Simulation of the intermittent behavior of SOL turbulence in TEXTOR.

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Abstract

A lot of experimental observations in magnetic confinement devices show that the particle and thus heat transport in the scrape-off layer (SOL) of the plasma is characterized or even dominated by turbulent intermittency. This process, characterized by (higher density) blobs which are projected radially outwards onto the wall, increases the wall erosion and reduces the divertor efficiency. In view of ITER and other machines under construction, this interaction of the plasma with the wall is still an important topic.

In this contribution, we analyse some simulations with the ESEL (Edge SOL Electrostatic) code [1], applied on the geometry of TEXTOR. Input-parameters for the model were taken from ohmic shots in TEXTOR. We completed and analyzed 2 different parameter scans; the output of the runs is compared to results of the real experiment.

Introduction

The ESEL code is a finite difference code, which solves an interchange plasma turbulence model in the 2D-situation of the scrape-off-layer. It couples the vorticity, density and temperature fields by an inhomogeneous magnetic field in a (x, y)-slab geometry on the low-field side (LFS) of the tokamak. As the real probe measurements in TEXTOR are done in the equatorial plane at the LFS, it makes sense to compare both results.

The reduced fluid equations, where ESEL is based upon, represent the drift ordered low-frequency dynamics of the electron density n, the electron temperature T and the electrostatic potential ϕ. They are in depth discussed in [1] and can be written down as

$$\frac{d\nabla_\perp^2\phi}{dt} = \mathscr{C}(nT) + \Lambda_{\nabla_\perp^2\phi}, \tag{1}$$

$$\frac{dn}{dt} = \mathscr{C}(nT) - n\mathscr{C}(\phi) + \Lambda_n, \tag{2}$$

$$\frac{dT}{dt} = \frac{7}{3}\mathscr{C}(T) - \frac{2}{3}T\mathscr{C}(\phi) - \frac{2}{3}\frac{T^2}{n}\mathscr{C}(n) + \Lambda_T, \tag{3}$$

The advective derivative and the curvature operator are abbreviated as $\frac{d}{dt} = \frac{\partial}{\partial t} + \frac{1}{B}\mathbf{b} \times \nabla\phi \cdot \nabla$ and $\mathscr{C} = -\frac{\rho_{s,0}}{R_0}\frac{\partial}{\partial y}$. All quantities are dimensionless and expressed in the Bohm normalization (typical temporal and spatial scales are chosen to be the ion gyro-frequency ($\omega_{ci,0} = eB/m_i$) and the drift-scale-radius ($\rho_{s,0} = c_{s,0}/\omega_{ci,0}$)). Here $c_{s,0} = (T_{e,0}/m_i)^{1/2}$ stands for the cold ion sound speed, $\frac{1}{B} = (1 + \frac{a+\rho_{s,0}x}{R_0})$ is the local inverse magnetic field strength. The Last Closed Flux Surface (LCFS; at $x = 20$ on fig. 1) on the LFS of the equatorial plane of the tokamak acts as the reference (zero subscripts for the normalization n_0,...).

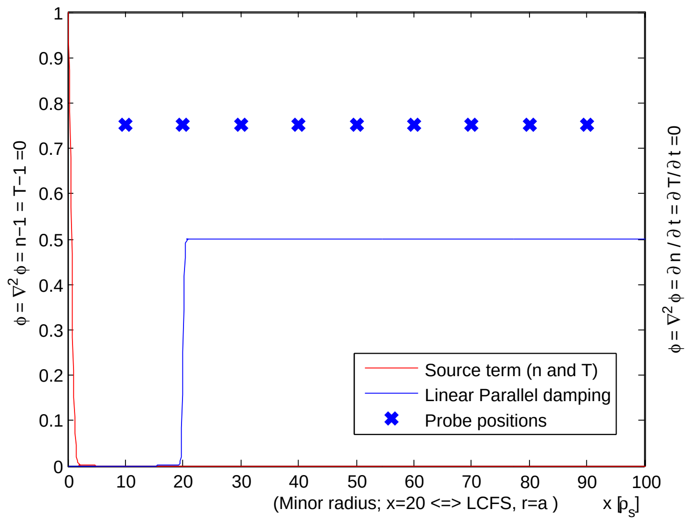

Figure 1: Parallel damping(in blue, restricted to SOL and the wall: $20 < x < 100$) and source terms(in red) on the left boundary.

The Λ_α terms on the right-hand side of Eqs. 1-3, represent the loss terms (dissipation as a result of perpendicular diffusion and the linear parallel damping to the divertor/limiter), as well as the source terms S_α:

$$\Lambda_\alpha = D_\alpha \nabla_\perp^2 \alpha - \frac{\alpha}{\tau_{\|,\alpha}} + S_\alpha$$

The damping coefficient $1/\tau_{\|,\alpha=T}$ for temperature is five times stronger than its counterparts for the vorticity and the density, due to the predominant parallel loss of hot electrons in the region of open magnetic-field lines [2]:

$$\tau_{\|,\nabla_\perp^2\phi} = \tau_{\|,n} = \frac{L_\| \omega_{ci,0}}{M_\| \xi c_s} = 5\tau_{\|,T},$$

where $M_\|$ is the Mach number (input parameter) and $\xi c_s = \sqrt{Z + T_i/T_e} c_s$ is the warm ion sound speed.

Results from simulation - discussion

All simulations presented here, are computed on a grid consisting of 512×256 grid-nodes, covering an (x,y)-slab of $100\rho_s$ by $50\rho_s$ respectively. The boundary conditions, used at every timestep of integration, are a traditional mix of Neumann and Dirichlet conditions. They are mentioned aside of fig. 1. TEXTOR relevant parameters ($R_0 = 1.75m$, $a = 0.46m$, deuterium plasma at $T_0 \approx 30$eV, reference density $n_0 = 0,4...5 \times 10^{19} 1/m^3$ and $B_T = 1.4T$) are used as input into the model, and several runs have been computed for different values of the edge density n_0. Part of the time-traces of the radial particle fluxes nv_x are shown in fig. 2 for some typical cases.

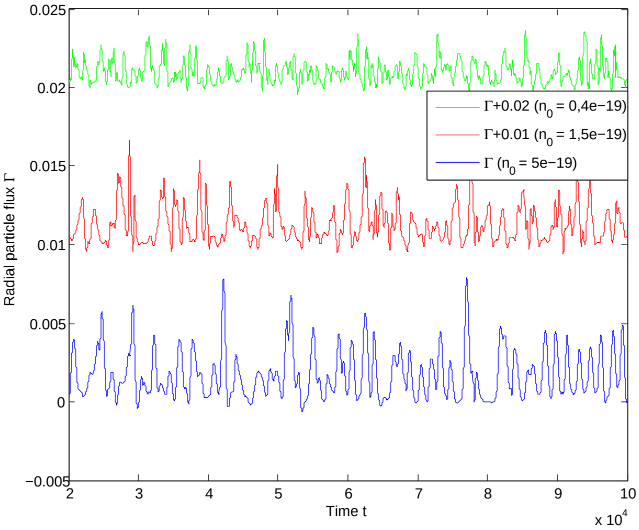

Figure 2: Radial particle fluxes for 3 different values of the reference edge density n_0. Measurements are taken at $x = 50$.

Note that we find the correct orders of magnitude ($10^{20} m^{-2} s^{-1}$) for the radial particle flux, when we take into account the normalization constant (for $n_0 = 5e19$ m^{-3} : $n_0\ c_{s,0} \approx 3e23$ m^{-2}s^{-1}). One can see several bursts in all the timetraces. Although, at first sight, these 'passing density blobs' look more extreme in the case of the higher edge densities, it is not so clear to distinguish the different cases by looking into more quantitative aspects of the intermittent behaviour of the particle fluxes. To do this, we have computed for all these cases the skewness (S) and the kurtosis (K) at the different radii of the 'probes' (fig. 3).

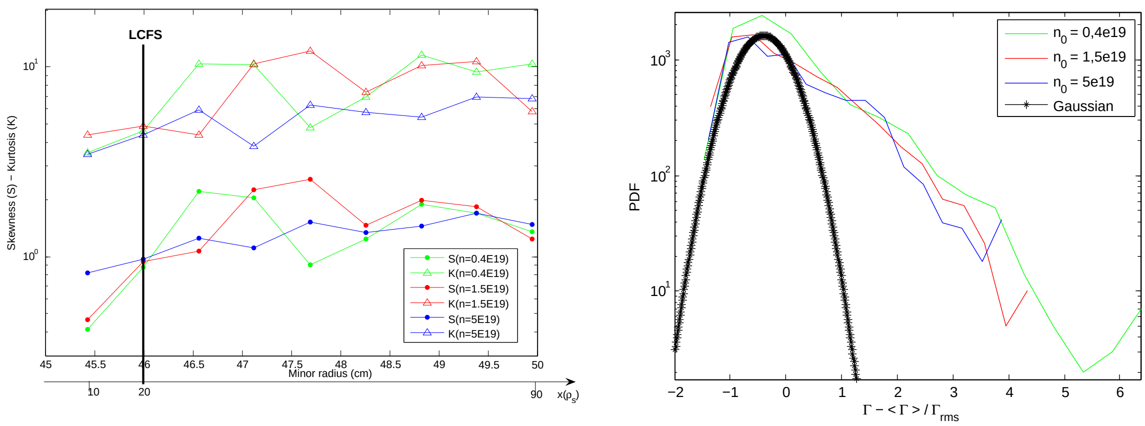

Figure 3: Left : Skewness and Kurtosis of the radial particle flux signal for different values of reference edge density n_0. Right : PDF of $\Gamma-$values at $x = 50$ for different values of n_0.

Once beyond the LCFS (towards the wall), one can easily see the clear tendency of growing intermittency (S=0,K=0 for normal distributions). On the other hand, there seems no clear relationship between the edge density n_0 and the intermittency in terms of S or K (all values have been studied from 0,4 up to 5×10^{19} m^{-3}). On the right hand side of fig. 3, we plotted the probability distribution function (PDF) for different cases. Here too we see more or less the same intermittent behavior, which is for all cases clearly non-normal. Apparently, the fact of normalizing the quantities (with respect to the reference density n_0, etc.) implies equal intermittent particle fluxes as a result of the simulations based on this set of equations. Unfortunately, this independence from the edge density is not confirmed by real experiments [3].

Another parameter-dependency in [3], was the one from the safety-factor. In order to make a comparison, we simulated 3 different cases for the same edge density reference $n_0 = 10^{19}\mathrm{m}^{-3}$, but with 2, 4 and 10 as q-values at the LCFS ($r = a$, see fig. 4). In particular for TEXTOR, with its toroidal limiter and the ALT-limiter, which is toroidal as well, this has serious consequences on the parallel connection length, used in the definition of the different parallel damping coefficients $\tau_{\parallel,\alpha}^{-1}$. Except for the 4 probes in the middle of the nearly marginal case $q(a) = 2$, the intermittent behavior of the radial particle fluxes seems to be inversely proportional with the safety-factor. However, lowering the connection length to the first contact with the wall, $L_{\parallel}$, implies a faster linear damping, thus making this result strange; the more because the real experiment in TEXTOR show a proportionality between $q(a)$ and the intermittency [3].

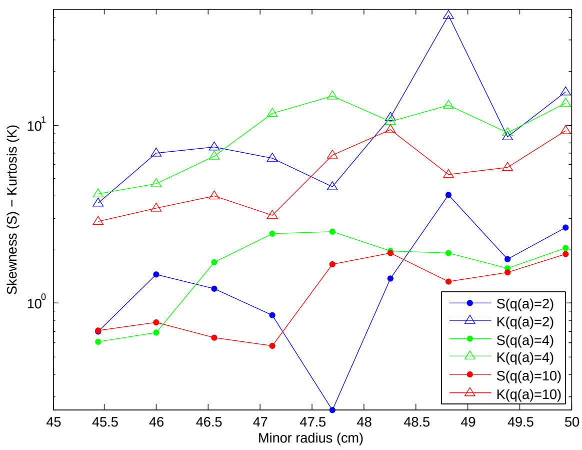

Figure 4: Skewness and Kurtosis of the radial particle flux signal for different values of edge safety factor $q(a)$.

Conclusion and outlook

In this paper, we discussed different runs of the ESEL code with the TEXTOR experimental parameters as input. It appeared that the experimental findings with respect to the dependency for the intermittency in the radial particle flux from the edge density, could not be confirmed. To our opinion, this is partly due to the normalization used by the code. On the other hand, we could not confirm the intermittency proportionality with the safety-factor $q(a)$.

References

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