SUPERSTRUCTURES IN RAYLEIGH-BÉNARD CONVECTION

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Rayleigh-Bénard (RB) convection, the flow in a box heated from below and cooled from above, is one of the paradigmatic systems in fluid dynamics [1, 2, 6] . In addition to the Rayleigh (Ra) and Prandtl (Pr) number, which parameterize the driving strength and fluid properties of the system, the domain aspect ratio $\Gamma = W/L$, i.e. the ratio of the cell width W to cell height L is a crucial parameter that characterizes the geometry of the system. Most Rayleigh-Bénard simulations and experiments at high Ra ($\sim 10^{10}$ and beyond) focus on very tall and thin cells, where the aspect ratio is much lower than one (i.e. $\Gamma \sim 0.2 - 0.5$). This reduces the cost of the simulation or experiment while retaining some of the essential physics especially in the form of global heat transfer properties. However, many natural instances of convection have very large, almost infinite aspect ratios [1, 2, 6].

Here we present a study of the heat transfer and the flow structures that are formed in Rayleigh-Bénard convection in very large aspect ratio cells [3, 7]. We consider three-dimensional direct numerical simulations (DNS) in a laterally periodic geometry [8] with aspect ratios up to $\Gamma = 128$ in the Rayleigh number range $Ra = 10^7 - 10^9$. We find, similarly as in other wall bounded flows such as pipe [5] and channel flow [4], that the large scale flow structures change significantly with increasing aspect ratio due to the formation of superstructures in the large aspect ratio regime. Up to an aspect ratio $\Gamma \approx 8$ we find the formation of one large scale flow structure, see figure 1b. For larger boxes we find the formation of multiple of these extremely large convection rolls, see figure 1a. We illustrate this by movies of horizontal cross-section of the bulk and the boundary layer and analyze them by using spectra in the boundary layer and the bulk. In addition, we study the effect of the large scale flow structures on the mean and higher order temperature and velocity statistics in the boundary layer and the bulk by comparing the simulation results obtained in different aspect ratio boxes.

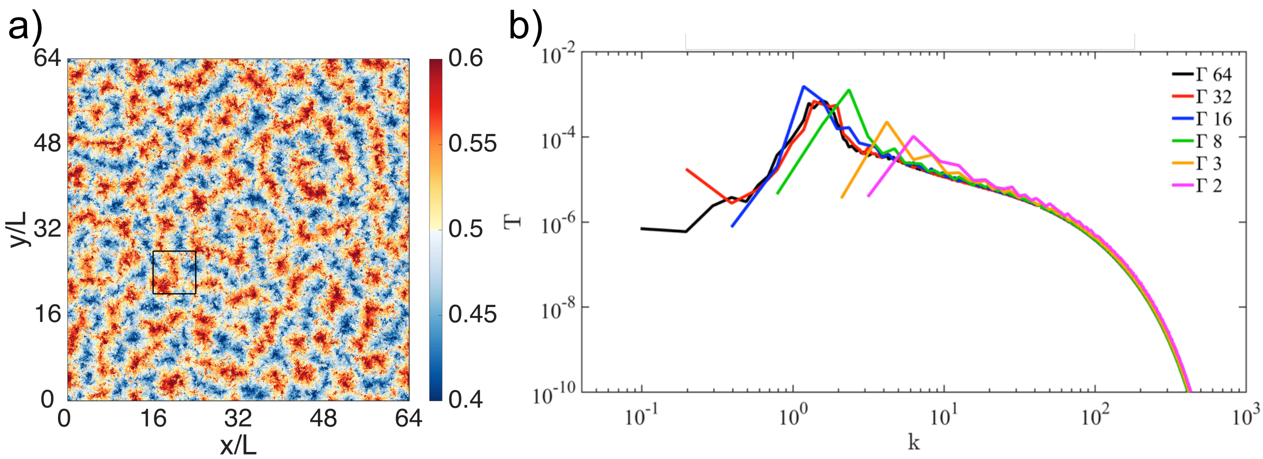

Figure 1. a) Snapshot of the temperature field at mid height for a simulation at $Ra = 10^8$ and $Pr = 1$ in a aspect ratio $\Gamma = 64$ system. b) Temperature spectra in the horizontal mid plane at $Ra = 10^8$ obtained in different aspect ratio cells.

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