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トカマク周辺乱流シミュレーションに向けた大域的ジャイロ運動論コードの拡張
Extension of Global Gyrokinetic Code for Tokamak Edge Turbulence Simulation

奥田 修平[1], 瀬戸 春樹[2], 今寺 賢志[1]
OKUDA Shuhei[1], SETO Haruki[2], IMADERA Kenji[1]

[1]京都大学, [2]量子科学技術研究開発機構
[1]Kyoto University, [2]National Institutes for Quantum Science and Technology

The plasma dynamics in the tokamak edge, the outer core region connecting with the SOL / divertor region, is of importance for fuel supply / impurity pumping, divertor heat load control, L-H transition, and so on. These are key issues for upcoming fusion devices like JA-DEMO. Gyrokinetic simulation is an essential tool to study these physics based on the first principle, but it is not easy to treat the edge region with higher q values and complex magnetic surface geometries in the same way as the core region [1].

First, to resolve these problems, we introduced a field-aligned coordinate system [2] to our global gyrokinetic code GKNET [1]. It can significantly reduce computational cost because wavenumbers of resonant instabilities become low in the direction along the magnetic field lines. It is particularly effective in edge regions where the higher poloidal mode number resonates with the higher q value. The field-aligned coordinates (x, y, z) are defined as

$$\begin{cases} x = \rho \\ y = y_{shift} - \zeta \\ z = \theta - \theta_0 \end{cases} \quad \text{with} \quad y_{shift} = \int_{\theta_0}^{\theta} \frac{B \cdot \nabla\zeta}{B \cdot \nabla\theta} d\theta,$$

where ρ is the label of the magnetic-flux-surface, θ is the straight-filed-line poloidal angle, and ζ is the geometrical toroidal angle respectively. In this coordinate system, the covariant basis vector $\boldsymbol{e}_z$ is parallel to the magnetic field line so that plasma fluctuations can be numerically resolved with fewer grid points in this direction. In fact, this has reduced the computation time of linear simulations by one order. But the wavenumber in the x direction written as $k_x = k_\rho + nq'z$ (n is the toroidal mode number and the prime symbol is the derivative with respect to the radial label ρ) has a secular cell deformation from the offset of the shift angle θ_0 for $q' \neq 0$, which deteriorates the accuracy of finite difference in the x direction. A shifted metric technique [3] is therefore introduced to reduce the secular cell deformation, which divides the torus into N segments with respect to the poloidal angle and sets an appropriate reference point in each segment θ_k for $k = 0, 1, \dots, N-1$.

Second, we developed an interface code for GKNET generating toroidal coordinates (ρ, θ, ζ) from numerical equilibria through IGS code [4] and constructing the computatonal domain with the field-alinged coordinates and the shifted metric. Figure 1 shows that the extended GKNET is applicable to a nonlinear simulation of ion temperature gradient (ITG) mode in the realistic magnetic field configuration such as JT-60SA ITER-like case [4]. In this case, it is estimated that the number of required computational grids is reduced to 1/74 by means of field aligned coordinates.

Finally, in this paper, we also report on an interface code under development that extends computational grids over the SOL/divertor region.

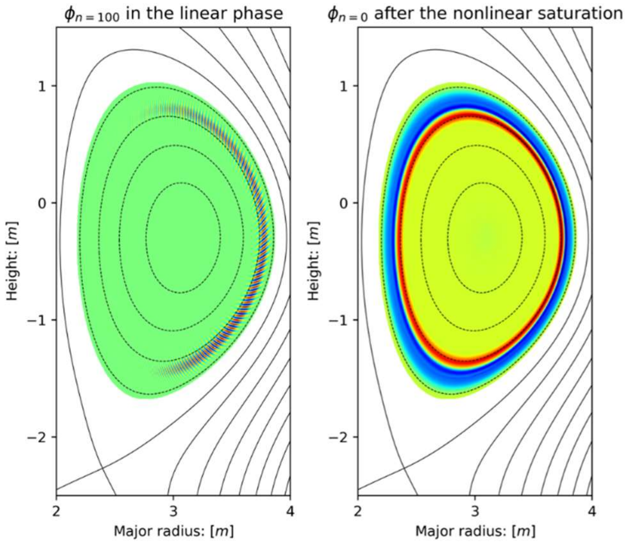

Figure 1. Poloidal plot of $n = 100$ electrostatic potential $\phi_{n=100}$ in the linear growth phase (left) and $\phi_{n=0}$ after the nonlinear saturation (right) calculated with shifted metric ($N = 8$) in JT-60SA ITER-like case equilibrium.

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