1st Asia-Pacific Conference on Plasma Physics, 18-22, 09.2017, Chengdu, China

Numerical Investigation of Zonal Flow Enhancement due to Conversion of Parallel Compression

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Abstract: Elucidation of the physics of zonal flows is one of the key subjects in magnetically confined fusion plasmas due to its both scientific and practical importance. Both the radial pattern and amplitude of the zonal flow are of great important because of their impact on plasma confinement. Scientifically, this is closely related to the question of the large scale structure formation (or order) from turbulence (or disorder), which is the long-standing problem in modern nonlinear physics. In plasma physics, the simplest model to study this problem in the context of drift wave turbulence is the 2D Hasegawa-Mima (HM) equation. Due to its simplicity, many direct numerical simulations (DNS) as well as analytical works have been carried out using the HM model for the past decades. There are some non-trivial extensions of this 2D HM model. One of them, which is of great interest in terms of scientific and practical point of views, is the 3D extension of it through the coupling of HM to ion-acoustic dynamics. This model is interesting because it contains the ion parallel dynamics, which is important in magnetic fusion experiments due to the presence of strong NBI heating, combined with the drift wave turbulence. Scientifically, we expect this model may reveal how the 2D picture in zonal flow generation is modified when 3D effect is taken into account, i.e., how the inverse cascade process is affected by the presence of ion flow dynamics. In this work, we perform nonlinear simulations of 2D and 3D HM models. They are implemented in the BOUT++ framework and successfully tested for different combinations of forcing rate coefficients, forcing locations, and dissipation coefficients. Results of 2D and 3D cases clearly show zonal flow structures, and the dominance of electrostatic potential energy in comparison with other energy components. An initial result shows that a significant change in the radial wavenumber of zonal flow structures due to the ion-acoustic coupling as shown in the figure 1. This implied that parallel flow dynamics has an influence on the selection of nonlinear radial wavenumber of zonal flows. Additionally, we observe that the 3D power spectrum is considerably different from the 2D cases, implying the impact of parallel compression on the inverse cascade process. More detailed discussions will be made in the conference.

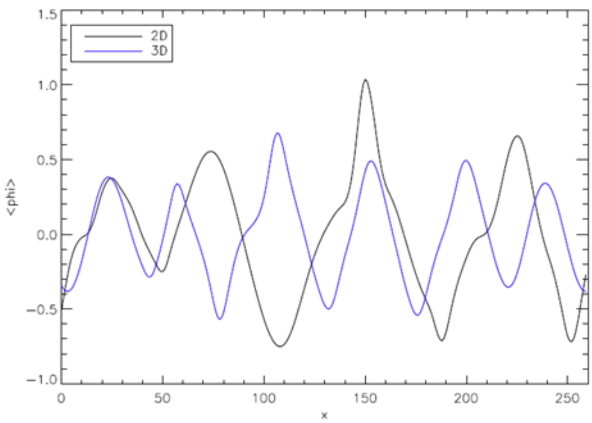

Figure 1. Profile of averaged zonal flow for 2D and 3D HM. Forcing rate coefficient of 0.12, forcing location of 20, viscous dissipation coefficient of 10^{-3}, and hyper-viscous dissipation coefficient of 2×10^{-4} are employed.