Nusselt-Rossby scaling in high-frequency harmonic modulation of rotating Rayleigh-Bénard convection

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We examine the phenomenon of rotating Rayleigh-Bénard convection with a time-varying rotation rate, referred to as mRRB, which introduces a shaking turbulence effect. By introducing a time-dependent rotation rate in the cylindrical domain, the buoyancy-driven dynamics of Rayleigh-Bénard convection is modified by the effect of rotation and the Euler force resulting from time-dependent rotation. The magnitude of the Euler force depends on the frequency and amplitude of the modulation, and it acts only in the circumferential direction, inducing a global structuring of the otherwise turbulent flow.

We report on Direct Numerical Simulation (DNS) results obtained in a cylindrical domain with height and diameter $H = D = 1$, filled with water and operated at a Rayleigh number $Ra = 10^8$. We investigate the impact of the modulation amplitude $\Delta\Omega$, characterized by a Rossby number $Ro^* \sim 1/\Delta\Omega$, at two modulation frequencies ω, characterized by a separate Rossby number $Ro_\omega \sim 1/\omega$. Our findings (figure 1) show a remarkable increase in the Nusselt number Nu compared to the non-rotating case, which is largely independent of Ro_ω and reaches an asymptotic regime where $Nu \sim (Ro^*)^{0.5}$.

The observed enhancement in heat transfer is attributed to efficient mixing at the top and bottom plates of the cylinder and a significant temperature gradient near the sidewalls at half height. The flow is dominated by the formation of a prominent pair of stacked toroidal convection rolls that are intimately linked to the efficiency of heat transfer in this regime.

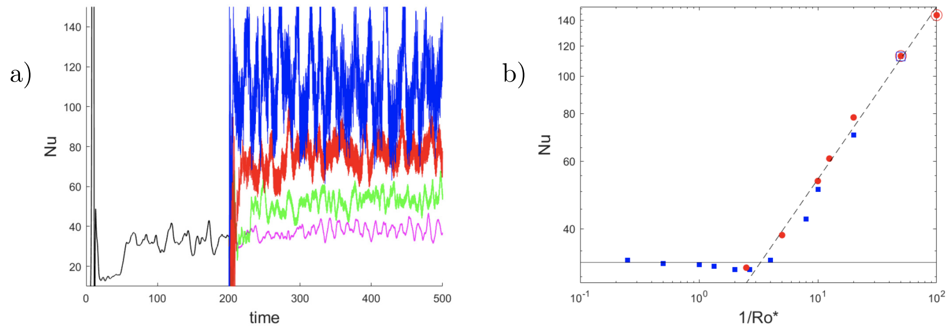

Figure 1: (a) Time signals of the Nusselt number. Modulated rotation is applied from $t = 200$. Black: non-rotational; Magenta: $Ro^* = 0.2$; Green: $Ro^* = 0.1$; Red: $Ro^* = 0.05$; Blue: $Ro^* = 0.02$. (b) Nusselt versus $1/Ro^*$ for $Ro_\omega = 0.2$ (blue squares) and $Ro_\omega = 0.1$ (red circles). Horizontal line: Nusselt number for the non-rotating situation; Dashed line: $Nu \sim (Ro^*)^{0.5}$.

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