to exceed the bandwidth of the ambient electrostatic micro-instabilities, as well as the bandwidth of Alfvén waves (i.e. Kubo number $Ku \geq 1$). These inequalities define a critical value of $\langle (\delta B)^2/B^2 \rangle$ for an effect on the transition. The implications for decoherence of the particle and heat flux are discussed, as well.

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[2]Chen, C. C., & Diamond, P. H. (2020). *Potential Vorticity Mixing in a Tangled Magnetic Field.* The Astrophysical Journal, **892(1)**, 24

[3]Kriete, D. M., McKee, G. R., Schmitz, L., Smith, D. R., Yan, Z., Morton, L. A., & Fonck, R. J. (2020). *Effect of magnetic perturbations on turbulence-flow dynamics at the LH transition on DIII-D.*Physics of Plasmas,27(6), 062507.