Comparison of Measured Turbulence Properties in High-Performance H-Mode Plasmas on DIII-D and with Gyrokinetic Simulations

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Quantitative comparisons of the calculated turbulence characteristics with fluctuation measurements in high performance H-mode plasmas on DIII-D show excellent agreement between the fluctuation amplitude and frequency spectrum (corresponding to poloidal wavenumber) for a moderate rotation discharge ($M_o \sim 0.2$). The calculated ion heat flux also closely match the experimentally inferred value, while the electron heat flux was slightly underestimated, perhaps due to significant contributions from higher-k turbulence not included in these initial nonlinear simulations; linear growth rate calculations show significant growth rates for ETG-scale turbulence. Identifying and improving the fidelity with which simulations reproduce experiment will increase confidence in their predictive capability and provide computational tools for future performance optimization. To assess this, multi-scale spatiotemporal properties of turbulence were measured with multiple fluctuation diagnostics (Beam Emission Spectroscopy, Doppler-Backscattering, Phase Contrast Imaging) in high-confinement hybrid scenario H-Mode plasmas on DIII-D. Low-wavenumber density fluctuation amplitudes range from 0.2-1% over $0.5 < \rho < 0.85$, while radial and poloidal correlation lengths are near 5 cm and 8 cm, respectively ($L_c \sim 10 \rho_i$) at mid-radius. The nonlinear simulations used the measured kinetic profiles, calculated heat sources, and magnetic equilibria, and include kinetic electrons and electromagnetic fluctuations, both of which are essential to obtaining accurate comparisons with experiment. While the fluctuation amplitudes were similar between experiment and simulation, the low-k correlation lengths and decorrelation rates showed moderate differences, which could result from a variety of causes such as non-local or multiscale physics not included in the simulations, missing or incorrect descriptions of zonal flow physics and/or electromagnetic effects, or the influence of processes such as ELMs and core tearing modes not included in the gyrokinetic model. Complementary measurements were obtained in higher toroidal rotation plasmas (Mach Number, $M \sim 0.5$) with otherwise similar kinetic profiles and dimensionless parameters ($\rho^*, q, \beta, T_e/T_i, \nu^*$) to test simulations at very high ExB shear. The measured turbulence amplitude and radial correlation lengths surprisingly stayed nearly constant as the ExB shear is increased by a factor of 2-3, while the poloidal correlation length increases with ExB shear, and the measured decorrelation rate scales closely with the local ExB shearing rate; the energy confinement time increases by nearly 50% at high average shear. Nonlinear simulations indicate that the turbulence in the high-rotation case is set by a delicate balance of strong ITG drive and ExB shear suppression, and obtaining converged nonlinear results with conventional ion-scale GYRO simulations has proved difficult. Progress in addressing these challenges with the newly-developed CGYRO nonlinear gyrokinetic code will be presented.

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