Parametric dependencies of low-k turbulence in NSTX H-mode pedestals

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Pedestal turbulence impacts global confinement by regulating the height and width of H-mode pedestals, and validating predictive models of pedestal turbulence is critical for the success of ITER and next-step devices. In this Paper, we characterize the poloidal correlation length and decorrelation time of pedestal turbulence in NSTX ELM-free, MHD-quiescent H-mode plasmas, plus we identify several parametric dependencies that influence pedestal turbulence quantities. Turbulence measurements in the pedestal show spatial scales are in the range $k_\perp\rho_s \approx 0.1$–$0.3$. Parametric dependencies indicate the poloidal correlation length increases at higher ∇n_e, $q/\hat{s}$, and δ, and decorrelation time increases at higher ∇T_i and decreases at higher ∇V_T. Shorter decorrelation time at higher ∇V_T is consistent with prior studies of enhanced H-mode confinement in NSTX [1], but longer correlation length at higher δ is counterintuitive with results that show pedestal height increases at higher δ [2]. In addition, the parametric scalings help identify long-wavelength instabilities that may limit pedestal height and width. For instance, the ∇n_e ∇T_i scalings point to ITG/TEM turbulence. The measurements and analysis presented here broadly characterize pedestal turbulence in high-performance spherical torus plasmas and establish validation benchmarks for pedestal and edge simulations.

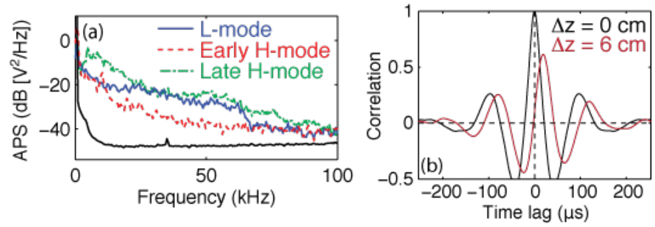

Figure 1: (a) BES auto-power spectra at r/a~0.9 and dark spectrum (black) and (b) time-lag auto and cross-correlation functions for poloidally-separated channels.

Turbulence quantities were obtained from beam emission spectroscopy (BES) measurements of localized low-k density fluctuations ($\Delta r \approx \Delta z \approx 2$ cm, $k_\perp\rho_s \leq 1$). BES observes Doppler-shifted D_α emission from deuterium heating beams [3]. Pedestal turbulence measurements were obtained from a poloidal array of BES channels at R=140 cm and $0.8 \leq r/a \leq 0.95$. Figure 1 shows example BES auto-power spectra and time-lag correlation functions. Note that the turbulence magnitude in the late H-mode phase can be comparable to L-mode turbulence. Correlation lengths and decorrelation times are calculated from time-lag cross-correlation functions (Figure 1b).

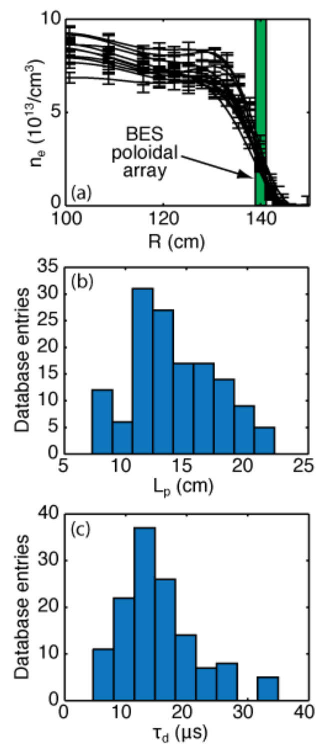

Figure 2: (a) Representative density profiles and BES measurement location, (b) poloidal correlation length, and (c) decorrelation time.

ELM-free, MHD-quiescent periods in H-mode plasmas with B_T = 4.4 kG were identified to populate a database with turbulence quantities and plasma parameters. Turbulence quantities and plasma parameters were averaged over 15-40 ms intervals. Figure 2 shows the distribution of turbulence quantities in the database. Note that BES measurements are typically near the base of the H-mode pedestal. Poloidal correlation lengths are typically 10–20 cm and $L_p/\rho_i \approx 8$–18. Decorrelation times are 7–30 μs (~ 7–10 a/c_s).

Parametric dependencies were identified using a stepwise multivariate linear regression (SMLR) algorithm that finds models in the form

$$\frac{\hat{y}_i - \bar{y}}{\sigma_y} = \sum_k \alpha_k \frac{x_{k,i} - \bar{x}_k}{\sigma_k}$$

where $\hat{y}$ are fitted turbulence quantities and x_k are plasma parameters. The SMLR algorithm begins with an initial model and adds or removes x_k parameters to minimize the model's error sum or squares (SSE) while ensuring model parameters retain statistical significance. The final model, one of many SSE local minima in the high dimensional x_k-space, depends upon the initial model in the search algorithm. Aggregating models with different combinations of plasma parameters provides a distribution of scaling coefficients (α_k) for each plasma parameter, plus the models provide α_k values for plasma parameters beyond that which a single model can provide. To identify multiple models, the SMLR algorithm was initialized with different initial models. Figure 3 shows α_k distributions for poloidal correlation length (L_p) measurements in H-mode pedestals. The α_k distributions indicate L_p increases at higher ∇n_e, q, $q/\hat{s}$, δ, β_e, and ν_e and L_p decreases at higher ∇T_e, T_i, and T_e/T_i. Similar analysis of decorrelation time (τ_d) indicates τ_d increases at higher ∇T_i and decreases at higher ∇V_T. Longer L_p at higher ∇n_e and longer τ_d at higher ∇T_i point to ITG/TEM turbulence, and q and ν_e dependencies provide insight into turbulence mediation by the GAM zonal flow.

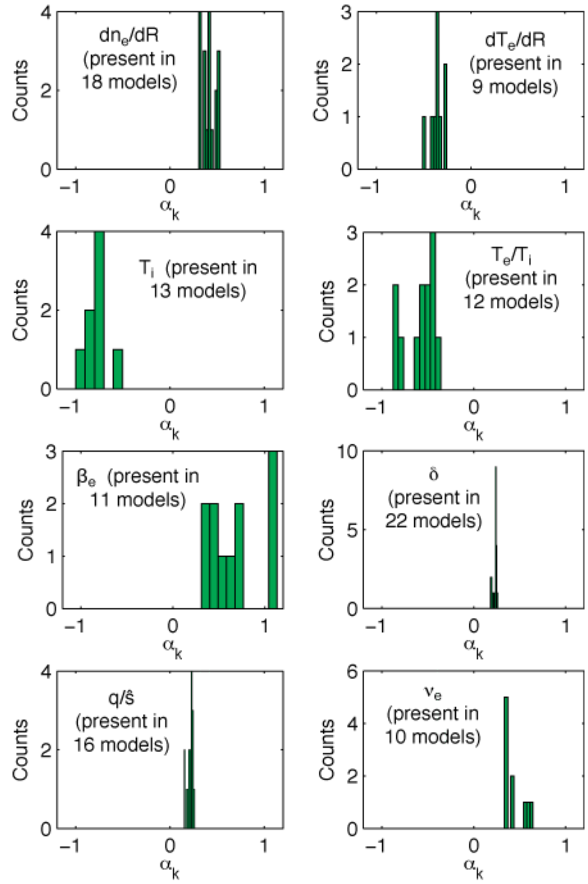

Figure 3: Poloidal correlation length scaling coefficient distributions from 35 regression models

In summary, we have measured pedestal turbulence quantities in NSTX ELM-free, MHD-quiescent H-mode plasmas and identified several parametric dependencies. The results aid identification of specific pedestal turbulent processes and, more importantly, establish validation benchmarks for pedestal/edge simulations.

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