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Impact of turbulent fluctuations on neutral particles transport with the TOKAM3X-EIRENE turbulence code

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The scrape-off layer (SOL) of tokamaks shows turbulent fluctuations, with fluctuation levels reaching order unity. On time scales much larger than the turbulence correlation time (typically ~10μs), convection by the fluctuating velocity field results in cross-field transport, modelled by an anomalous diffusion term in transport codes such as SOLPS[1], Soledge2d-EIRENE[2]. In fact, the latter codes solve mean field equations (i.e. time averaged fluid equations). A proper derivation of these equations shows that in addition to the gradient diffusion closure made on turbulent fluxes, a number of other non-linear terms are approximated in mean field codes. This is in particular the case for volumetric sources/sinks related to exchanges between neutrals and the plasma, as well as sputtered fluxes at the wall. Underlying fluctuations might thus affect the penetration depth of neutral particles into the plasma, as well as impurity production. Both ionization and sputtering are threshold processes, so that temperature fluctuations enhance these processes at temperatures close or below the threshold. Moreover, density fluctuations also play a role in the transport of neutral particles, reducing the opacity of plasma to the neutrals.

In this work, we apply these results to the analysis of global TOKAM3X-EIRENE 3D simulations in X-point geometry[3-5]. The statistical properties of turbulent fields relevant to this work are discussed, both in the far SOL and for the first time in the divertor, including recycling. This includes the Probability Distribution Functions (PDF) or the various fields involved (n_e, T_e for ionization, n_e, ϕ, T_i for sputtering) as well as correlations between these fields. The neutral particle transport and sputtered fluxes are recalculated on the mean field plasma, and compared to the mean neutral particle density/flows obtained from the turbulent simulation, so as to assess the effects of the fluctuations, in particular on the ionization balance in the divertor. The latter effects become more and more pronounced as the high recycling regime is approached, in particular because the plasma temperature is low enough so that ionization and sputtering are strongly non-linear, but not only: the ratio of the neutral particle mean free path to the size of turbulent structures also plays a key role. Fluctuation dressed ionization rate coefficients and sputtering yields to be used in mean field codes are derived, and their parametrization in terms of the mean fields is discussed.

References

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