Structure of thermal turbulence confined by moderate aspect ratio box

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Spontaneous flow reversals occur in buoyancy-driven fluid dynamical systems, e.g. the ocean, the atmosphere and the inner core of planets. Behaviors of large scale flow structures in these systems have attracted many interests and a typical example is reversals of geo-magnetic polarity. The most fundamental flow configuration for these systems is the Rayleigh-Bénard convection, convections in a fluid-filled cell heated from below and cooled from above. In this system, flow reversals of large scale flow in thermal turbulence regime are detected and statistically analyzed in the particular case of the two-dimensional (2-D) rectangular geometry with aspect ratio of unity. The occurrence of reversals sensitively depends on the aspect ratio and thus there is great importance to investigate behaviors of the large scale flows in 3-D rectangular geometry with larger aspect ratios.

We performed laboratory experiments of Rayleigh-Bénard convection with a moderate aspect ratio box filled with water. The box has horizontal cross section of 200 ×200 mm^2 and 40 mm in height giving the aspect ratio five. The wall of this box assumes thermal insulation and the boundary conditions are isotropic in the horizontal cross sections. Ultrasonic Velocity Profiling (UVP) was used to visualize the spatiotemporal structure of flows on a measurement line and predicted the 3-D structure of the flows all over the box. We fixed Rayleigh number $Ra = 6.4 \times 10^6$ and Prandtl number $Pr = 5.3$ at which thermal turbulence regime is expected. Fig.1 shows the spatiotemporal velocity map obtained in the measurement, where horizontal and vertical axes indicate time and distance, color represents velocity. We can observe flow keeping its direction over the measurement line and this is regarded as large scale flow in thermal turbulence. Besides there are several smaller scale flows accompanying the large scale flow with the size of about tens of millimeters which repeats appearance and disappearance everywhere on the line. We calculated spatial spectra from the velocity map and flow structures were objectively classified as large or small scale structures. Wavelength of the large one is the same with length of the box and that for the small ones corresponds to tens of millimeters we expected. This result agrees with past studies of numerical simulations. We also identified these 3-D structures by making instantaneous path line images at the same aspect ratio box with the grass cover. Fig.2 shows an example of path line images and some convective cells and rolls with the size of about tens of millimeters are identified. In addition, calculating power spectra of the velocity map indicates existence of a dominant frequency of the velocity oscillation in the order of 10^{-3} Hz. This oscillation is caused by periodic appearance of thermal plumes in a closed cell or roll that organize themselves both in space and time, and these generate coherent oscillations in thermal turbulence at any finite aspect ratio box. Finally we performed UVP measurement at the same aspect ratio box with the grass cover, where we can expect anisotropic large scale flows by non-uniform side wall thermal conditions. Fig.3 is the spatiotemporal velocity map of this measurement. There are two large scale structures of the flow having opposite flow directions, and corresponding instantaneous path line images tell us corresponding 3-D structures. These flow directions were kept for several thousand seconds and changed suddenly and spontaneously. This change resembles flow reversals in its time scale. There is also dominant velocity oscillation frequency in the same order as the box having uniform horizontal thermal condition at the wall on the power spectra calculated from the velocity map.

Keywords: Natural convection, Thermal turbulence, Large scale flow, Flow reversals

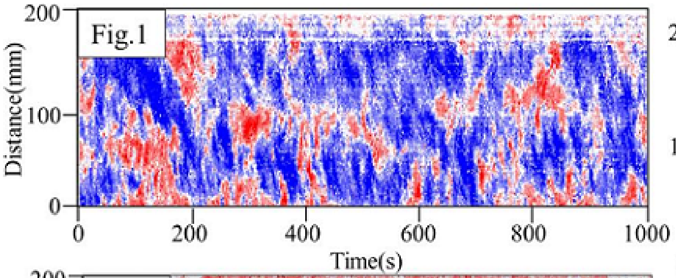
Fig.1

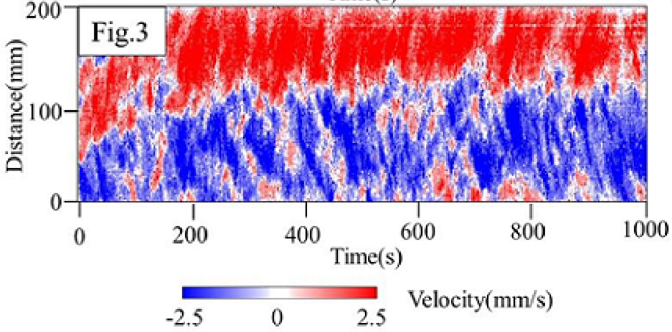
Fig.3

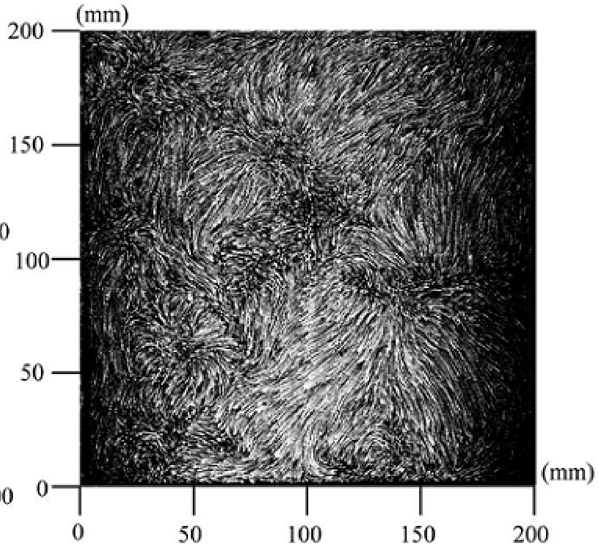

Fig.2