Numerical experiments on the drift wave - zonal flow paradigm for nonlinear saturation

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Abstract

This paper confirms that $E \times B$ shearing from toroidally symmetric (toroidal mode number $n = 0$) "radial modes" provides the dominant nonlinear saturation mechanism for drift wave $(n \neq 0)$ turbulence which in turn nonlinearly drives the modes. In common usage, this is loosely referred to as the "*drift wave – zonal flow paradigm*" for nonlinear saturation despite the fact that radial modes have several components distinguished in this paper: a residual or zero mean frequency "zonal flow" part and an oscillatory "geodesic acoustic mode" (GAM) part. Linearly, the zonal flows (and GAMs) are weakly damped only by ion-ion collisions, while the GAMs are strongly Landau damped only at low safety factor q. At high-q the Hinton-Rosenbluth residual flow from an impulse vanishes and only the weakly damped GAMs remain. With the linear physics and driving rates of the finite-n transport modes unchanged, this paper argues that GAMs are only somewhat less effective than the residual zonal flows in providing the nonlinear saturation and in some cases $E \times B$ shearing from GAMs (or at least the GAM physics) appears to dominate: transport appears to be nearly linear in the GAM frequency. By deleting the drift wave - drift wave nonlinear coupling it is found that drift wave - radial mode *nonlinear coupling triads* account for most of the nonlinear saturation. Furthermore the $E \times B$ shear components of the radial modes nonlinearly stabilize the finite n modes while the diamagnetic components nonlinearly destabilize them. Finally, from wave number spectral contour plots of the time-average nonlinear entropy transfer function (and rates), it is shown that the peak in entropy generation coincides with the peak in transport production while entropy dissipation (like Landau damping) is spread equally over all n-modes (including $n = 0$). Most of these conclusions appear to hold about equally well for all types of drift wave turbulence.

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