Capturing patterns in plasma turbulence simulations using data-driven surrogate models

R. Varennes[1], Z. Qu[1], R. Heinonen[2], P. Ghendrih[3], V. Grandgirard[3], Y. Cho[1], Ö. D. Gürcan[4], G. Dif-Pradalier[3], P. Diamond[5] X. Garbet[1,3]

[1] School of Physical and Mathematical Sciences, Nanyang Technological University, 637371, Singapore.
[2] Department of Physics and INFN, University of Rome, “Tor Vergata”, Via della Ricerca Scientifica, 1, 00186 Roma, RM, Italy.
[3] CEA, IRFM, F-13108 Saint-Paul-Lez-Durance, France.
[4] Laboratoire de Physique des Plasmas, CNRS, IP Paris, Universite Paris-Saclay, 91128 Cedex, Palaiseau, France.
[5] Department of Physics, University of California San Diego, La Jolla, California 92093, USA

contact: robin.varennes $\oplus$ ntu.edu.sg

A remaining challenge in the path of commercial nuclear fusion reactors is energy confinement. Indeed, extreme thermodynamical gradients are responsible for turbulence that diffuses energy from the core plasma to the wall of the reactor’s vessel, preventing access to the necessary fusion temperatures. To this day, the main parameters that govern this turbulent transport remain elusive. Data-driven surrogate models, based on simulation or experimental data, appear as a great tool to identify parameters minimizing transport while strengthening our understanding of the physical mechanisms at play.

In the presented work, machine learning algorithms are applied to simulation data obtained with the code TOKAM2D [1, 2] which resolves the Hasegawa-Wakatani set of equations [3], i.e. a simple model describing drift-wave turbulence in a 2D plane. By scanning a wide range of initial background density gradients and flows, these statistical methods link the output flux and Reynolds stress to an arbitrary number of quantities of interest (e.g., N-th order spatial derivatives of density and vorticity, turbulent intensity, etc.). While this study is intended as a foundation for scalability towards more complex and high-dimensional applications, it also provides insights into interesting physics.

For example, a similar work [4] has successfully correlated the flux to a contribution of the vorticity gradient - opening the debate on its role as a thermodynamic force - and found that the Reynolds stress structure is compatible with an antiviscous behavior. This previous work is here extended to the interchange instability - stemming from the curvature in toroidal fusion devices - which breaks intrinsic symmetries of the governing equations and carries properties significantly different from the drift-wave instability. The impact on the resulting flux and Reynolds stress is discussed.

References

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