LAGRANGIAN STATISTICS OF PARTICLES IN ROTATING TURBULENT CONVECTION

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Abstract The effect of background rotation on the dispersion of (inertial) particles in confined forced rotating turbulence and in turbulent rotating convection has been studied and compared where possible. We choose the coordinate system such that both the rotation vector and gravity is parallel to the vertical axis. With 3D Particle Tracking Velocimetry experiments we have quantified statistically the effect of system rotation on the PDFs and autocorrelations of velocities and accelerations of (passive) fluid particles in rotating turbulence. Subsequently we have extended this study by exploring the effect of system rotation and buoyancy on the dispersion of passive and inertial particles in rotating thermally driven turbulence between two horizontal flat plates. The PDFs of horizontal and vertical accelerations of passive particles in turbulent rotating convection show similar behaviour as found in the laboratory experiments in isothermal forced rotating turbulence. When the particles have inertia it is observed that the particles tend to collect in anticyclonic regions of the flow eventually resulting in depletion of particles in the bulk of the flow (and accumulating near the top and bottom wall).

INTRODUCTION

The effect of background rotation on the dynamics of fluid flows is ubiquitous in large-scale geophysical and astrophysical flows, as well as in the context of industrial rotating machinery. In many of these examples also buoyancy may play a crucial role. In this contribution we will discuss and compare Lagrangian data sets measured in (isothermal) forced rotating turbulence experiments and obtained by DNS of turbulent rotating convection.

ROTATING TURBULENCE

It is well-known that the Coriolis acceleration term in the Navier-Stokes equations is responsible for altering the flow dynamics including anisotropisation of turbulent flows: 3D turbulent flows subject to fast background rotation evolves towards a quasi-2D state, which is characterised by a strong damping of velocity gradient components along the direction parallel to the rotation axis (and formation of vortex tubes parallel to the rotation axis). Based on Lagrangian measurements by 3D Particle Tracking Velocimetry of the velocity and acceleration of tiny solid particles embedded in the rotating fluid, we have been able to quantify statistically the effect of system rotation on the PDFs and autocorrelations of fluid particle velocity and acceleration in rotating turbulence for a range of dimensionless inverse rotation rates (denoted by the Rossby number, defined as $Ro=U/(2\Omega L)$, with U and L the typical velocity and length scale in the turbulent flow and Ω the rotation rate). The Rossby number will be as small as 0.05 for the rapid rotation case [1,2]. Typical results will be discussed and in particular the behaviour of the acceleration PDFs, see Figure 1.

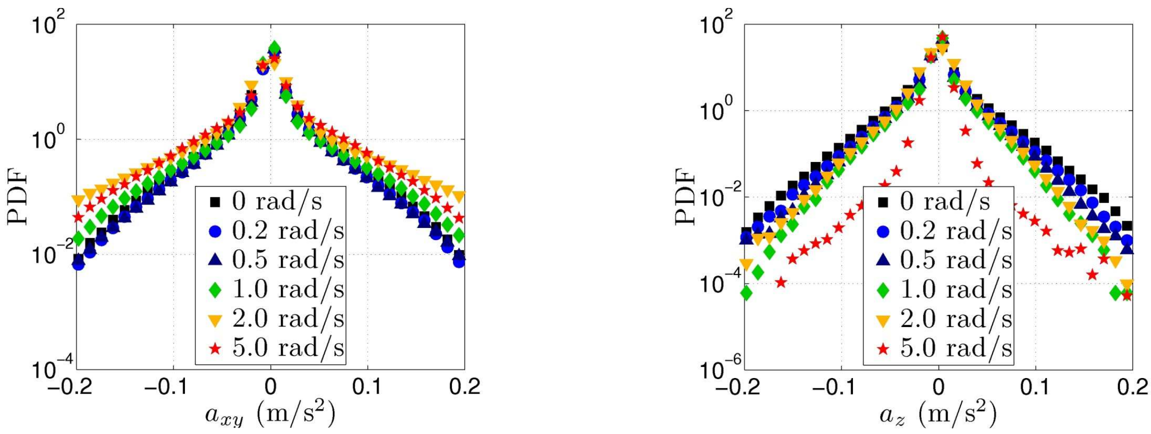
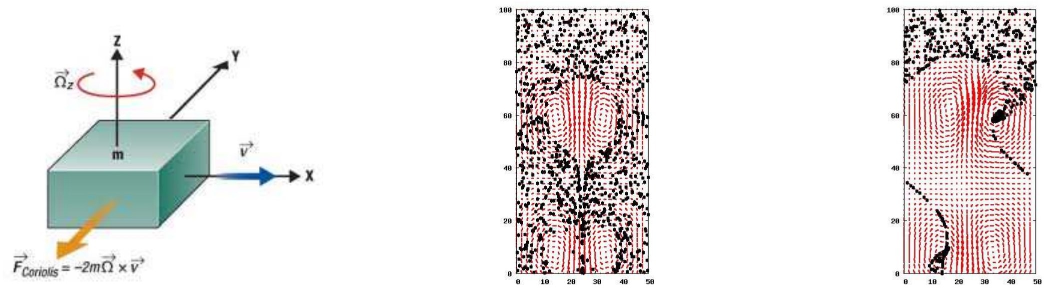


Figure 1. Horizontal (left) and vertical (right) acceleration PDFs of passive tracers from experiments in forced rotating turbulence for a variety of rotation rates. The PDFs are based on 8×10^6 (horizontal velocity) and 4×10^6 (vertical velocity) data points. Hardly any skewness is observed for all rotation rates. The kurtosis K is generally large (K>10) except for the highest rotation rate.

ROTATING THERMAL CONVECTION

Particle dispersion in buoyancy-driven rotating turbulence has been studied by DNS. We have used here a Lattice Boltzmann Method coupled with Lagrangian particle tracking algorithm [3] to investigate the behaviour of (inertial) particles released in turbulent rotating Rayleigh-Bénard (RB) convection. The flow domain is horizontally periodic and vertically confined. Both gravity and rotation are oriented in the vertical direction. Here we present the results of the acceleration PDFs of particles in both non-rotating and strongly rotating RB convection (for Ro=0.25). It is found that the bulk acceleration PDF in non-rotating RB turbulence is like in homogeneous isotropic turbulence whereas rotation introduces anisotropy similar to the acceleration PDFs obtained from experiments in (isothermal) forced rotating turbulence [2]. We will discuss these PDFs and dispersion results for passive fluid elements and those obtained for inertial particles in rotating convection.

When inertia starts to become important the Coriolis force should be included in the equations of motion of the particles according to the sketch in Figure 2. The Coriolis force introduces an additional compressibility mechanism for the particle velocities. It turns out that for Stokes number around unity, reflecting that particle relaxation time and typical flow time scale are similar in magnitude, inertial particles are depleted from cyclonic regions and accumulate in anti-cyclonic areas. This phenomenon is nicely illustrated in the middle and right panels of Figure 2. The consequences of the effect of the Coriolis force for inertial particles in rotating turbulent convection is shown in Figure 3.



a) b) c)

Figure 2. Numerical simulations of inertial particles with Stokes number of order unity in shallow fluid layers. b) Without rotation particles are swept out of the vortical structures, and c) with system rotation particles prefer anticyclonic regions.

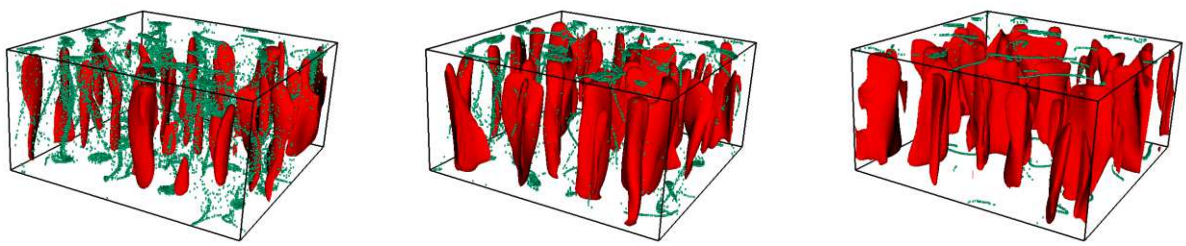


Figure 3. Representative plot of the heavy particle distribution at the initial time and at later times from numerical simulations in rotating Rayleigh-Bénard convection (Ro=0.25). The presence of the Coriolis force leads to enhanced ejection of particles from regions of cyclonic vorticity but accumulation in the region of anticyclonic vorticity. These particles are then transported towards the top and bottom walls by the vertical velocity outside the cyclonic vertical vorticity tubes. The pseudo-color plot indicates the presence of vertical vorticity tubes.

References

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