Mechanisms of drift wave based zonal flow transitions and bifurcations

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We have been examining the interaction between drift waves and zonal flows in a nonlinear sheared-slab Hasegawa-Wakatani resistive drift wave system, using the two-fluid code NLET. This system has been used as a paradigm for understanding zonal flows for years, showcasing a wealth of properties.

The evolution of the zonal flow system in question is determined by a single dimensionless parameter, \( \rho \) (with \( \rho \) being defined as the ratio between the ion sound Larmor radius \( \rho_s \) and the length scale of maximal drift wave growth at a given parallel shear length marked by \( L_\perp \)). As has been shown before, a certain parameter threshold \( \rho_{\text{crit}} \) exists, above which self-consistent zonal flows form. These flows have been shown to exhibit unusual properties when excited in a drift wave regime and computed with sufficiently high radial resolutions, yielding transport bifurcations and asymmetric flows which more pronounced peaks in the electron diamagnetic drift direction.

While the bifurcations themselves can be explained easily in a qualitative manner, arguing via the drift wave dispersion relation, the transport balance and the drift wave response to the flows, the actual existence of a parameter \( \rho_{\text{crit}} \) - below which no zonal flows form at all - requires a more complicated approach.

Such an approach is presented in this paper, explaining the underlying mechanism of the zonal flow transition via the interplay of two competing effects, that of the shear flow potential \( \phi \) and that of the approximate resonance gradient length over which the amplification and repulsion effects of a resonant surface can be felt. The latter depends on \( \rho \), decreasing for increasing values of the single dimensionless parameter, while the former does not.

Since a superposed shear flow reduces (increases) the acceleration of drift waves traveling down (up) the flow gradient, the former are amplified more as they spend more time in the vicinity of the resonant surface, resulting in more pronounced drift wave activity on the negative Reynolds stress side of the shear flow, resulting in overall positive turbulence viscosity, dampening the flows. Only for high enough values of \( \rho \) does the usual wave-kinetic tilting effect outbalance the resonance effect, adding an overall positive contribution to the Reynolds stress - thus resulting in zonal flow growth.