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On Acceleration Statistics in Turbulent Stably Stratified Shear Flows

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Introduction

An understanding of the Lagrangian acceleration properties in turbulent flows is of fundamental importance. Early work by Heisenberg [1] and Yaglom [2] was followed by more recent studies ranging from theoretical investigations (e.g. [3]) to applications such as the modeling of particle dispersion (e.g. [4]). This work is carried out using both experimental (e.g. [5]) as well as computational (e.g. [6, 7]) approaches.

The goal of this work is to investigate the Lagrangian and Eulerian acceleration statistics in turbulent stratified shear flows using direct numerical simulations. In addition, the corresponding Lagrangian and Eulerian time-rate of change statistics for fluctuating density and vorticity are considered. Both the mean shear rate $S = \partial U/\partial y$ and the mean stratification rate $S_\rho = \partial \varrho/\partial y$ are constant. The primary non-dimensional parameter, the Richardson number $Ri = N^2/S^2$ (where N is the Brunt-Väisälä frequency with $N^2 = -g/\varrho_0 S_\rho$), is varied from $Ri = 0$, corresponding to unstratified shear flow, to $Ri = 1$, corresponding to strongly stratified shear flow. The initial values of the Taylor-microscale Reynolds number $Re_\lambda = 56$ and the shear number $SK/\epsilon = 2$ are fixed. Details about the numerical method and the flow evolution can be found in Jacobitz et al. [8].

Turbulent Stably Stratified Shear Flow

The Lagrangian and Eulerian time-rates of change of vorticity are defined as $\boldsymbol{a}_L = \frac{\partial \boldsymbol{\omega}}{\partial t} + \boldsymbol{u} \cdot \nabla \boldsymbol{\omega}$ and $\boldsymbol{a}_E = \frac{\partial \boldsymbol{\omega}}{\partial t}$, respectively. This definition implies the perspective of an observer traveling with a fluid particle and the effects of shear and stratification are considered to be external forces.

Figure 1a shows the pdfs of the Lagrangian time-rate of change $\boldsymbol{a}_L$ of vorticity. The pdfs have a stretched-exponential shape and their variance decreases with increasing Richardson number Ri. A consideration of the terms in the vorticity equation shows that $\boldsymbol{a}_L$ is mainly determined by the vortex tilting and stretching term shown in figure 1c. This differs from the Lagrangian acceleration, which is mainly determined by the pressure gradient term in the Navier-Stokes equation (not shown here).

Figure 1b shows the pdfs of the Eulerian time-rate of change $\boldsymbol{a}_E$ of vorticity. At a given Richardson number Ri, $\boldsymbol{a}_E$ has a larger variance than $\boldsymbol{a}_L$. Again, a stretched-exponential shape is observed and the variance decreases with increasing Ri. Similarly to the Eulerian acceleration and the time-rate of change of fluctuating density (not shown here), $\boldsymbol{a}_E$ is mainly determined by the nonlinear term.

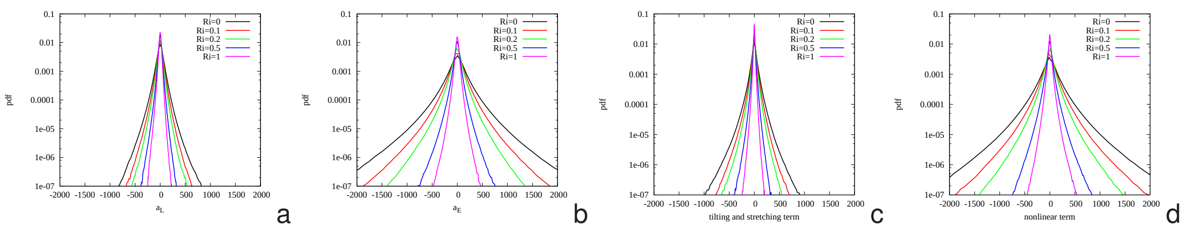

Fig. 1: Pdfs of Lagrangian (a) and Eulerian (b) time-rate of change of vorticity. Pdfs of the tilting and stretching (c) and the nonlinear (d) term in the vorticity equation. All terms are evaluated at $St = 5$.

References

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