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Diffusion Models for Reconstruction of Eulerian and Lagrangian Turbulent Data

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Abstract

We propose and test a machine learning method based on state-of-the-art diffusion models (DMs) for reconstructing turbulent data with spatial and temporal gaps. First, we validate our method on two-dimensional slices of three-dimensional rotating turbulence and compare the DM with generative adversarial networks (GANs). The DM shows superior accuracy in pointwise reconstruction and statistical analysis. We also present a stochastic approach to reconstruct missing spatial and velocity data along the trajectories of small objects passively advected by turbulent flows, including 3D tracers in homogeneous and isotropic turbulence and 2D trajectories from the NOAA-funded Global Drifter Program. Our conditional diffusion model captures highly non-Gaussian and intermittent scale-by-scale properties, showing greater accuracy and statistical power compared to Gaussian process regression. This method is applicable to geophysical flows, particle tracking, and other physical problems, providing robust tools for uncertainty quantification and risk assessment.

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