Enstrophy production constraint on relaxation in Hasegawa-Wakatani turbulence

Arash Ashourvan\textsuperscript{1,2}, P.H. Diamond\textsuperscript{1,2,3} and Ö.D. Gürcan\textsuperscript{4}

\textsuperscript{1}Center for Momentum Transport and Flow Organization,  
\textsuperscript{2}Center for Energy Research,  
\textsuperscript{3}Center for Astrophysics and Space Sciences (CASS) & Department of Physics,  
\textsuperscript{1}University of California San Diego, La Jolla, CA, 92093  
\textsuperscript{4}Laboratoire de Physique des Plasmas, Ecole Polytechnique, Palaiseau, France

We determine the relation between the physics of turbulent transport of particles and momentum, using the Hasegawa-Wakatani model, with both a density gradient and a quasi-equilibrium shear (zonal) flow. Our work is motivated by the observation of an inward particle flux in the experiments performed on CSDX. This flux develops shortly after the onset of spectral transfer, from the zonal flow back to the turbulence\textsuperscript{1}. Our study shows that for flute-like ($k_\parallel = 0$) perturbations, which are not screened by Boltzmann electrons, pure Kelvin-Helmholtz instabilities, energized by the flow vorticity gradient, relax the flow and drive an outward (down the density gradient) flux of particles ($\Gamma = \langle \tilde{n} \tilde{v}_x \rangle > 0$). However, for shear flow driven instabilities of finite $k_\parallel$, inward particle flux is produced at radii ($x$) for which $\omega_r/k_y > V_0(x) + v_d(x)\left[1 + \omega_i/Dk_\parallel^2\right]$, where $\omega_r$ and $\omega_i$ are the real and imaginary part of the mode frequency, $k_y$ is the poloidal mode number, $V_0$ is the flow velocity, $v_d(x) = -\rho_s c_s (\ln n_0(x))'$ is the electron drift velocity and $D$ is the parallel diffusion coefficient. Positivity of the production of the fluctuation potential enstrophy is used to elucidate the interaction between momentum and particle transport. Using potential enstrophy conservation in the H-W system, for given density and vorticity profiles, we obtain $\partial_t \langle \tilde{q}^2 \rangle / 2 = \langle \Pi \rangle$ $\langle \rho_s^2 V'_0(x) + v_d(x) \rangle / \rho_s c_s > 0$, where $\tilde{q} = \tilde{n} - \rho_s^2 \nabla_\perp^2 (e\tilde{\varphi}/T_e)$ is the potential vorticity of the fluctuations and $\Pi = \rho_s^2 \langle \tilde{v}_x \nabla_\perp^2 (e\tilde{\varphi}/T_e) \rangle$ is the vorticity flux. For $V_0(x) \approx 0$, this model reduces to the classic resistive drift wave instability problem for which the particle flux is outward. With nonzero $V_0$ and in the case where $\rho_s^2 V'_0(x) + v_d(x) > 0$, production of $\langle \tilde{q}^2 \rangle$ requires that, in order for the particle flux to be inward ($\Gamma < 0$) we must have $\Pi < \Gamma$. This establishes a new mechanism for up-gradient particle transport. Ongoing work focuses on determining the dependencies of the turbulent viscosity.