Geophysical Research Abstracts
Vol. 17, EGU2015-170, 2015
EGU General Assembly 2015

Effect of gravity on clustering patterns and inertial particle attractors

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In this contribution we study the clustering of inertial particles using a periodic kinematic simulation. The systematic Lagrangian tracking of particles makes it possible to identify the particles' clustering patterns for different values of particle's inertia and drift velocity. The different cases are characterised by different pairs of Stokes number St and drift parameter γ. For the present study $0 \leq St \leq 1$ and $0 \leq \gamma \leq 2$. The main focus is to identify and then quantify the clustering attractor - when it exists - that is the set of points in the physical space where the particles settle when time goes to infinity. Depending on gravity or drift effect and inertia values, the Lagrangian attractor can have different dimensions varying from the initial three-dimensional space to two-dimensional layers and one-dimensional attractors that can be shifted from an horizontal to a vertical position.

1 Introduction

Clustering could be defined as the propensity of an initially uniformly distributed cloud of particles to accumulate in some regions of the physical space. This is an important phenomenon to understand in order to explore, identify and possibly monitor some natural or hand-made mixing processes such as those causing rain formation sediments transportation, fuel mixing and combustion. In the present study in order to observe their clustering pattern, the particles are initially uniformly distributed in the flow and then their positions monitored as a function of time. In some cases a Lagrangian attractor is observed. That is the initially homogeneously distributed cloud of particles will end in a set of loci that does not evolve anymore with time. (But of course the particles are moving within that set.) It is the structure of that Lagrangian attractor and its dependency on St and γ numbers that is studied here. The main focus of this study is to evaluate the dimension of these attractors in a synthetic stationary field and to quantify them. This is done by using a nearest-neighbour distance analysis.

2 Numerical method

The underlying Eulerian velocity field is generated as a sum of random incompressible Fourier modes with a prescribed energy spectrum $E(k)$. With this method, the computational task reduces to the calculation of the trajectory of each particle placed in the turbulent field initially at $\mathbf{X}_0$. Unlike the classical KS decomposition [2] here the wavevectors $\mathbf{k_{ijl}} = (k_i, k_j, k_l)$ are implemented arithmetically to enforce a periodic condition for the flow field. $N_p = 25^3$ particles are initially homogeneously distributed, whenever a particles leaves the turbulence box domain (e.g. $\mathbf{X}_i > L_x$) it is then re-injected on the opposite side.

Following [1] the equation of motion for the inertial particle is derived from [3-4] and consists in a drag force and drift acceleration (weight):

$$\frac{dV}{dt} = \frac{1}{\tau_a} \left(u(x_p(t), t) - V(t) + V_d \right) \tag{1}$$

Three dimensionless parameters are introduced to make qualitative and quantitative analyses of the particles clustering. The Stokes number $St = \tau_a / \mathcal{T} = \tau_a u_{rms} / \mathcal{L}$, the Drift parameter $\gamma = V_d / u_{rms} = \tau_a g / u_{rms}$ and the Froude number $Fr = u_{rms} / \sqrt{g\mathcal{L}}$

3 Results and Discussion

The particles initially uniformly distributed in the flow field are allowed to evolve until an asymptotic clustering pattern - also referred to as Lagrangian attractor - is achieved.

The shape of this cluster varies from clear one-dimensional structures to three-dimension distributed structures or two-dimensional layer-like structures.

Three different cases as shown in Table [1] are considered with small increments in the Stokes number in the range [0-1].

Table 1: Different cases for studying the attractor topology for different range of Fr.

Case	Fr	St Range	Observed Patterns			
			1D-H	1D-V	2D-L	3D
E	1.01	0-1	✓	✓		✓
F	0.717	0-1		✓	✓	✓
G	0.548	0-1		✓	✓	

Cases of constant Froude number are easy to follow on, they correspond to the vertical rows e,f,g,h. For a given value of Fr, the intensity of clustering depends on the Stokes number. As St increases, the particles' one-dimensional clustering is first enhanced and then destroyed to eventually reappear in the form of a two-dimensional layer (2D-L) clustering.

For high values of Fr (low gravity), case E , particles settled on horizontal one-dimensional structures (1D-H) for low values of St but higher St values result into vertical one-dimensional structures (1D-V). For the mid range values of Fr, case F, the clear one-dimensional horizontal structure (1D-H) is no more observed, instead some intermediate (1D-HV) one-dimensional structures can be seen for low St values which converge into a layered curtain-like (2D-L) structure as St is increased. Finally, low values of Fr allow the particles to accumulate predominantly in the direction of gravity, so vertical patterns are identified such as 1D-V and 2D-L structures.

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