Mechanism of Symmetry Restoration in Turbulent Rayleigh-Bénard Convection

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Abstract

In turbulent thermal convection, the single-roll large-scale circulation in a cylindrical geometry is a result of spontaneous symmetry breaking. It was recently discovered that the axisymmetric flow structure can be restored when a minute amount of polymer additives is introduced (1). Although this symmetry restoration is accompanied by an anisotropic suppression of velocity fluctuations, it remains unclear whether such anisotropy is the cause or a consequence of the symmetry restoration. To resolve this question, we perform a series of numerical simulations of Rayleigh–Bénard convection incorporating both isotropic and anisotropic large-scale friction. Counterintuitively, isotropic friction preferentially damps horizontal motions and is able to restore a symmetric flow state, which cannot be found in an anisotropic friction case. These comparative simulations demonstrate that anisotropic suppression is a consequence rather than the cause of symmetry restoration. Additional simulations further show that the restoration cannot be attributed to flow laminarization either. We notice that flow symmetry restoration in turbulent thermal convection requires an orienting mechanism, for which buoyancy serves as a natural candidate. By comparing polymer-laden experimental data with numerical simulations employing large-scale friction, we find a common signature of buoyancy predominance in both systems, manifested by an enhanced and nearly time-symmetric velocity–temperature correlation. As buoyancy becomes predominant, the velocity field is slaved to buoyancy, leading to a buoyancy-aligned flow structure. We conclude that this buoyancy-dominated regime provides a necessary mechanism for restoring flow symmetry in turbulent thermal convection (2).
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(1) F. Xu, X.-S. Liu, X.-M. Li, and K.-Q. Xia, Restoration of axisymmetric flow structure in turbulent thermal convection by polymer additives, Phys. Rev. Lett. 134, 084001 (2025).
(2) G.-Y. Ding, F. Xu, and K.-Q. Xia, (to be submitted).

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