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Learning Stochastic Dynamics with Probabilistic Neural Networks to study Zonal Jets

Ira Shokar, Peter Haynes, and Rich Kerswell
Department of Applied Mathematics and Theoretical Physics, University of Cambridge

In this study, we present a deep learning approach to deriving a reduced-order model of stochastically forced atmospheric zonal jets. The approach provides a four orders of magnitude speed-up in simulating the jets, over numerical integration, together with a lower-degrees-of-freedom latent representation of the system- used to yield insight into the underlying dynamics.

We consider the behaviour of zonal jets on a beta plane as represented by a two-dimensional model driven by stochastic forcing, which parameterises the turbulence due to baroclinic instability. This idealised model gives a useful analogue for week-to-week variations in the large-scale dynamics of the tropospheric midlatitude jet - the driver of European weather. We establish that the time evolution of the jets depends both on the nonlinear two-way interaction between the mean flow and the eddies and, crucially, the time history of the stochastic forcing. As a result, the current state or recent history of the system does not predict the forward evolution but instead determines a distribution of possible time evolutions.

To model the flow, we utilise methods in manifold learning to learn a transformation to a latent representation of the system and then use a probabilistic neural network to model the stochastic latent dynamics. We verify the neural network's performance by comparing the statistical and spectral properties of an ensemble from the neural network, obtained via sampling in the latent space, with an ensemble of numerical integrations, with different realisations of the stochastic forcing- with identical initial conditions. To study jet variability, we use ensembles of trajectories in both the latent and observation space to quantify to what extent different system states are driven by deterministic or stochastic dynamics.