Influence of the diamagnetic drift contribution on the turbulent kinetic energy balance in isothermal interchange-dominated ExB turbulence in the scrape-off layer

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While turbulent transport is known to be of crucial importance to radial transport in the plasma edge, its treatment in mean-field transport codes leaves ample room for improvement. Recently, approaches to self-consistently model the turbulent transport coefficients based on the turbulent kinetic energy $k_\perp$ [1] and the turbulent enstrophy $\zeta_\perp$ [2] have been proposed for 2D isothermal interchange-dominated ExB turbulence in the scrape-off layer. These models solve additional transport equations for these new quantities characterizing the turbulence. Thus far, these improved transport models were studied based on somewhat simplified turbulence equations. In particular, isothermal cases were considered, and the vorticity ω contained only the contribution from the ExB velocity, i.e. $\omega_E = \nabla^2\phi$, where ϕ is the electrostatic potential. In this contribution, we investigate the impact of including also the diamagnetic drift contribution in the vorticity, i.e. $\omega = \omega_E + \omega_*$, where $\omega_* = T_i \nabla^2 \ln(n)$ with T_i the temperature and n the density, still assuming isothermal conditions. Previous work has already demonstrated that adding this contribution to the vorticity affects the characteristics of the turbulence and the transport [3]. Here we study the effect of this term on the balance of $k_\perp$ and resulting mean-field transport models.

As the diamagnetic velocity is now effectively included in the inertia, it also naturally appears in the $k_\perp$ equation. It is shown analytically that two new terms are introduced into this equation as a result. The first one acts a large new source of the total turbulent kinetic energy, while the second one acts as a large new sink. The second term, consisting of the correlation between polarization velocity fluctuations and the ion pressure gradient, was expected to enter and is consistent with earlier research [4]. The first term on the other hand has its origin in a commonly made approximation in the vorticity equation where the divergence operator on the polarization current is brought inside the total time derivative. This term is thus considered to be unphysical. Seeing it appear as a major source term of $k_\perp$ places some questions on the validity of models using this approximation in the vorticity equation.

Detailed derivations show that the only radial turbulent flux requiring closure in electrostatic drift turbulence is the turbulent ExB flux. Moreover, the new terms in the $k_\perp$ equation seem to approximately cancel each other. Therefore, further analytical work was undertaken to derive an equation for the turbulent kinetic energy for the ExB drift only (k_E). In this k_E equation, the two terms discussed earlier no longer appear, and only a correction term for the existence of ω_* needs to be added with respect to the equation derived in Ref. [1]. This correction is fortunately found to be small in the simulations that have been analyzed, such that the balance of k_E again reduces approximately to the familiar balance between interchange drive and current losses to the sheath. Nonetheless it is observed that the models developed earlier predict the turbulence level k_E less accurately. In addition, a correlation is observed between k_E and the unphysical term due to the treatment of the polarization current in the vorticity equation. From this, it is concluded that the terms due to the diamagnetic drift contribution to the vorticity implicitly interact with the dynamics and equilibrium level of the turbulent kinetic energy.

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