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Physics of Turbulence Spreading and Explicit Nonlocality

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Turbulence can spread from the linear unstable region into the stable or weak unstable region. Thus, turbulence spreading can introduce more turbulence than expected from the linear stability, therefore breaks the scenario of local turbulence [1]. Turbulence spreading can be important for topics related to core-edge coupling, magnetic island and transport scaling. We started from a simplified gyro-phase and bounce-phase-averaged kinetic equation, used the two-point correlation functions [2], derived a model for turbulence spreading [3]:

$$\frac{\partial \hat{I}}{\partial \hat{t}} = \mathcal{G} \otimes \frac{\partial}{\partial \hat{r}}\left[2\hat{D}_0 \hat{I} \frac{\partial}{\partial \hat{r}}\left(\hat{I} - \frac{\delta_b^2}{2}\frac{\partial^2}{\partial \hat{r}^2}\hat{I}\right)\right] + \mathcal{G} \otimes \hat{I} - \hat{I}^2$$

Explicit nonlocality means that the evolution of quantities at r are explicitly affected by other positions, as characterized by the Green's function convolution. The Green's function $\mathcal{G}(x) \propto e^{-|x|/\delta_b}$ comes from the inverting of potential vorticity to $\tilde{\phi}$, and has the kernel width of several δ_b (banana orbit width). This model recovers the usual spreading model when δ_b is small [4]. Nonlinear damping mechanism is obtained from the expansion of the intensity correlation separation in y_- direction. Nonlocal growth term is in the form of the convolution between the nonlocal kernel $\mathcal{G}(x)$ and the growth rate $\gamma(x)$. Results show that nonlocal effects, especially the nonlocal growth, thicken the turbulence spreading front and increase the speed of front propagation, as in Figure 1. As for the penetration into the stable region, penetration depth Δ_p linearly grows with δ_{b*}, as in Figure 2. At the same time, convolution reduces the growth rate in the unstable region, thus decreases the saturation level of turbulence. The total turbulence intensity in the unstable region follows a simple linear relation with nonlocality: $\bar{I}/\rho_*^2 = 1 - \delta_{b*}$. The ongoing work is trying to include the zonal flow effects in this model.

This model has the potential to apply to the energetic particles driven turbulence (larger δ_b). In the pedestal, where profile scale L_T is comparable to δ_b, the effective penetration could be enhanced. And this model may be useful for model reduction in gyro-kinetic simulations.

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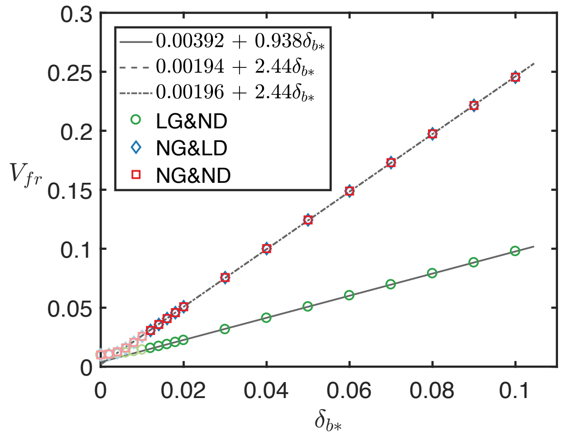

Figure 1. Leading edge propagation speed for different variation of models when varying δ_{b*} with $\rho_* = 0.01$.

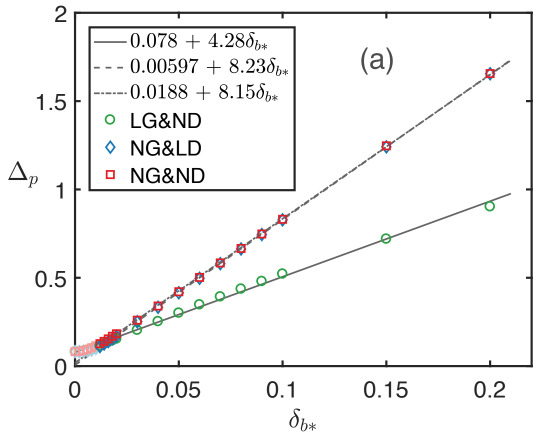

Figure 2. Front penetration depth Δ_p against δ_{b*}.