*33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-4.156 (2006)*

Statistical Analysis of Impurity Transport in Turbulent Plasmas

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Abstract

The advection properties of impurities in the resistive drift wave turbulence modeled by the Hasagawa-Wakatani equations are investigated. Impurities are modeled as a passive scalar advected by the plasma turbulent flow. Impurity advection is investigated for three regimes of Hasegawa-Wakatani Model, adiabatic regime, quasi-adiabatic regime and hydrodynamic regime. As the analysis method, structure function analysis is adopted. For impurity advection, multifractal property is found. We compare the diffusion coefficient of fluid impurity and test-particle simulation. It is found that both of them have similar value.

Introduction

It is important to understand transport mechanism in turbulent plasmas. Impurities in fusion confinement devices can affect the confinement properties in these machines. They can in particular enhance the radiative energy losses and dilute the hydrogen fuel within the core plasma. In this work we investigate the advection properties of impurities in the resistive drift wave turbulence modeled by the Hasagawa-Wakatani equations.

Hasegawa-Wakatani Equations

To investigate the plasma edge turbulnce, Hasegawa-Wakatani model is used. Following equations are the Hasegawa-Wakatani equations [1]:

$$\left(\frac{\partial}{\partial t} - D\nabla^2\right) n + \frac{\partial}{\partial y}\phi + c(n-\phi) = [n,\phi] \tag{1}$$

$$\left(\frac{\partial}{\partial t} - \nu\nabla^2\right) \nabla^2\phi + c(n-\phi) = \left[\nabla^2\phi,\phi\right]. \tag{2}$$

Where, n is the fluctuating component of the plasma density, ϕ is the electrostatic potential, D is diffusion coefficient and ν is viscosity. $[,]$ are the Poisson brackets. c is the adiabaticity parameter that is due to parallel electron conductivity. This model assumes that equilibrium magnetic field is constant in the z-direction, $B = B_0 z$. The x and y-directions correspond to radial and poloidal coordinates. The ions are considered as cold and temperature gradient effects are neglected. Equation(1) and eq.(2) are expanded in dimensionless variables. Normalizations are

$$e\phi/T_e \rightarrow \phi, \quad n_1/n_0 \rightarrow n, \quad \omega_{ci}t \rightarrow t, \quad x/\rho_s \rightarrow x. \tag{3}$$

The character of the system is controled by c, which is defined as

$$c = \frac{T_e k_z^2}{e^2 n_0 \eta \omega_{ci}}, \tag{4}$$

where T_e is electron temperature, η is electron resistivity and ω_{ci} is ion cycrotron frequency. For $c \gg 1$, we get the adiabatic regime where the Hasegawa-Wakatani system, reduces to the Hasegawa-Mima system. In the adiabatic regime, structures of n and ϕ are tightly coupled. While for $c \ll 1$, the hydrodynamic regime, it reduces to a 2D Navier-Stokes equation for the $E \times B$ flow vortices and a passive advection for the density fluctuations. For $c \approx 1$, the quasiadiabatic regime, the phase shift between n and ϕ occurs.

Impurity Passive-Fluid Model

Impurities n_1 are regarded as a passive scalar, that is, they are advected by the turbulence but do not have any influence on it [2]. Impurities are advected by following equation:

$$\left(\frac{\partial}{\partial t} - D\nabla^2 \right) n_1 = [n_1, \phi]\,. \tag{5}$$

Here, n_1 is the impurity density.

Impurity Test-Particle Simulation

To study the transport properties of turbulence, test-particle simulation is employed. The equations of motion for particles are obtained from fluid velocity at the particle position,

$$\frac{dr}{dt} = v(r,t)$$

where $r = (x(t), y(t))$ is the particle position at time t. For two-dimensional incompressible flows velocity may be expressed in term of a stream function $\psi(x,y,t)$ [3]. In this paper, potential ϕ is used as a stream function.

$$\frac{dx}{dt} = -\frac{\partial \phi}{\partial y}, \qquad \frac{dy}{dt} = \frac{\partial \phi}{\partial x}.$$

Structure Functions

Intermittency refers to the non-uniform distribution of dissipative structures. Intermittency has an important dynamical consequence. One of the methods to study intermittency is through structure functions. Structure functions are essentially generalized correlation functions. This method is widely used in the study of neutral fluid turbulence [4]. For field u of a fully developed turbulent state, structure function of order q is defined as

$$S_q = \langle |u(x+r) - u(x)|^q \rangle$$

where r is spacial separation of two quantities, $\langle \cdots \rangle$ is the ensemble average. We use absolute values in calculating the structure functions because this is statistically more stable. If u is self-similar over some range of space separation, then the q-th order structure function is expected to scale as

$$S_q(r) = C_q r^{\zeta_q}, \tag{6}$$

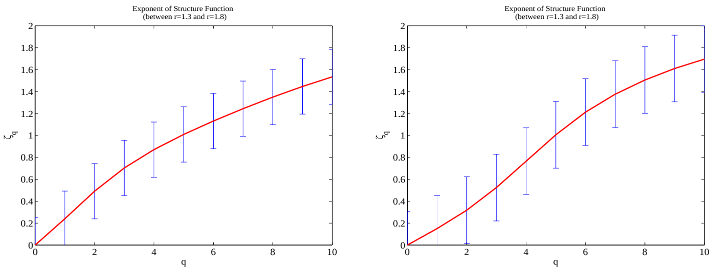
where C_q can be a function of r, ζ_q is the exponent of the structure function. Structure functions have a power-law dependence on the separation r.

Simulation Results

The result are obtained for 256^2 grids, box size $L = 64$. The diffusion coefficient D and viscosity coefficient ν are $D = \nu = 0.01$. Three regimes are investigated, (i) adiabatic regime $c = 5$, (ii) quasi-adiabatic regime $c = 0.7$ and (iii) hydrodynamic regime $c = 0.01$. Only the results of quasi-adiabatic regime (c=0.7) are presented in this paper.

Structure Function Analysis

Figure(1) shows structure function exponent of vorticity and impurity, as a function of q. Deviation of ζ_q from a linear dependence on q indicates that existence of irregular redistribution of the energy in the turbulent cascade. Both vorticity and impurity have intermittent phenomenon. Table(1) gives the values of exponent of structure function of vorticity and impurity. They are of the same order in magnitude as those of density and potential. This indicates that the characteristics of their turbulence are correlated to each other.



(a) Vorticity (b) Impurity

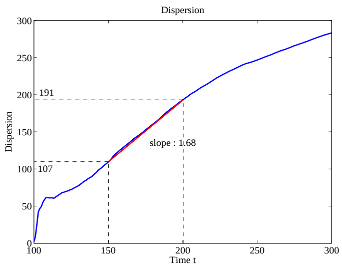
Figure 1: Exponent of structure function

Diffusion of Impurities

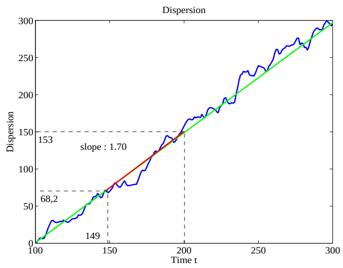
In this research, diffusion of two models of impurity transport by turbulent plasma are compared, one is a passive scalar density and the other is a test-particle. Figure(2) shows the time dependence of dispersion. D^{diff} for impurity transport as a passive scalar in the quasiadiabatic

Table 1 : Exponents of structure function

q	1	2	3	4	5	6	7	8	9	10
density	0.4989	1.1092	1.7324	2.2873	2.7678	3.1962	3.5904	3.9610	4.3141	4.6532
potential	0.5317	1.2461	2.0964	2.9867	3.8581	4.7003	5.5212	6.3293	7.1297	7.9252
impurity	0.1496	0.3180	0.5243	0.7646	1.0058	1.2126	1.3761	1.5054	1.6103	1.6956
vorticity	0.2403	0.4907	0.7030	0.8704	1.0088	1.1312	1.2439	1.3490	1.4464	1.5343



(a) Diffusion of impurity as fluid



(b) Diffusion of impurity as particle

Figure 2: Diffusion of Impurity

regime is 0.84 and $D^{\rm diff}$ for impurity transport as a test-particle in the quasiadiabatic regime is 0.85. These values are similar.

Summary and Conclusion

In this paper, the properties of impurity advection in a resistive drift wave turbulene has been investigated. The exponent of structure function of vorticity and impurity are found to be of the same order as that of density and potential. It indicates that their turbulent characteristics are correlated. In the analysis of impurity diffusion, the diffusion coefficient of impurity as a passive scalar density and a test-particle in plasma edge turbulence are compared. It is found that both give similar value of diffusion coefficient in the quasiadiabatic regime, $D^{\rm diff} = 0.84$ for the passive scalar model, $D^{\rm diff} = 0.85$ for test-particle model. This work demonstrates that one can use passive scalar simulation approach to study impurity transport as it provides similar results to test-particle simulation in less time-consuming.

References

[1] A.Hasegawa and M.Wakatani, Phys.Rev.Lett **50**, 682 (1983).

[2] M.Priego, O.E.Garcia, V.Naulin, and J.Juul Rasmussen, Phys.Plasmas **12**, 062312-1 (2005).

[3] A.Provenzale, Annu. Rev. Fluid Mech, **31**, 55 (1999)

[4] Mogens H.Jensen, Phys.Rev.Lett **83**, 76 (1999).