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VALIDATION OF GYROKINETIC TRANSPORT SIMULATIONS USING DIII-D CORE TURBULENCE MEASUREMENTS

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Validation of Gyrokinetic Transport Simulations Using DIII-D Core Turbulence Measurements

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It is now widely recognized that the development of a predictive modeling capability for ITER and beyond requires the validation of transport codes against experimental measurements at multiple levels. Towards this end, the first direct comparisons of drift-wave turbulence amplitudes, power spectra, and correlation lengths predicted by the gyrokinetic code GYRO [1] against experimental observations are presented. Both local and non-local fixed gradient simulations are used in this study, while the experimental measurements were obtained in a series of repeatable, steady low-power L-mode discharges. Spatially localized measurements of density fluctuations were obtained via beam emission spectroscopy (BES) [2]. Similarly localized measurements of electron temperature fluctuations were obtained via a newly implemented correlation electron cyclotron emission (CECE) diagnostic on DIII-D [3]. To address the issue of profile stiffness, comparisons using results from GYRO simulations run in a newly implemented fixed-flux mode (which predicts the equilibrium profiles needed to match the fluxes obtained via power balance) are presented in addition to traditional fixed-gradient simulations.

Using local, fixed gradient simulations, we are able to achieve good agreement with both heat fluxes and measured fluctuation characteristics at r/a = 0.5, while under-predicting the magnitude of both at r/a = 0.75. In order to conduct accurate comparisons of simulated turbulence characteristics against experimentally measured results, it is essential to use synthetic diagnostics [4] which describe the various sensitivities of the diagnostic under consideration. In this study, synthetic BES and CECE diagnostics are created by convolving the turbulent fluctuation fields calculated by GYRO with point spread functions (PSFs) which reproduce the spatial sensitivities of these diagnostics in the (R,Z) plane (Fig. 1). This convolution is done at each timestep of the simulation, yielding timetraces which can then be processed in identical fashion as the experimentally measured timetraces. A comparison of

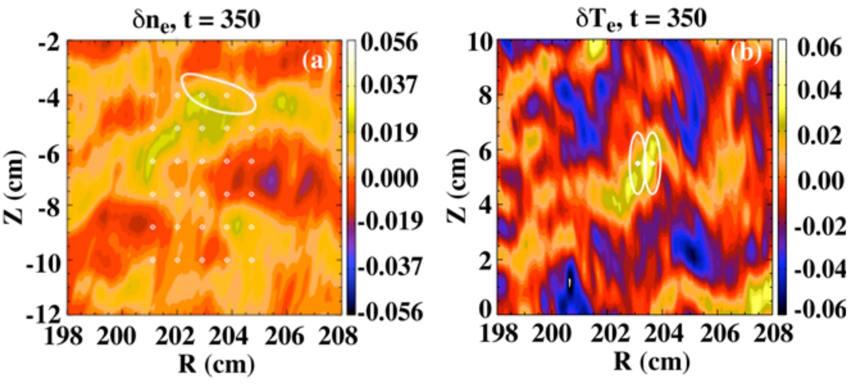

Fig. 1. Snapshots of normalized fluctuation electron density $\delta n_e = \tilde{n}_e / n_{e0}$ (a) and temperature $\delta T_e = \tilde{T}_e / T_{e0}$ (b) from a local fixed-gradient simulation at r/a = 0.5. 50% contours of the BES and CECE point spread functions are overlaid in white on the corresponding fluctuation fields. The white diamonds represent the center locations of the 30 BES channels (a) and the two CECE channels (b).

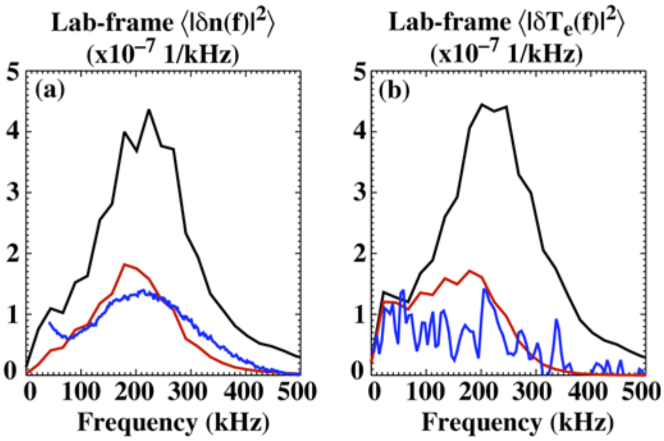

Fig. 2. Comparisons of the GYRO-predicted unfiltered (black), synthetic (red) and experimentally measured (blue) power spectra of normalized density (a) and electron temperature (b) fluctuation at r/a = 0.5.

the lab-frame frequency power spectra calculated from the (unfiltered) GYRO results, the synthetic diagnostic results, and the experimental measurements are shown in Fig. 2. Using local, fixed-gradient GYRO simulations centered at r/a = 0.5 in this set of discharges which take experimentally measured profiles and geometries as inputs, good agreement (to within 20%) is achieved with experimental heat diffusivities obtained via a power balance analysis using the ONETWO code [5]. Furthermore, we find very good agreement between the synthetic and experimental density fluctuation spectra, but moderately over predict the magnitude of the electron temperature fluctuations. A comparison of radial and vertical density correlation functions calculated with these three signals (unfiltered, synthetic, and experimental) also yields very good agreement between the synthetic and experimental results. Here, we find very little difference between any of the vertical correlation functions, while the synthetic and experimental radial correlation functions (which are in very good agreement) are significantly larger than the unfiltered value. Additional local, fixed-gradient simulations at r/a = 0.75 are found to under-predict the experimental heat fluxes by a factor of 4. Turbulent amplitudes are correspondingly under-predicted by a factor of 2, consistent with the weak turbulence scaling of fluxes proportional to the square of fluctuation amplitudes. Interestingly, the correlation functions at these locations, as well as the “shapes” of the lab-frame frequency spectra, exhibit very good agreement between the synthetic and experimental results, suggesting that the spatial structure of the turbulence is being correctly predicted even if the amplitudes of that structure are not. Further examination of the discrepancy in heat fluxes via non-local fixed-gradient simulations indicates that using the experimental profiles, GYRO is able to match the ONETWO results inside r/a = 0.5, but under-predicts them at larger radii.

Recognizing that the stiffness of drift-wave transport can magnify the importance of small uncertainties in profiles and their gradients, a new code named TGYRO [6] is used to drive GYRO simulations in a fixed-flux, rather than fixed-gradient, mode. In this mode, TGYRO self-consistently adjusts temperature and density profiles at each radial location until the GYRO-predicted energy and particle fluxes match those determined by the experimental power/flow balance analysis. Using this mode, one compares the experimentally measured and TGYRO-adjusted profiles, rather than fluxes, to assess the success of the model. Initial results from this new mode will be presented, with special attention paid to the impact of uncertainties in the particle source and equilibrium $\vec{E}\times\vec{B}$ shearing rate on the results.

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