Statistical Analysis of ITG Turbulence*

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Abstract

The fluctuations computed in plasma microturbulence codes are best viewed as a particular realization from an underlying turbulent ensemble. Benchmarking between codes can be achieved by comparing realization-independent characterizations of the turbulent fluctuations, such as the fluctuation spectra, correlation functions, and thermal transport coefficients. Results from the global particle code, GTC, and continuum code, GYRO, are compared with each other and with results from the flux-tube particle code, PG3EQ, and continuum code GS2 in order to benchmark the gyrokinetic codes within the Plasma Microturbulence Project (PMP). We examine parameter scans about the Cyclone test case in which a suite of gyrokinetic particle and gyrofluid simulation codes undertook the same three-dimensional simulation of electrostatic ion-temperature-gradient (ITG) turbulence in a tokamak plasma using physical parameters matching those in an General Atomics Doublet III-D (DIII-D) high-confinement (H-mode) shot #81499. We find significant but not full agreement among the PMP codes.

The self-consistent potential observed in microturbulence simulations can be separated into a flux-surface-averaged piece, $\langle\phi\rangle$, and the deviations from the flux-surface-average, $\delta\phi \equiv \phi - \langle\phi\rangle$. The flux-surface-averaged piece, $\langle\phi\rangle$, does not play a direct role in transport because it can only generate flows within a flux surface. However, $\langle\phi\rangle$ does play an important role in determining the saturated intensity of the ion-temperature-gradient (ITG) fluctuations, $\langle|\delta\phi|^2\rangle$. We characterize the intensity of the ITG turbulence by evaluating it on a cut through the outboard mid-plane, $\langle|\delta\phi|^2(r,\theta=0,\zeta,t)\rangle_\zeta$, where $\theta=0$ labels the outboard mid-plane of the tokamak and ζ is the toroidal angle. The two-point correlation functions and power spectrum of $\delta\phi$ are computed using data from all PMP codes and found to be remarkably similar, showing little variation with either the code employed in the simulation or with system size

The ITG thermal transport χ_i and fluctuation intensity $\langle|\delta\phi|^2\rangle_\zeta$ exhibit intermittency. The heat transport comes in bursts, or "storms" which appear to propagate in radius. Using GKV we observe that χ_i is nearly proportional to $\langle|\delta\phi|^2\rangle_\zeta$. Figure 2(a) shows the radial variation in the time-average of χ_i from a a/ρ-scan of simulations using the GYRO global continuum gyrokinetic code (a is the tokamak minor radius while ρ is the ion gyroradius) and shows substantial variation in χ_i, in both radius and with a/ρ. The radial variation in χ_i at large a/ρ can be reproduced within the error bars shown in Fig. 2a in individual runs (reproducing parameters at particular radii) of the flux tube codes, GS2 and PG3EQ; while GTC results for χ_i at large a/ρ lie within about 30% of the GYRO and flux tube results. Figure 2(b) shows the time average of the ratio of χ_i to $\langle|\delta\phi|^2\rangle_\zeta$. We see that the variation in χ_i associated with variation in a/ρ is almost entirely explained by variation in the turbulence intensity, $\langle|\delta\phi|^2\rangle_\zeta$. There remains only a weak radial variation in this ratio. A nearly linear relation between the thermal diffusivity and the fluctuation intensity is a prominent feature in the simulations, independent of simulation code.

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