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How to Apply a Turbulent Transport Model Based on a Gyrokinetic Simulation for Helical Plasmas

ヘリカルプラズマにおける，ジャイロ運動論解析に基づく乱流輸送モデルの輸送シミュレーションへの適用方法

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How to apply a reduced model for the turbulent ion heat diffusivity [M. Nunami *et al.* Phys. Plasmas, **20** 092307 (2013)] derived from a gyrokinetic code to a transport simulation is proposed. The reduced model is given by the function of the linear growth rate of the ion temperature gradient (ITG) mode and the decay time of zonal flows. The ion temperature gradient scale length is chosen for the modeling the linear growth rate of the ITG mode from a gyrokinetic code. The calculation of a low computational cost reproduces the results of the reduced model within allowable errors.

1. Introduction

Turbulent transport is one of the most critical issues for plasma confinement in magnetic fusion devices. Recently, a large number of the gyrokinetic simulations have been done in toroidal plasmas. The GKV-X code solving the gyrokinetic equation has been used to examine the ITG mode and zonal flows in the LHD [1]. The reduced model of $\chi_i \sim \rho_{ti}^2 v_{ti} f / R$ is taken [2] for the high-T_i LHD discharge of the shot number 88343, where f is a function of $\mathcal{L}$ and $\tilde{\tau}_{ZF}$. Here, $\mathcal{L}$ (= $\int \tilde{\gamma}_{\tilde{k}_y} / \tilde{k}_y^2 d\tilde{k}_y$), where $\tilde{\gamma}_{\tilde{k}_y}$ is the normalized linear growth rate of the ITG mode and $\tilde{\tau}_{ZF}$ is the normalized decay time of zonal flows [3]. However, it is costly to carry out linear calculations of the growth rate by the gyrokinetic simulation at each time step of the dynamical transport code, such as TASK3D [4]. In this study, how to apply the reduced model for the ITG mode derived from the gyrokinetic simulation to the transport code is shown with a low computational cost, while the accuracy of the gyrokinetic simulation is maintained. Modeling of the term $\mathcal{L}$ is necessary. The ion temperature gradient scale length L_{T_i} is chosen for the parameter to apply $\mathcal{L}$ to avoid the gyrokinetic calculations of the linear growth rate at each time step of the transport simulation. The formula of the zonal flow decay time is needed to be calculated at the given field configuration. The additional modeling for the turbulent ion heat diffusivity is applied to the transport code and enables us to study the simulation results with the experimental results in LHD.

2. The Additional Modeling of the Turbulent Ion Heat Diffusivity

The linear analysis is done using the GKV-X code for the additional modeling of the turbulent ion heat diffusivity. The ITG instability is examined in the high-T_i LHD discharge #88343 [5]. As the function of the ion temperature gradient scale length L_{T_i}, the parameter $\mathcal{L}$ is modeled by

$$\mathcal{L} = a(\rho)\left(\frac{R}{L_{T_i}} - \frac{R}{L_{T_c}}\right), \quad (1)$$

where L_{T_c} is the normalized critical ion temperature gradient for the ITG instability. The dependence of $\mathcal{L}$ on R/L_{T_i} is examined with all plasma parameters fixed except the ion temperature gradient. The values of R/L_{T_C} and the slope $a(\rho)$ are obtained. When we calculate the value of the ion heat diffusivity in the dynamical transport code, the fitting polynomials of R/L_{T_C} and $a(\rho)$ are used as $R/L_{T_C} = 4.0929\text{-}3.7681\rho+19.712\rho^2+11.087\rho^3 \text{-}14.272\rho^4$ and $a(\rho) = 0.38661\text{-}0.070919\rho+0.2571\rho^2 +0.95949\rho^3\text{-}0.92978\rho^4$. Figure 1 shows the comparison between $a(\rho)(R/L_{T_i} - R/L_{T_c})$ and $\mathcal{L}$ in Eq. (1) with the root mean square of ($a(\rho)(R/L_{T_i} - R/L_{T_c}) / \mathcal{L}$ -1) given by $\sigma = 0.13$. The zonal flow decay time $\tilde{\tau}_{ZF}$ is examined. The fitting

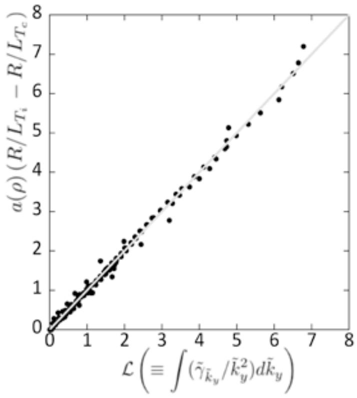

Fig. 1 Comparison between the modeled function in terms of L_{T_i} and $\mathcal{L}$.

function for $\tilde{\tau}_{ZF}$: $\tilde{\tau}_{ZF}(\text{fit}) = 0.98565\text{-}0.65943\rho +2.4471\rho^2+3.2337\rho^3\text{-}2.8382\rho^4$ is used throughout the transport simulation. The first modeled turbulent ion heat diffusivity is shown as

$$\frac{\chi_i^{FTS(1)}}{\chi_i^{GB}} = C_0\left(C_T a(\rho)\left(\frac{R}{L_{T_i}} - \frac{R}{L_{T_e}}\right)\right)^{\delta}, \tag{2}$$

where the numerical coefficients are given in [2]. The second modeled turbulent ion heat diffusivity is also shown as

$$\frac{\chi_i^{FTS(2)}}{\chi_i^{GB}} = \frac{A_1\left(a(\rho)\left(\frac{R}{L_{T_i}} - \frac{R}{L_{T_e}}\right)\right)^{\alpha}}{A_2 + \tilde{\tau}_{ZF}(\text{fit})/\left(a(\rho)\left(\frac{R}{L_{T_i}} - \frac{R}{L_{T_e}}\right)\right)^{1/2}}. \tag{3}$$

The numerical coefficients are also given in [2].

3. Transport Analysis Using the Additional Modeled Turbulent Diffusivity

The transport dynamics is examined using the modeled turbulent ion heat diffusivity, when the integrated code, such as TASK3D is performed. The dynamics of the radial T_i profile is simulated by solving the diffusion equation as

$$\frac{\partial}{\partial t}\left(\frac{3}{2}nT_i\right) = -\frac{1}{V'}\frac{\partial}{\partial \rho}(V'Q_i) + P_{hx} + P_{hi}, \tag{4}$$

where P_{hx} is the heat exchange term and P_{hi} is the absorbed power of ions. The ion heat flux Q_i is set as $Q_i = -<|\nabla\rho|^2> n(\chi_i^{FTS} + \chi_i^{NEO})\partial T_i/\partial\rho$, where χ_i^{NEO} is the neoclassical diffusion coefficient of ions. The value of the ion temperature is fixed at the initial state in the shaded region $0.785 \le \rho \le 1.000$ shown in Fig. 2. We show the simulation results for the stationary ion temperature profile at t=0.1s with the dotted (Eq. (2)) and solid (Eq. (3)) curves in Fig. 2. The dashed curve indicates the radial profile of T_i at t=2.23s in the LHD discharge #88343. The simulation results for the radial T_i profile show a good agreement with the experimental result. When Eq. (3) is used, the better agreement between the experimental and the simulation results is obtained. For modeling $\mathcal{L}$, three runs at the different values of L_{T_i} are needed at a radial point. It takes about one hour per one time of the program run. If the value of $\mathcal{L}$ is calculated at each time step in TASK3D, about one hundred thousand times of the program run are necessary at a radial point.

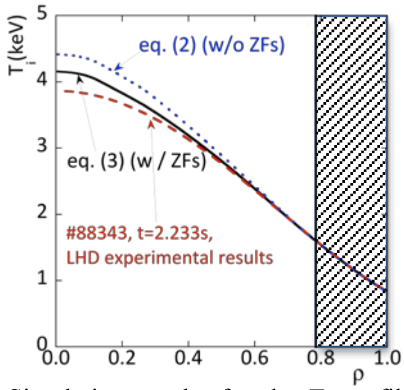

Fig. 2 Simulation results for the T_i profile are shown with Eq. (2) (the dotted curve) and Eq. (3) (the solid curve) for the turbulent ion diffusivity.

4. Summary

To reduce the simulation cost, how to apply the transport model based on a gyrokinetic simulation to a dynamical transport code is shown within the accuracy of the gyrokinetic simulation. The value of the reduced model is reproduced by the modeled turbulent ion heat diffusivity. The simulation results by applying the additional modeled turbulent ion heat diffusivity to TASK3D are shown. So far, we concentrate on the ITG turbulence in helical plasmas. To apply the reduced model of the turbulent diffusivity to a transport code, the similar method discussed here can be used for the other modes. The dependence of the turbulent heat diffusivity on the field configuration and the plasma profiles for the LHD and different devices will be investigated.

Acknowledgments

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