



Data-driven nonlinear turbulent flow scaling with Buckingham Pi variables

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Nonlinear machine learning for turbulent flows can exhibit robust performance even outside the range of training data. This is achieved when machine-learning models can accommodate scale-invariant characteristics of turbulent flow structures. This study presents a data-driven approach to reveal scale-invariant vortical structures across Reynolds numbers that provide insights for supporting nonlinear machine-learning-based studies of turbulent flows. To uncover conditions for which nonlinear models are likely to perform well, we use a Buckingham-Pi-based sparse nonlinear scaling to find the influence of the Pi groups on the turbulent flow data. We consider nonlinear scalings of the invariants of the velocity gradient tensor for an example of three-dimensional decaying isotropic turbulence. The present scaling not only enables the identification of vortical structures that are interpolatory and extrapolatory for the given flow field data but also captures non-equilibrium effects of the energy cascade. As a demonstration, the present findings are applied to machine-learning-based super-resolution analysis of three-dimensional isotropic turbulence. We show that machine-learning models reconstruct vortical structures well in the interpolatory space with reduced performance in the extrapolatory space revealed by the nonlinearly scaled invariants. The present approach enables us to depart from labelling turbulent flow data with a single parameter of Reynolds number and comprehensively examine the flow field to support training and testing of nonlinear machine-learning techniques.

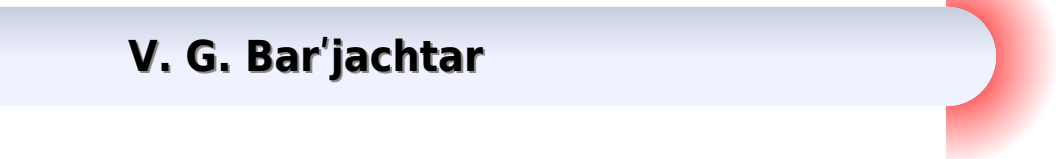
Key words: machine learning, isotropic turbulence

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