Zonal Flows in Ion and Electron Temperature Gradient Turbulence

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In the fusion research, numerous theoretical and experimental studies have been done on zonal flows as an attractive mechanism for realizing a good plasma confinement [1]. Damping processes of zonal flows in the ion temperature gradient (ITG) turbulence were analytically investigated by Rosenbluth and Hinton [2,3] for tokamaks and by Sugama and Watanabe [4,5] for helical systems based on the gyrokinetic theory. One of the important results from these theoretical works is a prediction of the so-called residual flow, which is an undamped component of an initially-supplied source flow in a collisionless time scale. It was verified by gyrokinetic simulations [4–7] that the zonal flow, which is added initially as an impulse, shows the convergence to the theoretically predicted value after oscillations of the geodesic acoustic mode (GAM) [8] are damped. The accurate theoretical descriptions of zonal-flow behaviors are critical in correctly predicting the turbulent transport of fusion plasmas. In fact, it was argued that predictions of larger turbulent diffusivities made by gyrofluid simulations than by gyrokinetic simulations are due to the gyrofluid model which causes complete damping of the initial flow and no residual component [2,3]. Also, these gyrokinetic analyses of the zonal-flow dynamics are beneficial in searching for favorable magnetic configurations where zonal flows are less damped and accordingly turbulent transport is reduced. In the present paper, collisionless dynamics of zonal flows in ion and electron temperature gradient (ITG/ETG) turbulence in toroidal plasmas are investigated by gyrokinetic theory and simulation. It is elucidated how the zonal-flow dynamics are influenced by magnetic geometry and vary between the ITG and ETG turbulence cases. Furthermore, examining velocity-space structures of the distribution function, a novel kinetic-fluid closure model is derived, which can reproduce the same zonal-flow time evolutions with low computaional costs as those obtained from the gyrokinetic simulation.

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