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Characteristics of Turbulence Driven Multiple-Channel Transport in Tokamaks, and Comparison with Experiments

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New features of toroidal momentum and energy transport in tokamaks found from our global gyrokinetic simulations are reported in this paper with focus on non-diffusive characteristics. i) An important nonlinear flow generation process has been identified due to the residual stress (a non-diffusive element of the momentum flux) produced by electrostatic turbulence of ion temperature gradient (ITG) modes and trapped electron modes (TEM). Symmetry breaking in the parallel wave number spectrum induced by turbulence self-generated low frequency zonal flow shear has been identified to be a key, universal mechanism for driving residual stress. The ITG turbulence driven "intrinsic" torque associated with residual stress is shown to increase close to linearly with the plasma pressure gradient, consistent with experimental observations in various devices. Nonlinear residual stress generation in collisionless TEM turbulence by both the fluctuation intensity and the intensity gradient in the presence of broken $k_\parallel$ symmetry due to zonal flow shear is observed for the first time. Simulations also suggest the existence of other mechanisms beyond $\mathbf{E}\times\mathbf{B}$ shear for $k_\parallel$ symmetry breaking. Moreover, the momentum pinch, another non-diffusive element, is also identified in the simulation of TEM turbulence. ii) Considerable non-diffusive, inward ion and electron heat fluxes associated with wave-particle energy exchange can be produced by the CTEM turbulence with typical DIII-D parameters. Moreover, the CTEM driven particle flux is shown to carry a large portion of the outward, convective flux for both electron and ion energy and toroidal momentum. iii) The ∇T_e-driven CTEM turbulence in specific parameter regimes is found to generate remarkably large fluctuation structures via inverse energy cascades, which may have a natural connection to the generation of blobs at the edge. iv) Trapped electron physics is shown to play a critical role in the ITG marginality regime in determining plasma transport.