A simple model of interactions between electron temperature gradient and drift-wave turbulence

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Abstract

One of the key challenges in magnetic confinement research is to understand the underlying causes of anomalous particle and heat transport. In most theories and models of turbulent transport, there is assumed to be one dominant kind of instability which is taken as the sole driver of all of the transport channels. In reality, multiple instabilities on different scales may coexist (i.e. ion temperature gradient-driven drift-waves (DITG) on $\rho_s = C_s \,/\, \Omega_{ci}$ scales, and electron temperature gradient (ETG) driven modes on $\rho_e = V_{Te} \,/\, \Omega_{ce}$ scales). Previously, it has been argued (or more often, tacitly assumed) that the separation in temporal and spatial scales meant that interactions between instabilities on different scales were generally negligible relative to the nonlinear "self" interactions of a particular instability. However, with the rise in interest in the ETG mode as a source of electron heat transport, and given the possibility of the simultaneous presence of DITG turbulence, it is important to consider their interactions in a more quantitative fashion. This question is particularly important as much of the motivation for ETG-based transport models has arisen from arguments about the presence of large (relative to ρ_e) structures driven by the ETG turbulence, such as "streamers" or electron skin depth ($c \,/\, \omega_{pe}$) scale eddies, which reduce the effective scale separation between the ETG and DITG turbulence. Towards this end, a self - consistent theory for the interaction between ETG and DITG turbulence has been developed. Random shear suppression of ETG turbulence by DITG modes is studied, as well as the back-reaction of the ETG modes on the DITG turbulence via stresses. It is found that the large-scale ETG dynamics can be sensitive to shearing by short-wavelength DITG modes (such as trapped electron modes). A novel interaction mechanism, DITG modulations of the electron temperature gradient, is shown to be quite significant, particularly as it opposes the shearing effects of the DITG turbulence. The profile modulation interaction also points toward the possibility of a rich spectrum of nonlinear spatio-temporal interactions between ETG and DITG turbulence. Of particular interest is the possibility that the DITG profile modulations could lead to a strong increase in the intermittency or "burstiness" of the ETG-driven heat flux. Conversely, the back-reaction of the ETG on the DITG turbulence is found to be weak. A generalized predator-prey model that incorporates the different cross-mode interactions has been developed. The importance of different interactions is quantified via scalings which sensitively depend upon the electron - ion mass ratio; in particular, it is shown that different interactions have different mass-ratio scalings. The implications of these findings for the relevance of ETG-driven transport, particularly in transport barriers, is discussed, along with potential avenues for further quantifying the strength of cross-mode interactions.