Low-dimensional model of the large-scale circulation of turbulent Rayleigh-Bénard convection with free-slip upper boundary

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Large-scale circulation (LSC) of turbulent convective flow is characterised by complex temporal dynamics and significantly affects the processes of heat and mass transfer. Many studies are devoted to the analysis of LSC in cylindrical cavities, in which its features of formation and various kinds of orientation change are described in detail. Significantly fewer works are devoted to the peculiarities of LSC in cubic cells. This study deals with convective flow in a rectangular cell with an aspect ratio 2:1:1 (horizontally extended) at Rayleigh numbers Ra=1.2 10^8 and Pr=6.1. The lower boundary is no-slip and heating uniformly, and the upper one is free, i.e., a fixed heat flux and free-slip. The lateral boundaries were thermally insulated. Numerical simulations were performed using OpenFoam. As expected, we found a quasi-stable LSC in the vertical plane towards the extended side, but with significant quasiperiodic oscillations in the perpendicular planes (see Fig. 1). Particularly surprising is the appearance of rotation in the horizontal plane. We test the ability of a low-dimensional turbulence model to describe the dynamics of LSC based on structures such as convection rolls.

We apply the proper orthogonal decomposition to the joint velocity and temperature fields of an enriched database that captures the statistical symmetries of the problem. Similar to the results of the paper[1] we found that quasi-stable state consists of a superposition of three types of structures but in our case there are three modes of large-scale 2D-rolls, which form LSC. These modes are sufficient for the model can reproduce the regular evolution of the angular momentum. This model contains nonlinear triad interactions and artificial injection and dissipation forces. The model with six modes simulates LSC, which behaves stochastically as in the turbulent flow.

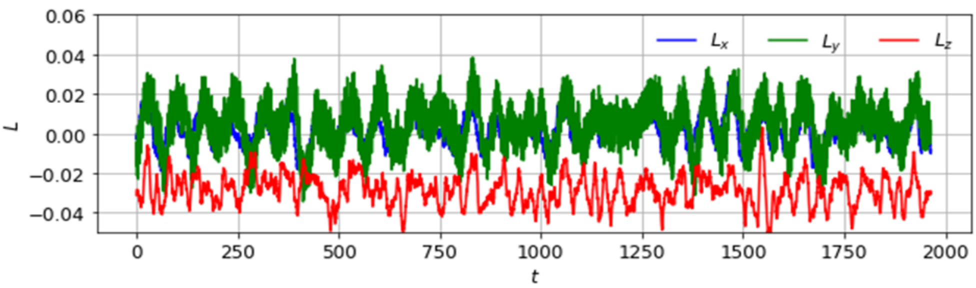

Figure 1: Temporal evolution of the angular momentum components: L_y is the angular momentum of a rotation in the horizontal plane, L_x and L_z – in the vertical planes.

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[1]Soucasse et al., *J. Fluid Mech.* **881**, 23 (2019).