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VALIDATION STUDIES OF GYROFLUID AND GYROKINETIC PREDICTIONS OF TRANSPORT AND TURBULENCE STIFFNESS USING THE DIII-D TOKAMAK

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Validation Studies of Gyrofluid and Gyrokinetic Predictions of Transport and Turbulence Stiffness Using the DIII-D Tokamak

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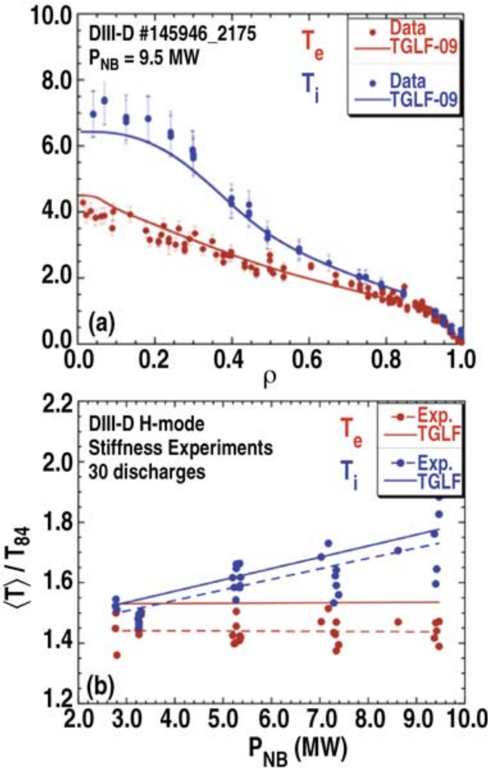

Fig. 1. (a) Comparisons of TGLF predictions (—) of T_i and T_e to measured profiles (•) (b) Comparisons of predicted volume-averaged T_i and T_e profiles normalized to their value at ρ = 0.84 against measurements.

A series of carefully designed validation experiments conducted on DIII-D to rigorously test gyrofluid and gyrokinetic predictions of transport and turbulence stiffness in both the ion and electron channels have provided an improved understanding of the experimental fidelity of those models over a range of plasma parameters. Modeling results previously presented at the 2010 IAEA FEC meeting [1] predicted ITER to be in a strongly stiff transport regime, such that large changes in heating power (and thus transport) yield only small changes in plasma gradients and profiles. The first experiment conducted was therefore designed to test predictions of H-mode core transport stiffness at fixed pedestal density and temperature, in order to mimic as closely as possible the modeling scenarios reported in Kinsey *et al.* [1]. In low triangularity plasmas, a factor of 3 variation in neutral beam injection (NBI) heating was obtained, with modest changes pedestal conditions that slowly increased with applied heating. In these plasmas, the electron temperature profile was essentially invariant with increased heating, while only a small increase (primarily at smaller radii) was observed in the ion temperature. The measurements and trends with increased NBI heating are well-reproduced by the quasilinear TGLF [2] transport model (Fig. 1), which predicts that the electron transport is dominated by electron temperature gradient (ETG) modes across the entire simulation domain ($0<\rho<0.84$), and that the ion transport is neoclassical inside ρ=0.2-0.4. These results provide significant additional support for the fidelity of the TGLF model for H-mode parameters [1].

Building upon these assessments of model fidelity in reproducing the overall core profile stiffness, a second set of experiments was performed to quantify the relationship between the local electron heat flux Q_e and electron temperature gradient by varying the deposition profile of electron cyclotron heating (ECH) about a specified reference radius. Applying this technique to low current (I_p= 0.8 MA), low density ($\overline{n}_e = 2.0\times10^{19}$ m^{-3}) L-mode plasmas with no other external heating, a critical inverse electron temperature gradient scale length has been identified for the first time in DIII-D. A separate heat pulse analysis obtained provides an independent confirmation of the critical $1/L_{\rm Te} = -\nabla T_{\rm e}/T_{\rm e}$ value.

Initial analysis of these discharges using TGLF and the nonlinear gyrokinetic code GYRO [3] yield an interesting spectrum of agreement and disagreement between code and experiment. Linear growth rate analyses support the experimental observation of a critical gradient near the measured critical value of $a/L_{\rm Te,crit} = 2.0 \pm 0.3$, transitioning from near-zero values below that gradient to finite and increasing values above it. Both TGLF and nonlinear, local, low-*k* GYRO simulations predict similar levels of near-zero turbulence and transport at or below the experimental critical gradient and experimentally relevant levels of transport above it (Fig. 2). However, both codes also systematically underpredict the power balance transport analyses in both the electron and ion (not shown) channels. It is found that approximately 50% increases in both $a/L_{\rm Te}$ and $a/L_{\rm Ti}$ are needed in the TGLF calculations of $Q_{\rm e}$ and $Q_{\rm i}$ to match the power balance calculations, larger than the ~25% uncertainty in the experimental gradients. This disagreement provides an interesting counterpoint to the close agreement observed in the H-mode validation study described above, and provides an avenue for improving our models and understanding of electron turbulence.

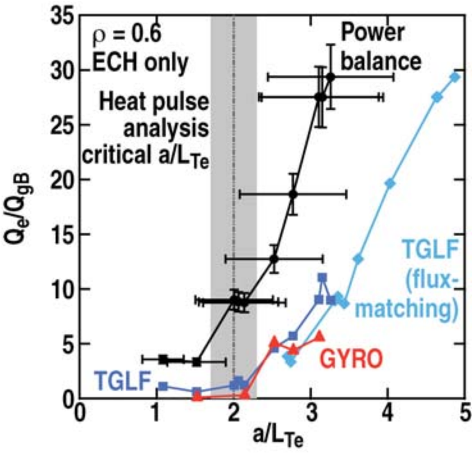

Fig. 2. Comparison of power balance $Q_{\rm e}$ calculations against TGLF and GYRO predictions.

These results build upon a number of previous validation studies [4] of electron transport at DIII-D, the most recent of which used similar variations of ECH deposition to measure scalings of local gradients and fluctuation properties. New gyrokinetic modeling findings that go beyond those reported in DeBoo *et al.* [4] indicate that both local and global GYRO simulations predict similar transport levels to each other, and that both approaches are generally able to reproduce the magnitudes and scalings of the electron (but not ion) heat flux with $1/L_{\rm Te}$, as well as the low-*k* $T_{\rm e}$ fluctuations (Fig. 3).

The validation studies described above, as well as additional studies focusing on scalings with other parameters such as plasma elongation, provide clear tests of model and code fidelity in predicting electron transport and turbulence over a wide range of plasma conditions. As part of the DIII-D contribution to the 2012 US Joint Research Target on Electron and Particle Transport, a summary of code-experiment comparisons of electron transport and turbulence will be presented.

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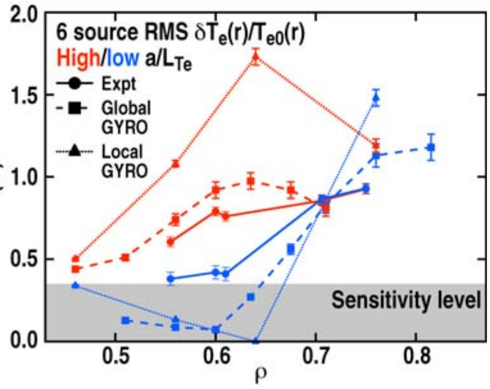

Fig. 3. Comparison of measured $T_{\rm e}$ fluctuations (●) to predictions from global (■) and local (▲) GYRO simulations.

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