§14. Extension of Gyrokinetic Simulation Code GKV and its Application to Turbulent Transport

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The gyrokinetic simulation code GKV has been applied to a variety of problems on turbulent transport in tokamak and helical plasmas, such as the ion/electron temperature gradient (ITG/ETG) turbulence, the trapped electron modes, the kinetic ballooning modes (KBM), and the zonal flows. After development of the first version based on the electrostatic gyrokinetic equations of a single particle species with the adiabatic response of background species (electrons or ions), the simulation code has been continuously extended with including the electromagnetic effects, the gyrokinetic ions and electrons. Since then we have obtained remarkable results from GKV simulations on the multi-scale ITG and ETG turbulence, the ITG turbulence in LHD plasmas with the experimental configurations and parameters, and the KBM turbulence in tokamak and helical plasmas.

To further enhance applicability of the GKV code, recent efforts have been devoted to introduction of multiple ion species, where one needs to take into account of collisions of unlike species ions. In a general case with different ion temperatures, a new model collision operator is necessary to be introduced, because the conventional linear collision operators were valid only for ion species with the same temperature. This extension enables us to carry out the GKV simulation for multiple ion species including impurity ions as well.

Another way of code extension is directed to increase the computational and numerical efficiencies. The GKV code has been implemented for peta-Flops computers such as the K computer. The high efficiency of parallel computation is also advantageous in use of the new Plasma Simulator system at NIFS.

The numerical efficiency is associated with the simulation scheme employed in the code. The GKV is a local flux tube simulation code, where a thin simulation box is set along a field line on a torus. The flux tube code is quite efficient for simulation of ballooning type mode structures. However, if the mode structures of turbulence fluctuations extend over one poloidal turn, one needs to use a longer simulation domain covering multiple poloidal turns. Typically, it happens in case with a low magnetic shear, and leads to a sever restriction on the time step size due to secular increase of the radial wavenumber and numerical breaking of the ballooning symmetry. In order to overcome the difficulties in the conventional flux tube model, we have developed a new simulation method using multiple flux tubes which are serially connected along the field line like a train, that is, the flux tube train model[1)]. It is noted that, while each flux tube covers only one poloidal turn, mode structures elongated in the parallel direction are dealt with in the neighboring tubes. The flux tube train model is well benchmarked against the conventional model for the ITG turbulence simulation with the adiabatic electron response in a tokamak with a low magnetic shear (where $\hat{s} = 0.2$)[1)], and demonstrates the advantages for the numerical stability and the symmetry preserving property.

The flux tube train model may also be fruitful for simulating the ITG/TEM turbulence in a tokamak even with a magnetic shear of $\hat{s} \sim 1$. As the electrons moves fast along the field line with much higher speed than ions, the parallel mode structures are often elongated. Also, if the ETG/TEM modes with low poloidal wavenumbers of $k_\theta \rho_{te} \ll 1$ remain unstable, the mode structures broaden in the parallel direction. Recently, we have carried out the electrostatic ITG/TEM turbulence simulation in a tokamak configuration by using the flux tube train model, where the number of tubes N_t are changed as $N_t = 1$, 2, and 4. Here the safety factor $q = 2.8$, and the magnetic shear $\hat{s} = 2$. Other parameter settings are similar to those of a DIII-D benchmark test case. The obtained heat transport coefficients for ions and electrons, χ_i and χ_e, are plotted in Fig. 1. One finds both χ_i and χ_e increase as N_t in consistent with the ITG turbulence simulations for a low shear tokamak. This is because artificial enhancement of the parallel correlation of turbulence fluctuations lowers the saturation level of turbulence as well as the transport flux. So far, about 10-20% enhancement of the transport coefficient is observed in Fig. 1. More quantitative comparisons remain for future works including the electromagnetic fluctuations which influence stability of the linear ITG modes.

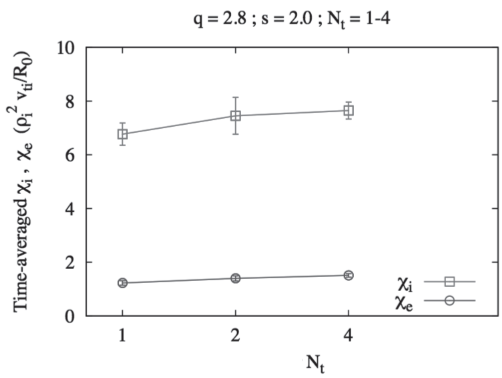

Fig. 1. The ion and electron heat transport coefficients (that is, χ_i and χ_e, respectively) obtained from the GKV simulations with the flux tube train model, where N_t means the number of flux tubes.

1) Watanabe, T.H. et al.: Phys. Plasmas **22**, 022507 (2015).