§11. A Flux Tube Train Model for Toroidal Plasma Turbulence Simulation

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Drift wave turbulence in toroidal plasmas, such as tokamak and helical plasmas, has been intensively investigated by means of direct numerical simulations, as it is supposed to be a main cause of the anomalous transport of mass, momentum, and heat. In plasmas with a strong toroidal magnetic field, turbulence often shows the quasi-two-dimensional nature, where the parallel scale-length is much longer than the perpendicular wavelengths of turbulence. In case with the finite magnetic shear, the turbulence fluctuation intensity has a peak on the outer side of the torus, which is known as the ballooning mode structure. In order to numerically handle the drift wave turbulence with the ballooning mode structure, the flux tube model has been developed [1], where the local turbulence fluctuations are efficiently captured in a simulation box set up along a toroidal field line.

In application of the flux tube model to drift wave turbulence, however, one needs to be careful to exclude artificial enhancement of turbulence correlation in the field-aligned direction. In order to reduce the artificial effect, it has been proposed to extend the simulation domain in the parallel direction, which simultaneously demands secular increase of the radial wavenumber, $k_r = |\hat{s}\theta k_\theta|$, where $\hat{s}$ is the magnetic shear, θ is the poloidal angle, and k_θ means the poloidal wavenumber. This method is straightforward, but may be inefficient if the mode structure has a long tail along the field line leading to a large value of k_r, because the higher k_r requires the severer Courant condition. Actually, in case with a moderate value of instability growth rate of the ion temperature gradient mode, the mode structure extending to $\theta = \pm 8\pi$ demands the simulation box size of 16π in the field-aligned direction.

In order to overcome the numerical difficulties, we have developed a new simulation model which consists of a train of flux tubes connected along the field line. The new model is free from the secular increase of k_r as the simulation domain is limited to $\theta = \pm\pi$, but can exclude the artificial increase of the turbulent correlation by connecting different flux tubes. This can be clearly seen in plots of turbulent intensity on the θ-k_r plane (see Fig. 1). The conventional flux tube model shows that the turbulent intensity peaks at every 2π in θ but with higher k_r as found in the upper panel of Fig. 1. In contrast, no secular increase of k_r appears in the flux tube train model (see the lower panel of Fig.1) as turbulence simulated in in each flux tube is statistically equivalent by construction. The results clearly demonstrate that the quasi-modes in the ballooning representation are equally treated, even in a numerical sense, by use of the flux tube train model.

Comparison of the turbulent transport flux obtained from the conventional flux tube model and the flux tube train model confirms agreement of the two schemes (up to the case of flux tube length of 16π for the conventional model; see Fig. 2). Thus, it is verified that the new model has numerical advantages to the conventional one while providing the same transport coefficient.

Application of the flux tube train model to other kinds of turbulence is currently in progress, and will be reported elsewhere.

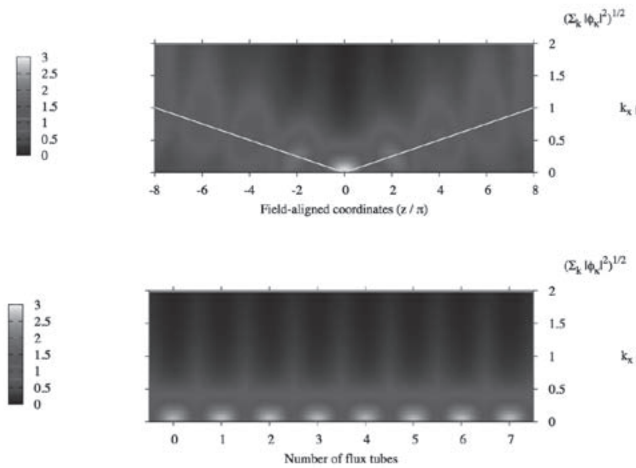

Fig. 1. Turbulence intensity (power of electrostatic potential fluctuations) plotted in θ-k_r plane. Upper and lower panels show results from the conventional flux tube model and the flux tube train model, respectively.

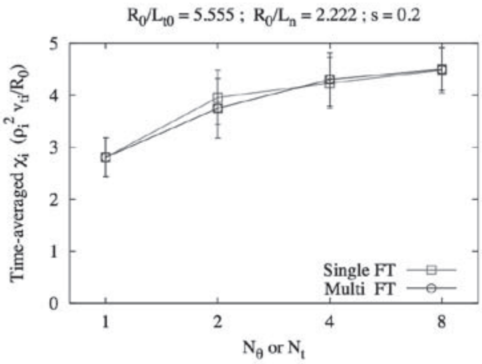

Fig. 2. Comparison of the turbulent heat transport obtained by the conventional flux tube model (open squares) and the flux tube train model (open circles).

1) Beer M.A., Cowley S.C. and Hammett G.W.: Phys. Plasmas **2** (1995) 2687.