8th Asia-Pacific Conference on Plasma Physics, 3-8 Nov, 2024 at Malacca

A high-fidelity gyrokinetic surrogate model with machine learning

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Energy confinement quality determines the size and cost of a tokamak. Plasma turbulence and transport cause fluctuations in the confinement time, leading to a few percent change in the hot core. Understanding the origin and properties of plasma turbulence is a critical issue in Tokamak's research. Gyrokinetic theory and models have been used to solve these problems, but these codes are expensive [1]. Plasma physicists develop different codes for different tasks, as computational speed and fidelity have been a trade-off.

The application of machine learning in constructing surrogate models has revolutionized the ability to achieve both high accuracy and efficiency. However, building these models necessitates a significant dataset of simulation results for ML model training, creating a challenge. While surrogate models aim to accelerate simulation code, the cost of gathering a large simulation result dataset, particularly for nonlinear gyrokinetic models, is prohibitively expensive.

To address this issue, we have developed a novel surrogate model construction methodology. We create a sizable simulation result dataset with low fidelity but rapidity results, then generate a small high-fidelity simulation result to fine tune our model. This method enables us to attain the ideal combination of precision and speed for the gyrokinetic surrogate model.

We are currently developing a surrogate model for the wave number spectrum (k) using GKW [2] and GX [3]. Our initial focus is on Ion Temperature Gradient (ITG) modes, characterized by four parameters, to demonstrate our approach. We collected 8800 simulation results using GX and 1097 high-fidelity results using GKW. Since obtaining the ground truth for gyrokinetic outputs (e.g., thermal diffusivity χ_i) in tokamak experiments is challenging, we consider GKW results as the ground truth for testing our surrogate model. Therefore, we generated an additional 1000 high-fidelity GKW results. We used all GX results for model training and 100 GKW results for fine-tuning.

Our efforts have resulted in a successful surrogate model that is comparable in fidelity to GKW. The average similarities for Φ_{kx} and Φ_{ky} between surrogate model and GKW are **0.957** and **0.970**. For X_i, our results align well with theoretical predictions [4]. Additionally, it is orders of magnitude faster than GKW simulation. Moving forward, we plan to expand the model by incorporating additional parameters and conducting further research to create a complete gyrokinetic surrogate model.

The computational work for this article was partially performed on resources of the National Supercomputing Centre, Singapore (https://www.nscc.sg). This research is supported by the National Research Foundation, Singapore.

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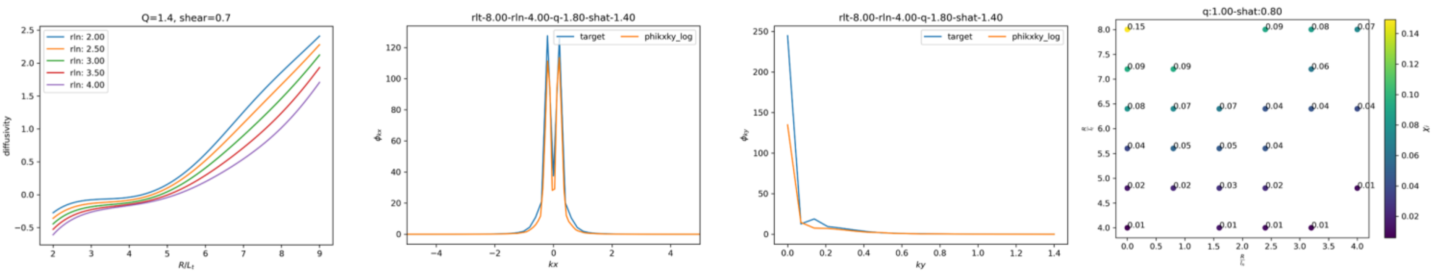

Figure 1. Comparison of results between the surrogate model and the GKW simulation code. (a) Thermal diffusivity X_i vs $\frac{R}{L_n}$. (b) and (c) Comparisons between surrogate model and GKW results for Φ_{kx} and Φ_{ky}. (d) Subset of GKW data.