Confinement shape influence on scaling of turbulent Rayleigh Bénard convection

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Introduction

Turbulent Rayleigh-Bénard convection (RBC) in a fluid heated from below and cooled from above is one of the challenging problem in nonlinear physics, with many important applications in nature and engineering systems. Experimental, analytical and numerical methods have been employed to investigate several aspects of convection in different geometries. The most well-studied geometry is an upright cylindrical cell; in contrast, flow dynamics and its structure in cubic confinement have been studied much less. Daya and Ecke (2001)[1] first, showed that fluctuations at the center of cylindrical and near cubical convection cells differ considerably regarding the scaling with Ra number. In the present work, we use LES methodology to shed light on physical processes occurring in a cubic cell that could explain the different statistics and scaling of turbulent fluctuations when comparing with cylindrical geometry.

Mathematical model and Results

We perform Large-Eddy Simulations (LES) of turbulent convection in a cubic cell for Ra numbers between 10^6 and 10^{10}. The simulations were carried out using a finite-difference fractional step method and subgrid-scale (SGS) fluxes of momentum and heat were both modeled through a Lagrangian dynamic Smagorinsky model [2]. We apply the no-slip condition on all six walls. The vertical lateral walls are perfectly adiabatic and the top and bottom walls are isothermal with a fixed density (temperature) difference.

Flow structure: Figure 1(a) illustrates the time average streamlines for $Ra = 10^6$. The flow exhibits a "mean wind"(LSC) moving along one diagonal with two small recirculation regions in the opposite corners, the latter is not observed in cylindrical cells due to its rotational symmetry. Our results also show inhomogeneity of local heat flux on the top and bottom plates that depend on the LSC direction. Scaling of the root-mean-square fluctuations of density and velocity measured at the cell centre are in excellent agreement with the scaling measured by [1] (Fig.1(b,c)) for nearly cubic cell. We also observed that the time averaged spatial distributions of density fluctuations are strongly inhomogeneous in the horizontal mid plane with the largest density gradients occurring at the corners where hot and cold plums mix in the form of strong counter-rotating eddies [3].

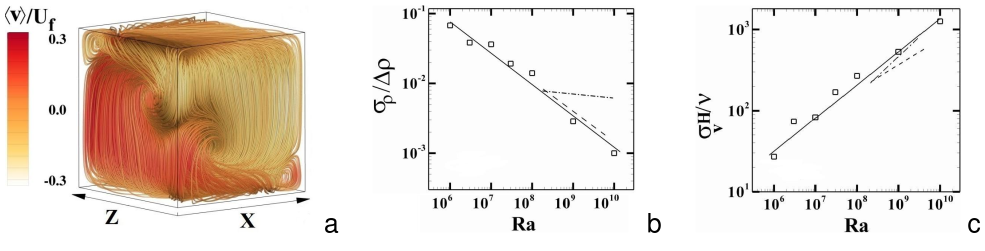

Fig. 1: (a) streamlines within the full convection cell, shows the diagonal orientation of LSC at $Ra = 10^6$, $Pr = 0.7$. Normalized fluctuation in (b) density and (c) vertical velocity of our simulation, dash and dashed dotted lines are power law fits for near cubic cell and cylindrical cells of [1] .

References

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