24Cp07

大域的ジャイロ運動論コードに対するfield aligned coordinateの実装
Implementation of field aligned coordinate to global gyrokinetic code

今寺 賢志，奥田 修平，元古 修平， 岸本 泰明
IMADERA Kenji, OKUDA Shuhei, GENKO Shuhei, and KISHIMOTO Yasuaki

京都大学大学院 エネルギー科学研究科
Graduate School of Energy Science, Kyoto University

Gyrokinetic full-*f* simulation is an essential tool to study turbulent transport and profile evolutions self-consistently. It directly solves the gyrokinetic Vlasov equation coupled with the field equation in 5D phase space so that the numerical cost becomes expensive, which requires sophisticated code development for utilizing HPC infrastructures. Our full-*f* gyrokinetic code GKNET [1] has installed 3D MPI+OpenMP decomposition, however, it is necessary to do more improvement for larger-scale simulations, especially in the case where electron is treated kinetically.

In this talk, we address our recent progress of numerical techniques to perform such larger-scale simulations. One is the implementation of field-aligned coordinate, which reduces the cost and keeps numerical accuracy to reproduce ballooning-type ion-scale turbulence. The field-aligned coordinate (x, y, z) is defined as

$$\begin{cases} x = r \\ y = q(r)\theta^* - \zeta \\ z = \theta^* \end{cases}$$

where r is the torus minor radius, θ^* is the straight-filed-line poloidal angle, and ζ is the toroidal angle. In this coordinate system, the covariant basis vectors $\boldsymbol{e}_y$ and $\boldsymbol{e}_z$ are parallel to the toroidal direction and magnetic field line, respectively. As the result, z direction can be numerically resolved by fewer grid points for long-wavelength perturbations, and the grid points along y direction can be also reduced by assuming the wedge torus. The gyrokinetic quasi-neutrality condition is solved by 1D FFT for y direction in addition to 4th-order FDM for x and z directions. By assuming $k_z \ll 1$, we can efficiently utilize the iteration matrix solver for z direction, while the LU decomposition is applied for x direction. Figure 1 shows (a) the dispersion relation and (b) the eigenfunction of toroidal ITG mode obtained by the field aligned and toroidal coordinate versions in the Cyclone base case. We find that both cases can get almost same results, while the convergence of grid points in the field aligned version roughly becomes 1/4 〜 1/8 compared with that in the toroidal coordinate one because of the above advantages.

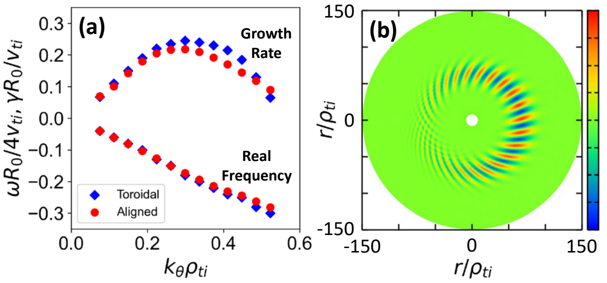

Fig. 1: (a) The dispersion relation of toroidal ITG mode obtained by GKNET with field aligned and toroidal coordinates. (b) The poloidal counter of the eigenfunction with $k_\theta \rho_{ti} = 0.37$ in the field aligned case.

The other improvement is the utilization of GPU. Based on the OpenACC parallelization, we have accelerated the 5D loop (“Vlasov” & “Collision”) and optimized the communication and computation hiding (“Collision” and “SendRecv”) by using asymptotic communication. Figure 2 shows the computation time to calculate the gyrokinetic Vlasov equation by using MPI and MPI+OPENACC parallelization at MARCONI 100 [2]. We find that the total cost can be reduced by 1/40〜1/50, which demonstrates the GPU acceleration efficiently works.

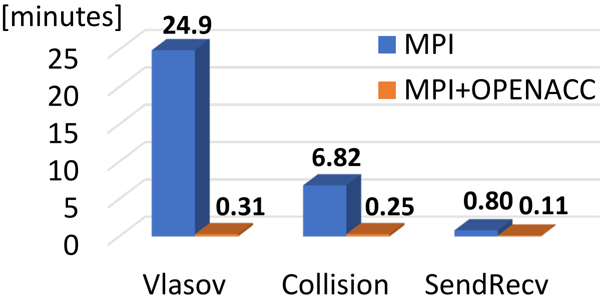

Fig.2: Computational time of each part by using MPI and MPI+OPENACC parallelization at MARCONI 100. The numbers of used CPU (IBM POWER9 AC922) and GPU (NVIDIA Volta V100) are 256 and 64, respectively.

Reference

[1] K. Imadera, *et al.*, Proc. 25th FEC, TH/P5-8 (2014).
[2] https://www.hpc.cineca.it/hardware/marconi100.