DYNAMICAL PROPERTIES OF PREFERENTIAL CONCENTRATION AND CLUSTERING OF INERTIAL PARTICLES IN TURBULENT FLOWS

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Abstract We analyze one-way coupling DNS of heavy particles in homogeneous turbulent flow over a large range of Stokes numbers at $R_\lambda = 180$. We focus on preferential concentration and clustering aspects, and more particularly on their dynamical properties.

INTRODUCTION

Turbulent flows laden with inertial particles have raised many interest in the last decade due to their wide range of applications (pollutant dispersion, engine and chemical reactor optimization, cloud physics ...) but also because of the striking features observed in this context: preferential concentration of particles and settling velocity enhancement. Preferential concentration has been addressed by many authors and robust statistical results are now established: particles tend to accumulate in some regions of the flow and this accumulation, mostly driven by the Stokes number (St), is maximal for $St \simeq 1$. Related to preferential concentration is the existence of clusters that could be defined as ensembles of particles that stay together on time scales long compared to typical time scales of the flow. We are interested in characterizing the existence and dynamics of such clusters and we do so by analyzing DNS data performed at various Stokes numbers.

SIMULATIONS AND ANALYSIS PROCEDURE

Simulation

Our DNS data come from the open data provided at `http://mp0806.cineca.it/icfd.php` and are similar to those used in [1]. Fluid velocity field $\mathbf{u}$ is obtained by solving the Navier-Stokes equations with a large scale forcing achieving a Taylor Reynolds number $R_\lambda = 180$ in a periodic box at a grid resolution of 512^3.
The particle dynamics is obtained from a minimal one-way model taking into account only the Stokes drag. The Stokes number is defined as $St = \tau_p/\tau_\eta$ with τ_η the Kolmogorov time scale and $\tau_p = \frac{a^2(\rho_f+2\rho_p)}{9\nu\rho_f}$ with a the particle radius and ρ_f and ρ_p the fluid and particle densities. Eleven values of St are used from $St = 0$ to $St = 4.1$. For each case, 128000 particles are tracked. More details can be found on the web page cited above.

Tracking clusters

Following [4], local concentration is measured around each particle at each time step by using Voronoï tessellations. To each particle is associated a Voronoï cell whose area $\mathcal{V}$ is the inverse of the local concentration in particles. Preferential concentration is characterized as $\sigma_\mathcal{V}$ the second order moment of Voronoï area Probability Density Function (PDF). Clusters are defined as connected components of particles whose local area is below a given threshold as in [3].

RESULTS

Preferential concentration and clusters

The Voronoï area PDF are calculated for each St and found to be log-normal. Their second order moment $\sigma_\mathcal{V}$ is higher than the one expected for uniformly distributed sets of particles meaning that preferential concentration is always present. $\sigma_\mathcal{V}$ reaches a maximum for $St \simeq 1-2$ which confirms the very classical observation that preferential concentration is maximal for Stokes numbers around unity.
Clusters can be identified at any non vanishing Stokes numbers. At each time step, several clusters are present in the simulation. We characterize their size and geometrical features.

Dynamical results

Each computed quantities (related to preferential concentration or to clusters) is dynamically followed along the simulation in a Lagrangian frame, particularly the local concentration around each particle as shown on fig. 1-left for three particles. We can see that the local concentration has an intermittent behavior exhibiting violent fluctuations. This intermittency is characterized by computing Lagrangian statistics associated to preferential concentration and to clustering. These statistics are also used to get information on the dynamics of clusters. For example, we are able to compute statistics of the time spent in clusters as well as in depleted regions and to exhibit their dependence on Stokes number. It appears

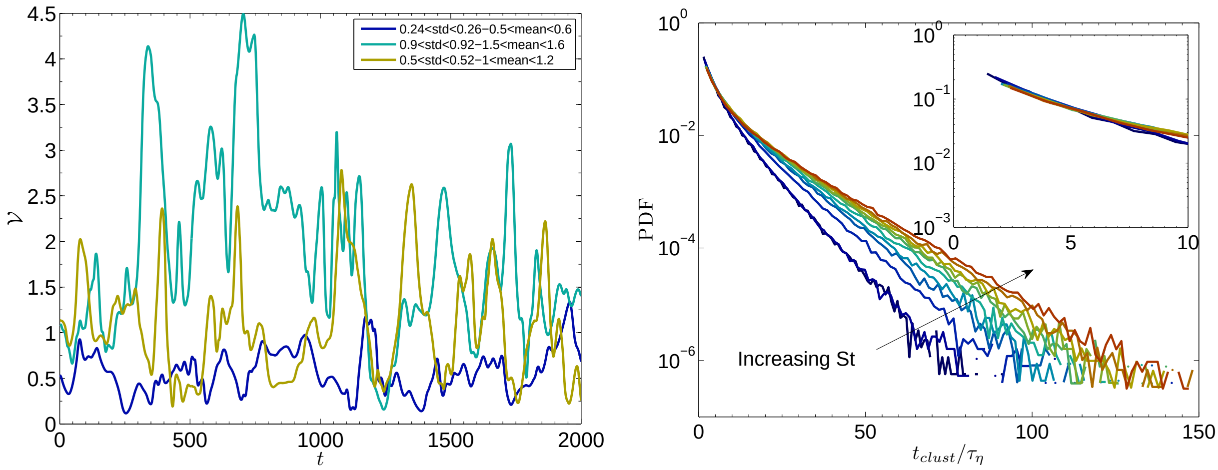

Figure 1. Left: trajectories in a Lagrangian frame of $\mathcal{V}$ for three particles at $St = 0.31$. Right: Probability Density Function of the time particle spend in clusters for various St, inset: zoom of at low t_{clust}/τ_η.

that these time distributions have large exponential tails allowing the definition of characteristic time-scales driven by St as shown on fig. 1-right. Our results are compared to the related work of Meneguz et *al.* [2].

CONCLUSION

Using DNS data we have studied the dynamical properties of heavy inertial particles in a homogeneous turbulent flow at $R_\lambda = 180$. We have mostly focused our study on preferential concentration and clustering and we have shown that the associated dynamics are intermittent with intense fluctuations. The clusters dynamics exhibits characteristic time scales whose dependence on St has been studied. A further step would be to extend our study to different R_λ and to cases including gravity effect who are more relevant for practical applications.

References

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