Contribution ID: **944** Type: **Regular Poster**

An Improved Equation-Free Method for Gyrokinetic Profile Evolution of Tokamak Plasmas

Friday 14 May 2021 12:10 (20 minutes)

Cross-field transport of particles, energy and momentum due to turbulent fluctuations and collisional neoclassical orbital dynamics generally determines the confinement level, and consequently the fusion power production, achievable in magnetic confinement fusion devices. To confidently predict the performance of next-step burning plasma experiments, including ITER, comprehensive models of transport processes are therefore required \1. The inherently multiscale nature of transport processes, however, presents an enormous difficulty for direct numerical simulation based on first-principles kinetic models due to the large computational resource requirements and a possible accumulation of numerical error. Here, we present our recent work \2 in developing a multiscale method for accelerating kinetic simulations based on the equation-free projective integration method of Keverekidis and Gear \[3]. Our scheme has been implemented in the 4-dimensional gyrokinetic, neoclassical particle-in-cell code XGCa \[4] and is being explored as a possible tool for extending gyrokinetic simulations to the transport time scale. It has been shown to accurately reproduce transport due to microscopic guiding-center orbital dynamics under Coulomb collisions, while achieving a computational speed up of over 4x compared to brute force time stepping. The approach is general and can be applied in a straightforward manner to include the effects of turbulence on transport.

Equation-free projective integration uses appropriately initialized short time scale computational experiments from high-fidelity models to estimate local time derivatives of lower-fidelity quantities evolving over large space-time scales. By estimating time derivatives directly from high-fidelity simulation data, it eliminates the need for explicit closed-form equations describing the evolution of the lower-fidelity quantities. In our application, the high-fidelity model is the gyrokinetic model describing the evolution of gyro-center phase space distribution functions, and the low fidelity quantities of interest are a small set of low-order gyro-center fluid moments, including density and temperature. This approach is distinct from other multiscale techniques involving couplings between separate models for turbulence and transport \[5,6] in that the fluid moment evolution comes directly from gyrokinetics. A three stage "lift-evolve-project"time stepping procedure is employed in the equation-free approach, where one cycle consists of :

1. "Lifting"fluid moments to a consistent phase space distribution function used to initialize a gyrokinetic code.
2. Evolving the fully resolved gyrokinetic code over a number of timesteps, "restricting"the distribution function at each step to obtain a short time history of the fluid moments.
3. "Projecting"(or extrapolating) the fluid moments over a large time step based on the time derivative estimation based on the time history data obtained in step 2.

A major contribution of our work was in the construction of a kinetically-informed "lifting"operator, which maps the set of low-order fluid moments to a consistent phase space distribution function and necessarily involves information loss. Previous attempts to use the equation-free method in kinetic plasma simulations with maximum-entropy based lifting operators were limited due to the appearance of spurious transient oscillations \[7] which occurred after lifting. Our method takes distribution function information available from a previous time step as a starting point for a velocity space expansion of the lifted distribution function. By using previous time step distribution function data, non-Maxwellian perturbations that have developed over time in the system are preserved and spurious oscillations are mitigated.

We have performed validation tests using the XGCa code, comparing the results of our method to long-time reference solutions coming from brute force direct numerical simulation in XGCa for a neoclassical ion heat transport problem. Our method is shown to accurately reproduce ion temperature profile evolution (Figure 1) and ion heat flux evolution (Figure 2) over the transport time scale while achieving a computational speed up of over 4x compared to brute force time stepping. This is a promising result, demonstrating the possibility of using first-principles kinetic models to perform tokamak simulations on the transport time scale. As a follow up to this study, we will consider the inclusion of turbulent transport for this problem.

Indico rendering error

```
Could not include image: [404] Error fetching image
```

Indico rendering error

Could not include image: [404] Error fetching image

References :

\1 J.E. Kinsey, G.M. Staeble, J. Candy, R.E. Waltz and R.V. Budny, Nucl. Fusion 51 (2011) 083001.
\2 B. Sturdevant, S.E. Parker, C.S. Chang, and R. Hager, to appear in Phys. Plasmas (2020), DOI: 10.1063/1.5141337.
\[3] I.G. Kevrekidis, C.W. Gear, J. Hyman, P. Kevrekidis, O. Runborg, and C. Theodoropoulos, Comm. Math. Sci. 1 (4) (2003) 715-762.
\[4] R. Hager and C.S. Chang, Phys. Plasmas 23 (2016) 042503.
\[5] M. Barnes, I.G. Abel, W. Dorland, T. Gorler, G.W. Hammett, and F. Jenko, Phys. Plasmas 17 (2010) 056109.
\[6] J.B. Parker, L.L. LoDestro, D. Told, G. Merlo, L.F. Ricketson, A. Campos, F. Jenko, and J.A.F. Hittinger, Nucl. Fusion 58 (2018) 05004.
\[7] M. A. Shay, J.F. Drake, B. Dorland, J. Comput. Phys. 226 (2007) 571-585.

Affiliation

Princeton Plasma Physics Laboratory

Country or International Organization

United States

Author: STURDEVANT, Benjamin J. (Princeton Plasma Physics Laboratory)

Co-authors: PARKER, Scott E. (University of Colorado, Boulder); CHANG, Choong-Seock (Princeton Plasma Physics Laboratory and KAIST); HAGER, Robert (Princeton Plasma Physics Laboratory)

Presenter: STURDEVANT, Benjamin J. (Princeton Plasma Physics Laboratory)

Session Classification: P7 Posters 7

Track Classification: Magnetic Fusion Theory and Modelling