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Turbulent electric potential generation for particle trajectories integration

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The quality of energetic particle confinement in a nuclear fusion reactor is a key factor in the reactor's efficiency. One way of studying the behavior of energetic particles in detail is to integrate "test particle" trajectories into a previously calculated turbulent electric potential field. The high cost of calculating the turbulent field, and the size of the data, make it very difficult to use this method to integrate trajectories over a long period of time. This is why the development of a reduced model to obtain the turbulent field is an important matter. A low-cost turbulence generation model would enable much more detailed studies to be carried out on the transport of energetic particles in a turbulent field. The turbulence obtained must, of course, have similar characteristics to the turbulence actually calculated.

In order to develop a low-cost turbulence generation model, a first step is to represent the turbulent field in a reduced way. For this, the use of a variational auto-encoder (VAE) [1] is relevant. The VAE learns to encode an instantaneous turbulent field (a 2D or 3D matrix) in a reduced-dimensional space (latent space), and to reconstruct it from this latent representation. For best results, training is not performed on the images of the potential, but on their Fourier transform.

Once an efficient VAE has been obtained for encoding and decoding a turbulent field, the turbulence must be generated in a relevant way. To achieve this, we study the evolution of the representation of turbulent fields in latent space. A neural network is trained to predict the next position in latent space from the current position. The result is a transition probability function in latent space. The relevance of this function can be improved by taking into account the variation of certain field characteristics (power spectral density, turbulence intensity).

The combination of a high-performance VAE and a relevant transition probability function in latent space enables the low-cost generation of a turbulent electric potential. This method is first applied to the Hasegawa-Wakatani model, a 2D model of turbulence in a magnetized plasma. It will then be applied to a 3D potential, obtained with GYSELA5D code [1]. The models are trained on the multi-GPU partitions of the IDRIS Jean Zay supercomputer.

References:

[1] V. Grandgirard, J. Abiteboul, J. Bigot, T. Cartier-Michaud, N. Crouseilles, G. Dif-Pradalier, C. Ehrlacher, D. Esteve, X. Garbet, P. Ghendrih, et al. A 5d gyrokinetic full-f global semi-lagrangian code for flux-driven ion turbulence simulations. Computer physics communications, 207:35–68, 2016.
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