HIERARCHY OF TURBULENT TRANSPORT MODELS WITH THE SOLEDGE3X CODE

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Accurate modelling of cross-field turbulent transport in the edge plasma of tokamaks remains a significant challenge. Many key experimental features, such as the formation of edge transport barriers, are still difficult to simulate, especially for ITER-sized tokamaks. Predicting the scrape-off layer (SOL) width or the power load imbalance between the inner and outer divertor legs remain an open issue, and yet their characterization is essential to determine the plasma regimes to be developed in future fusion power plants. First-principle modelling of edge plasma turbulence is therefore a key area of research in the fusion community, as it allows to extrapolate from present day experiments to future tokamaks. With the aim at predicting edge turbulence in tokamaks, the first-principle fluid code SOLEDGE3X has been developed. In this paper, the main characteristics and results are shown. In particular, H-mode like transition with supressed edge turbulence is obtained when injecting high power in the reference plasmas analysed from the TCV tokamak, which shows a path to predict H-mode transitions in tokamaks.

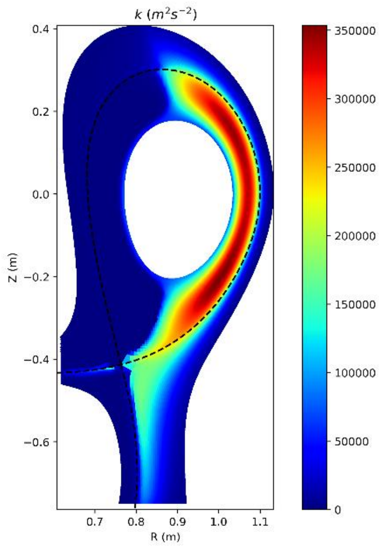

Figure 1: Prediction of turbulence intensity by k-epsilon like reduced model for edge plasma interchange driven turbulence on TCV.

Inspired by the hierarchy of models used to simulate turbulence in the neutral fluid community, the SOLEDGE3X fluid code incorporates a broad range of models with varying fidelity [1], which allows a stage approach analysis to the problem of edge turbulence. These range from empirical diffusivities, which are used to perform so-called "transport" simulations, to full-scale 3D first-principle turbulence modelling, where turbulent structures are self-consistently simulated. In between, a reduced approach inspired by the k-epsilon model [2], widely used in the computational fluid dynamics community, is proposed to capture key features of edge plasma turbulence and incorporate them into transport simulations [3]. Specifically, the growth of the turbulent energy "k" is governed by the primary interchange and drift wave instabilities, while turbulence saturation is achieved through a semi-empirical closure based on scaling laws. Such approach allows for a quick assessment of the main turbulent characteristics of the plasma edge.

In this contribution, we present a direct comparison of various approaches to describe turbulence: empirical transport modelling, transport modelling with k-epsilon prediction, and first-principle modelling, all applied to the same reference TCV-X21 plasmas, a series of low magnetic field ohmic L-mode discharges which was specifically produced as a scenario for validating edge turbulence models [4]. All SOLEDGE3X simulations include plasma recycling with neutrals and carbon impurities. The fluctuation levels, and cross-field transport predicted by the k-epsilon model can be directly compared with first-principle simulations and experimental measurements. A special focus will be put on comparing the behaviour in the divertor area where divertor localized filaments observed experimentally with fast cameras could be recovered by the modelling [5]. Furthermore, with respect to first-principle modelling, we place special emphasis on comparing electrostatic turbulence with electromagnetic turbulence, as SOLEDGE3X now includes induction effects, Ampere's law, and the impact of magnetic fluctuations (so-called magnetic flutter) [6].

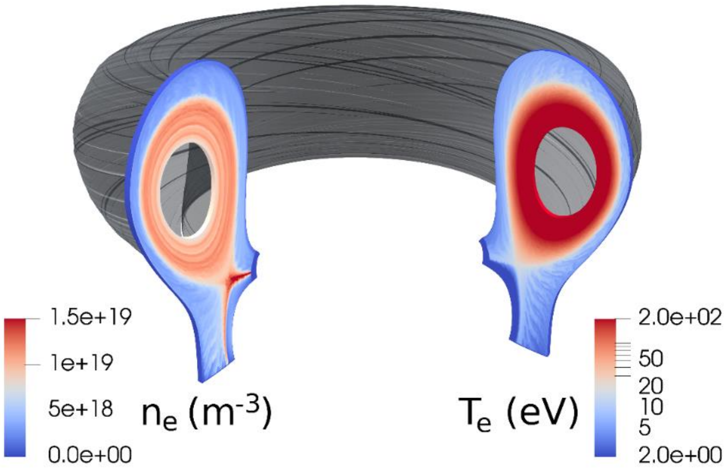

Figure 2: 3D rendering of TCV-X21 SOLEDGE3X simulation. Left slice: electron density, Right slice: electron temperature.

From the numerical point of view, it is important to evaluate the different levels of turbulence description in terms of predictability versus computational cost. The hierarchy of models in SOLEDGE3X can be integrated to reduce the overall numerical cost of self-consistent, predictable turbulent simulations for full-size tokamaks. The numerical cost of reaching particles and energy balance for ab-initio full scale first principle turbulent simulations remains indeed prohibitive and for that reason, full 3D turbulent simulations often focus on transients. Combining first principle modelling with reduced turbulent transport models open the way to self-consistently address the turbulent transport over long time scales and predict the interplay between mean field profiles and small scale turbulent structures, thus bridging the gap between 2D transport codes and 3D turbulence codes.

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