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Experimental study of large-scale circulations in turbulent convection

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We studied experimentally formation of coherent large-scale circulations (semi-organized structures) in turbulent convection in air flow. Semi-organized structures are observed in the atmospheric convective boundary layers (CBLs) and in laboratory experiments and they do not exhibit real similarity with turbulence. Their lifetimes are much larger than the largest time-scales of turbulence. In the atmospheric shear-free convection these structures represent large, three-dimensional, long-lived Benard-type cells (cloud cells) composed of narrow uprising plumes and wide downdraughts. In our experimental study of the semi-organized structures we investigated turbulent convection in a box equipped with two heat exchangers mounted at the top and bottom walls of the chamber. We used Particle Image Velocimetry to determine the turbulent and mean velocity fields, and a specially designed temperature probe with twelve sensitive thermocouples to measure the temperature field and the local convective heat flux. When the aspect ratio of the box (the ratio of the horizontal to the vertical sizes) was equal to 1 we observed one large-scale circulation, and when the aspect ratio of the chamber was equal to 2, we observed two large-scale circulations. These coherent structures are superimposed on a small-scale fully developed turbulent convection. We found that thermal structure inside the large-scale circulation is neither homogeneous nor isotropic. The warm thermal plumes accumulate at one side of the large-scale circulation, and cold plumes accumulate at the opposite side of the large-scale circulation. We also studied the process of destruction of the large-scale circulation by external forcing using a pair of oscillating vertical grids. The large-scale circulation exists when the frequency of the grid oscillations is less that 2 Hz. We demonstrated that the redistribution of the heat flux plays a crucial role in the formation of coherent large-scale circulations in turbulent convection.