Generation and Reconstruction of Lagrangian Turbulence with Stochastic Generative Models

Michele Buzzicotti, Luca Biferale, Tianyi Li, Fabio Bonaccorso, Luca Centurioni

Abstract

Lagrangian turbulence lies at the core of numerous applied and fundamental problems. However, despite decades of theoretical, numerical, and experimental research, no existing model can accurately reproduce particle trajectories' statistical and topological properties in turbulent flows. This talk presents a machine learning framework based on a state-of-the-art diffusion model to generate single particle trajectories in three-dimensional turbulence at high Reynolds numbers [1]. This approach bypasses the need for direct numerical simulations or experiments to obtain reliable Lagrangian data. Our results show that the model reproduces key statistical features across time scales, including fat-tailed velocity increment distributions, and anomalous scaling laws. Additionally, we extend this method to reconstruct missing spatial and velocity data along trajectories of small objects passively advected by turbulent flows, such as oceanic drifters from NOAA's Global Drifter Program [2]. The method accurately reconstructs velocity signals while preserving non-Gaussian, intermittent scale-by-scale properties. Notably, the model is flexible enough to handle different data gap configurations and to exploit correlations enabling superior performance over traditional Gaussian Process Regression methods. This work highlights the potential of machine learning in advancing Lagrangian turbulence research and addressing longstanding challenges in the field. This work was supported by the ERC under the European Union's Horizon 2020 research and innovation programme Smart-TURB (Grant Agreement No. 882340).

References

[1] Li, T., Biferale, L., Bonaccorso, F., Scarpolini, M. A., Buzzicotti, M., *Synthetic Lagrangian turbulence by generative diffusion models*, *Nature Machine Intelligence* **1–11** (2024).

[2] Li, T., Biferale, L., Bonaccorso, F., Buzzicotti, M., Centurioni, L., *Stochastic Reconstruction of Gappy Lagrangian Turbulent Signals by Conditional Diffusion Models*, arXiv:2410.23971 (2024).