## Effect of Ion Temperature Gradient Driven Turbulence on the Edge-Core Connection for Transient Edge Temperature Sink

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Ion temperature gradient (ITG) driven turbulence simulation for a transient edge temperature sink localized in the poloidal plane is performed using a global Landau-fluid code in the electrostatic limit. Pressure perturbations with  $(m, n) = (\pm 1, 0)$  are induced by the edge sink, where *m* and *n* are poloidal and toroidal mode numbers, respectively. It was found in the previous simulation [M. Yagi *et al.*, Contrib. Plasma Phys. **54**, 363 (2014)] that the nonlinear dynamics of these perturbations are responsible for the nonlocal plasma response/transport connecting edge and core in a toroidal plasma. Present simulation shows, however, that the ITG turbulence in the core region dissipates the large-scale  $(m, n) = (\pm 1, 0)$  perturbations and weakens the edge-core connection observed in the previous simulation.

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Transient transport events have been observed in toroidal magnetic confinement systems, which cannot be explained by the conventional local transport models [1]. For example, the cold pulse experiment showed a rapid transient increase of electron temperature in the plasma core in response to an abrupt cooling at the edge. Time scale of such transient events was much faster than the diffusive time scale. Recent experiment indicated that a longrange fluctuation plays a role for the fast pulse propagation [2]. Although the nonlocal transport was also theoretically investigated based on the one dimensional integral heat flux model [3], detailed mechanism is still unknown.

Recently, a nonlocal plasma response to edge density sources has been found in global fluid simulations that are based on the 4-field reduced magnetohydrodynamics (RMHD) model [4,5]. A poloidally-localized and toroidally-elongated particle source is applied in the edge region in the saturation phase of resistive-ballooning-mode (RBM) turbulence. The nonlocal transport appears in the core region far from the edge source. Numerical experiments showed that both nonlinear and toroidal couplings between axisymmetric Fourier modes are responsible for the nonlocal transport. Especially dynamics of the (m, n) = $(\pm 1, 0)$  pressure perturbations  $\tilde{P}_{\pm 1,0}$ , whose origins are directly put into the system by the edge source, play an essential role to produce the nonlocal transport, where m and *n* are poloidal and toroidal mode numbers, respectively. In the above simulation RBMs are unstably active in the edge region, while no remarkable turbulence is observed in the core region. Although drift wave turbulence such as ion temperature gradient (ITG) driven turbulence may play an important role in the actual core plasma, the 4-field RMHD model cannot treat the ITG turbulence. The  $\tilde{P}_{\pm 1,0}$  perturbations can be affected by the ITG turbulence. Moreover, they are also ingredients of geodesic acoustic mode (GAM) oscillations of zonal flows (ZFs) [6, 7]. Hence, it is interesting to investigate what happens in the nonlocal response/transport observed in the previous simulation [4] if the ITG turbulence exists in the core region.

In order to investigate effects of the ITG turbulence on the nonlocal plasma response/transport to the edge source and/or sink, we have modified a global Landau-fluid code R5F used for the ITG-ZF/GAM studies [6-10]. The R5F code is based on a 5-field Landau-fluid model which has an ion temperature  $T_i$  equation in addition to the equations in the 4-field RMHD model. Hence, the 5-field model is a superset of the 4-field RMHD model. The 5-field model can be reduced to a 3-field electrostatic model by assuming the adiabatic electron response [8-10]. In this paper for simplicity as a first step, we perform an electrostatic ITG turbulence simulation based on the 3-field model in which the edge density source effect is implemented as a sink in the  $T_i$  equation. A toroidally-elongated cylindrical source/sink (n = 0) is applied similarly to the previous study [4],

$$S = S_{\rm AMP} \exp\left(-\frac{r^2 + r_{\rm s}^2 - 2rr_{\rm s}\cos\theta}{2\Delta^2}\right),\tag{1}$$

where parameters are chosen as  $r_s = 0.8$ ,  $\Delta = 0.1$  and  $S_{AMP} < 0$ , corresponding to an edge  $T_i$  sink in the low field side. The radius *r* is normalized by the minor radius *a*, and  $\theta$  is the poloidal angle. We use initial profiles of the density  $n_e$ , temperature  $T_i = T_e = T$  (normalized by the central *T* value) and safety factor *q*, which were used in the pre-

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Fig. 1 Temporal evolution of temperature fluctuation energy. The sink is applied during  $400 \le t \le 450$ .

vious ZF/GAM simulation studies because we know well the behavior of ITG-ZF/GAM systems without the edge source/sink [9]:  $n_e = 0.8 + 0.2e^{-2r^2}$ ,  $T = 0.35 + 0.65(1-r^2)^2$ and  $q = 1.05 + 2r^2$ . These profiles are different from, but similar to previous ones [4]. The aspect ratio is chosen R/a = 4 and the normalized ion Larmor radius is  $\rho_i/a = 0.005$ . The radial grid number is 512. The R5F code uses the spectral method in poloidal and toroidal directions. The Fourier modes included in the calculations are ones having resonant surfaces between 0.2 < r < 0.8with  $\Delta n = 4$ ,  $n_{\text{max}} = 100$ , and non-resonant n = 0 components from m = 0 to m = 20, where  $\Delta n$  and  $n_{\text{max}}$  are the interval and maximum number of n, respectively.

The edge temperature sink is given during  $400 \le t \le 450$  after the ITG turbulence saturates as shown in Fig. 1. Note that the time *t* is normalized by  $a/v_{ti}$  and the duration of sink  $(50a/v_{ti})$  is similar to the source duration  $(240R/v_A)$  for the previous simulation [4], where  $v_{ti}$  and  $v_A$  are the ion thermal and Alfvén velocities, respectively. The n = 0 components of fluctuation energy increase rapidly with the onset of the sink, while several high *n* components start to increase also. This indicates that the ITG turbulence grows due to the steepened gradient of  $T_i$  by the sink.

Nonlocal plasma response/transport of a kind observed in the previous simulation has not been observed in the present simulation. Figure 2 shows spatio-temporal evolution of the " $\cos \theta$ " component of  $\tilde{T}_{\pm 1,0}$ . The edge sink in Eq. (1) puts only this component into the system. Dynamics of the large-scale  $\cos \theta$  component of  $\tilde{P}_{\pm 1,0}$  play an important role in the nonlocal transport in the previous simulation by connecting the core region with the edge. In the present simulation, however, this component is stirred by the ITG turbulence in the core after the sink is terminated (t > 450). As a consequence, its radial wavelength becomes shortened considerably in the core region. We perform a comparative simulation where nonlinear coupling effects are turned off artificially, and the ITG turbu-



Fig. 2 The  $\cos \theta$  component of  $\tilde{T}_{\pm 1,0}$  as a function of radius and time.



Fig. 3 The  $\cos \theta$  component of  $\tilde{T}_{\pm 1,0}$  as a function of radius and time in the case that nonlinear coupling effects are turned off artificially after the onset of the sink (t = 400).

lence cannot affect the  $\cos \theta$  component of  $\tilde{T}_{\pm 1,0}$ . For this case, the  $\cos \theta$  component input by the sink keeps longer radial wavelength as shown in Fig. 3 and could connect the edge with the core similarly to the previous simulation. Thus existence of turbulence in the core can be an obstacle for the nonlocal transport via  $\tilde{P}_{\pm 1,0}$ . The GAM oscillations, on the other hand, naturally relate to the "sin  $\theta$ " component of  $\tilde{P}_{\pm 1,0}$ . If the source/sink having the sin $\theta$  component is applied, the GAM oscillations may be excited by the source/sink. We will investigate further the nonlocal response/transport through the core-edge connection for various cases by improving simulation models.

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