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Numerically Modelling Stochastic Lie Transport in Fluid Dynamics

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We present a numerical investigation of stochastic transport for the damped and driven incompressible 2D Euler fluid flows. According to Holm (Proc Roy Soc, 2015) and Cotter et al. (2017), the principles of transformation theory and multi-time homogenisation, respectively, imply a physically meaningful, data-driven approach for decomposing the fluid transport velocity into its drift and stochastic parts, for a certain class of fluid flows. We develop a new methodology to implement this velocity decomposition and then numerically integrate the resulting stochastic partial differential equation using a finite element discretisation. We show our numerical method is consistent.

Numerically, we perform the following analyses on this velocity decomposition. We first perform uncertainty quantification tests on the Lagrangian trajectories by comparing an ensemble of realisations of Lagrangian trajectories driven by the stochastic differential equation, and the Lagrangian trajectory driven by the ordinary differential equation. We then perform uncertainty quantification tests on the resulting stochastic partial differential equation by comparing the coarse-grid realisations of solutions of the stochastic partial differential equation with the "true solutions" of the deterministic fluid partial differential equation, computed on a refined grid. In these experiments, we also investigate the effect of varying the ensemble size and the number of prescribed stochastic terms. Further experiments are done to show the uncertainty quantification results "converge" to the truth, as the spatial resolution of the coarse grid is refined, implying our methodology is consistent. The uncertainty quantification tests are supplemented by analysing the L2 distance between the SPDE solution ensemble and the PDE solution. Statistical tests are also done on the distribution of the solutions of the stochastic partial differential equation. The numerical results confirm the suitability of the new methodology for decomposing the fluid transport velocity into its drift and stochastic parts, in the case of damped and driven incompressible 2D Euler fluid flows. This is the first step of a larger data assimilation project which we are embarking on.