
Multiple hysteresis loops in a quasi-1-D RBC cell

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Abstract

In this study, we performed a series of extremely long-duration ($O(1e5)$ free-fall time units) numerical simulations of quasi-one-dimensional Rayleigh–Bénard convection with an aspect ratio of $\Gamma = 0.1$. The simulations spanned a narrow Rayleigh number range of $7.9e7 \leq Ra \leq 8.51e7$ at a fixed Prandtl number of $Pr = 4.34$. Three distinct flow states were identified: time-invariant convection, quasi-periodic chaos, and aperiodic intermittency. By conducting ‘quasi-static’ simulations with $Ra(t) = Ra_0 + ct$, where c is the rate of change of Ra , we revealed three evident hysteresis loops that characterize the transitions between different flow states: a ‘normal’ loop between convection and intermittency, an ‘inverse’ loop between intermittency and chaos, and an ‘anomalous’ loop between chaos and convection (with a long-lived metastable intermittent state). The existence of multiple hysteresis loops not only confirmed the memory effects in purely buoyancy-driven flows but also reshaped the understanding of non-equilibrium dynamical systems.

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