Evolution of flow topology with Prandtl number in turbulent Rayleigh-Bénard convection

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A fascinating feature of turbulent Rayleigh-Bénard convection (RBC) is the emergence of well-defined large-scale circulation (LSC). However, at present, there is no unified understanding of how the Prandtl number (Pr) affects the LSC. We conducted an experimental study of the effects of the Pr on the LSC in quasi-two-dimensional turbulent RBC. The experiments were carried out in three rectangular convection cells, with Pr ranging from 7.0 to 244.2 and Rayleigh number (Ra) ranging from 2.03×10^8 to 2.81×10^9. Flow visualization shows that evolutions of the flow topology with Ra are dramatically different in the low Pr and high Pr regimes. Fourier mode analysis of the flow field reveals that the critical Ra (Ra_c), above which the single roll is formed, increases with Pr. We in addition found that Ra_c scales with Pr as $Ra_c \sim Pr^1$, in the three Pr ranges: $4.3 \leq Pr \leq 13.5$, $28.6 \leq Pr \leq 61.7$ and $94.3 \leq Pr \leq 144.3$. We then tilted the convection cell with a small angle to induce the horizontal component of Ra, thus stronger horizontal velocity component is achieved. Surprisingly, we found that with the tilt the flow topology completely changed from side-by-side double-roll to a single roll in the high Pr regime. While in low Pr regime, the flow topology does not change with the tilt, but the strength of the single roll is enhanced. This implies that the flow topology is mainly determined by the relative magnitude of the horizontal and the vertical component of the velocity. Our results also reveal that the increase of Pr suppresses the horizontal component of the velocity thus hinders the transition from side-by-side double-roll to single roll.

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