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Understanding the interaction between turbulence and zonal-flow in stochastic predator-prey model using sparse regression

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It has been known that turbulence-driven zonal flow in the magnetically confined plasma, which is toroidally and poloidally symmetric shear flow, plays a crucial role in controlling the saturated level of drift-wave turbulence. A popular dynamical model describing the interaction between turbulence and zonal flow is the predatorprey model [1, 2]. If the predator-prey model keeps the gist of dynamics, it could possibly be captured in dynamical identification.

In this work, we try to solve the inverse problem, i.e., the identification of the dynamical process from the global gradient-driven gyrokinetic simulation data. To this end, we use the sparse identification of nonlinear dynamics (SINDy) to extract the dynamics of the turbulence and the zonal flow [3]. Firstly, we extract the most likely predator-prey equations to describe the time series data from the gyrokinetic simulation featuring the evolution of turbulence and zonal flow. Interestingly, we find a significant deviation in the dynamics from the conventional predator-prey model.

In order to remedy this discrepancy, we adopt a stochastic predator-prey model to capture the intermittent nature of turbulence. To construct a stochastic model, we evaluate the joint probability density function (PDF), P(X, Y, T), from the simulation data as a function of $X = |e\phi/T_{i0}|^2$, $Y = |V_{E\times B}/V_{Ti0}|^2$, and T, which represent turbulence intensity, zonal flow strength, and time, respectively. We obtain the PDF by counting the number of points in each section of the domain of X, Y , and T under the assumption of the equal weighting of each point, and fit a smooth function, $\hat{P}$, to it by using spline interpolation. $\hat{P}$ then represents a stochastic nature of dynamics of turbulence-zonal flow interaction which provides another view of this problem [4]. From $\hat{P}$, we compute dynamical friction and diffusion coefficients in the Fokker-Planck equation.

$$\frac{\partial p}{\partial t} = \frac{\partial}{\partial x}\left[(c_3' x + c_2' xy)\, p\right] + \frac{\partial}{\partial y}\left[(c_4' y + c_1' xy)\, p\right] + c_7' \frac{\partial^2 p}{\partial x^2} + c_8' \frac{\partial^2 p}{\partial x^2}$$

A more detailed analysis of the stochastic properties will be presented at the conference.

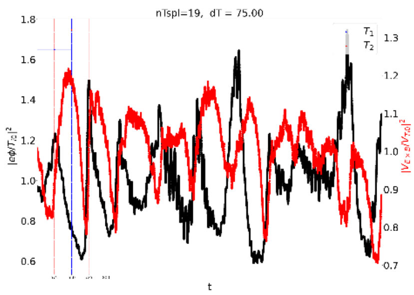

Figure 1. Gyrokinetic simulation data in r/a=0.45- 0.55. The black solid line indicates the turbulence amplitude and the red solid line indicates the zonal flow amplitude. Both values are normalized by the mean of turbulence and zonal flow, respectively.

References

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[3] Brunton, Steven L., Joshua L. Proctor, and J. Nathan Kutz. 2016 Proceedings of the national academy of sciences 113 3932-3937.

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