
Boundary layer dynamics in 3d Rayleigh-Bénard convection

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Abstract

We study numerically turbulent Rayleigh-Bénard convection in layers of aspect ratio 4:4:1 with periodic side boundaries for Rayleigh numbers Ra between $1e5$ and $1e11$ at Prandtl number $Pr=0.7$. Due to statistical homogeneity in horizontal directions, no sustained global mean flow is observed. Near-wall dynamics is characterized by velocity and temperature fluctuations for all Ra , building a permanently changing patchwork of local shear-dominated flow regions of different orientations interspersed by local shear-free regions for prominent plume ejection. Both types occupy an area fraction that remains approximately constant with Ra (even for different Pr). The boundary layer is organized in a hierarchical bottom-up way; central local building blocks are thermal plumes. They form a self-similar network that gets ever finer with Ra at fixed distance from the wall and coarser with growing wall distance at fixed Ra . The “mesh width“ of this network remains in a nearly fixed ratio with the thermal boundary layer thickness; this ratio is additionally bounded from below by the critical wavelength of the marginally unstable thermal boundary layer segments. Different initial conditions of the system, which were realized by additional sinusoidal shear modes of finite amplitude, relaxed to the same attractor in phase space. This was probed by global transport measures, Reynolds and Nusselt numbers. A steady forcing, which maintains such sinusoidal shear mode, causes logarithmic mean profiles of velocity and temperature, however, the dynamics remains buoyancy-dominated without impact on global transport. This changes only when turbulent mixed convection is generated by a constant pressure gradient. A turbulent boundary layer is then generated with classical logarithmic scaling and enhanced global transport. Our studies underline the non-standard character of the near-wall regions in turbulent Rayleigh-Bénard convection when compared with standard wall-bounded flows.

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