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Modeling of gyrokinetic turbulent transport in helical plasmas

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A quantitative prediction of turbulent transport is one of the most critical issues for realizing magnetic fusion energy. Nonlinear gyrokinetic simulations of turbulent transport in helical plasmas require a large number of mesh points along field lines in order to resolve helical ripple structures and consume the computer resources much larger than for tokamaks. Still, it is not easy to couple the nonlinear gyrokinetic simulation with an integrated transport simulation code. Thus, the reduced model, which can quickly reproduce the gyrokinetic turbulent transport coefficients or fluxes, is highly demanded. In the previous studies, the reduced model for the ion turbulent heat diffusivity obtained from gyrokinetic simulations using adiabatic electrons was presented as a function of the linear growth rates for the ion temperature gradient (ITG) modes and the linear zonal flow decay time [1]. In addition, it was shown how to apply this reduced model of the ion heat diffusivity to the transport code [2].

The ITG mode and zonal flows in the Large Helical Device (LHD) have been studied. The gyrokinetic simulation with kinetic electrons has been performed for the high ion temperature LHD discharge (shot number 88343). Based on the temperature and density profiles, and field configuration from the LHD experimental results of the high-T_i plasmas at t=2.2s and of the low-T_i plasmas at t=1.8s, 1.9s, the electron and ion temperature gradients, the density gradient, and the safety factor radially change. The GKV simulation with the kinetic electrons is performed for the three dimensional equilibrium field configurations with R=3.75m for the high-T_i plasmas and with R=3.6m for the low-T_i plasmas. In the low-T_i plasmas, the magnetic field configuration is shifted inward. In the inward shifted field configuration, the helical magnetic structure can enhance the generation of zonal flows. To construct a new transport model which evaluates turbulent particle and heat transport, simulations are performed to solve nonlinear gyrokinetic equations for electrons and ions [3]. The nonlinear GKV simulations are performed in the high-T_i and low-T_i plasmas. The nonlinear saturation is found in the time evolutions of the fluxes. Linear gyrokinetic simulations are also done to calculate the poloidal wave-number spectra of the quasilinear fluxes [4] with taking into account the linear growth rates and zonal flow responses for an appropriate parameterization of the fluctuation amplitudes. The values of the mixing length estimate by the simulation with the kinetic electron are several times larger than those by the simulation with the adiabatic electron. Effects of kinetic electrons on zonal flows are investigated. The linear zonal flow response function with the kinetic electron decays faster than that with the adiabatic electron. The zonal flow decay time decreases radially outward due to the trapped electron. The turbulence fluctuation increases outward. Therefore, the ion energy flux is found to increase radially outward. In the adiabatic electron case, the zonal flow decay time increases outward and the ion energy transport decreases outward [1]. The resultant quasilinear fluxes are compared with the nonlinear simulation results. The value of the ion heat flux is determined by the reduced model for the ion heat diffusivity in the high-$T_i$discharge plasmas of the LHD, because the nonlinear simulation results are reproduced by the reduced model better than the quasilinear ion energy flux. The values of the electron energy flux and the particle flux are found from the ratios of the electron energy and the particle fluxes to the ion energy flux as the results of the quasilinear analysis. This model is installed into the integrated transport code for simulating evolutions of the plasma profiles in the LHD. To quickly evaluate the model particle and heat fluxes in the transport code, further parametrizations of the linear growth rates by the ion temperature gradient scale lengths are carried out. The stationary plasma profiles obtained from the transport simulation will be compared with those from the LHD experiments.

References

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