Global nature of zonal flow due to the finite band width

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The generation of zonal flows in micro-scale drift wave turbulence has been intensively studied based on Hasegawa-Mima (HM) turbulence model in terms of a modulational instability analysis [1, 2], but spectrum nature of zonal flow has not been discussed. Here, we have been developed an eight-wave coupling model which may involve the most primary spectral structure of zonal flows to analyze the nonlinear modulation interaction. This minimum model includes two components of zonal flows, two pump waves and two pairs of sidebands, which represent the spectral structures of zonal flows and turbulence. The dispersion relation of the zonal flow instability is derived. The maximum growth rate of zonal flow is chosen from all unstable roots by calculating the eleventh order algebraic dispersion relation with respect to the complex zonal flow frequency $\omega_q = \Omega_q + i\gamma_q$. It is found that zonal flow instabilities are qualitatively and quantitatively different in the two cases with and without the spectral structures of zonal flows and pump waves. This result shows a *global* nature of zonal flows in the system of drift wave turbulence and zonal flows. In the case with single zonal flow component, the growth rate is the same as that in the conventional four-wave coupling model, which is also confirmed in the wave kinetic approach [3]. When two spectral components of zonal flows are included, the zonal flow instability is enhanced for given pump spectrum, which shows the significance of zonal flow spectrum. In order to justify the validity of the eight-wave coupling model and to investigate the dependence of the initial phase of the pump waves on the zonal flow instability, a spectral code is advanced to solve 2D HM equation. Numerical simulations have proved the analytical prediction on the enhancement of zonal flow instability due to the global nature. It is also shown that the more initial phase becomes coherent, the more the zonal flow instability is enhanced. Turbulence and zonal flows are spatially localized so that the interaction between turbulence and zonal flow becomes strong. It is noted that the saturation levels in both cases are almost same while the growth rates are quite different. Furthermore, the zonal flow instability in the limit of finite spectral band width of zonal flow is discussed compared with the conventional four-wave coupling model.

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