Questioning the quasilinear nature of turbulent transport by means of gyrokinetic flux-driven nonlinear simulations

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Efficiently operating a nuclear fusion device requires understanding and predicting turbulent transport processes. Reduced quasilinear models, backed on gyrokinetic gradient-driven nonlinear simulations, reveal extremely powerful in recovering experimentally measured steady state fluxes at low cost. However, flux-driven nonlinear simulations as well as experimental measurements reveal new features, such as transient and non-local dynamics like avalanches and turbulence self-organization close to marginal stability. We perform gyrokinetic simulations with GYSELA code [1] and focus on the impact of such forcing on turbulence properties. In particular, we study numerically the effect on stationary zonal flow on turbulent structures, and access the quasilinear nature of fluctuations.

The angular rotation of electric potential structures is computed as the best-fitting non-linear registration of 3D images. This results in a mostly toroidal rotation. Its projection against $\nabla\varphi - q\nabla\theta$, i.e. the direction transverse to B and contained on magnetic surfaces, agrees well with the same projection of the stationary zonal flow velocity. This suggests that the parallel dynamic compensates the poloidal ExB drift on average, so as to yield a mostly toroidal motion. This explains why the ballooning character is preserved despite significant poloidal flows. The sign of the computed radial velocity correlates well with that of the stationary zonal flow shear rate, as already reported [2, 3]. This leads to either converging or diverging layers at local extrema of zonal flows. Most surprisingly, turbulent correlation time and length are affected differently in these 2 different layers, hence questioning the universal picture of turbulence decorrelation by zonal flows. Finally, the complex temporal dynamics of inferred velocities suggest a different role for zonal flow fluctuations.

Quasilinear framework assumes that the linear relationship between perturbations hold in the non-linear regime. Phase relations between electric potential and pressure are investigated numerically. The heat flux is decomposed into the product of pressure and radial ExB velocity fluctuation amplitudes times the sine of the phase shift. Statistical analysis shows that the phase distribution is radially-uniform over the whole radial domain $0 \leq r/a \leq 1$ and narrow around $0.3^{rad} \pm 0.1^{rad}$. The majority of the flux variance appears to be governed by the amplitude fluctuations. Those phase relations have been compared to the expected linear properties computed with the quasilinear code QuaLiKiz [4], run with time-averaged profiles. QuaLiKiz prediction for the phase shift is higher, around 0.6^{rad}, and exhibits a stronger radial dependency. The possible roles of nonlocal features and of the proximity to marginal stability are currently explored and will be reported.

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