Investigation of the turbulent boundary layer in high Rayleigh number convection in air using long PIV sequences

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This contribution reports on near-wall flow field measurements in turbulent Rayleigh-Bénard convection (RBC) in air at a fixed Prandtl number $Pr = 0.7$ and Rayleigh number $Ra = 1.45 \times 10^{10}$. For the experiment the large scale convection (LSC) was confined to a rectangular box of $2.5 \times 2.5 \times 0.65$ m³ made of transparent acrylic sheets (**Fig. 1**). The temperature difference between the bottom and top wall is ΔT=10K.

Prior video-graphic visualizations of the bottom boundary layer flow by means of laser light sheet illumination of small particles indicated the presence of highly dynamic flow behavior at flow conditions that classical stability analysis predicts to still be in the laminar regime (du Puits et al., 2014). While theory predicts a transition to turbulence at Reynolds numbers based on displacement thickness of $Re \approx 420$ the present investigation exhibits highly unsteady flow at a much lower Reynolds number of $Re \approx 200$.

The measurements rely on the acquisition of long, continuous sequences of particle image velocimetry (PIV) data from which both statistical and spectral information can be retrieved. Contrary to conventional implementation of the PIV technique the field of view is restricted to a narrow strip, generally extending in wall-normal direction. In this way both the acquisition frequency and the total number images of the employed high-speed camera are proportionally increased. The narrow field of view coupled with the increased sensitivity of modern high-speed cameras allows the use of continuous wave (CW) lasers whose light is spread into a narrow light sheet. The temporally oversampled data allows the use of multi-frame PIV processing algorithms which reduces measurement uncertainties with respect to standard dual-frame analysis.

Alongside with providing valuable flow statistics the long continuous PIV data additionally gives insight into spatio-temporal interdependencies, allowing, for instance, correlation between inner and outer flow dynamics. Here it is found that the wall shear stress, determined through measurement of the velocity gradient at the wall, is strongly influenced by vertical motions of the outer bulk flow of the large-scale convection.

Both flow visualization as well as the PIV data clearly show the intermittent character of the boundary layer flow field as exhibited in **Fig. 2**. The two contrasting flow states are separated by 1.7 seconds. With the help of the PIV data it can be demonstrated that the entrainment of turbulent structures from the mean wind into the boundary layer acts, alongside with the destabilization due to inner shear, as a second mechanism on its path to turbulence. Both contributions must be considered when predicting the critical bound towards the "ultimate regime" of thermal convection (Kraichnan, 1962).

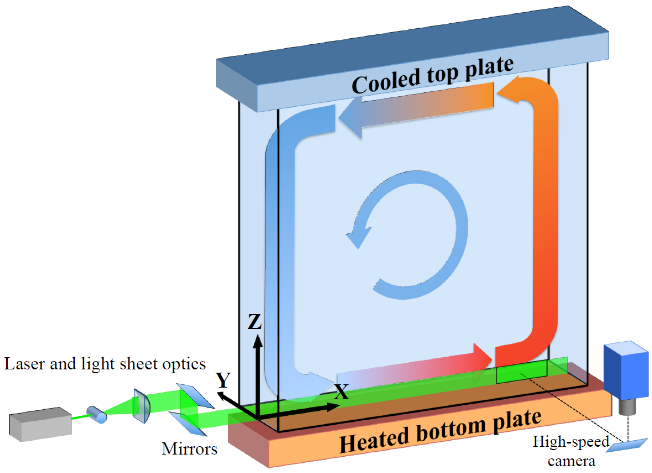

Figure 1: Setup for PIV measurement on the rectangular RB cell. Laser light sheet is aligned with the bottom wall to capture the bottom boundary layer

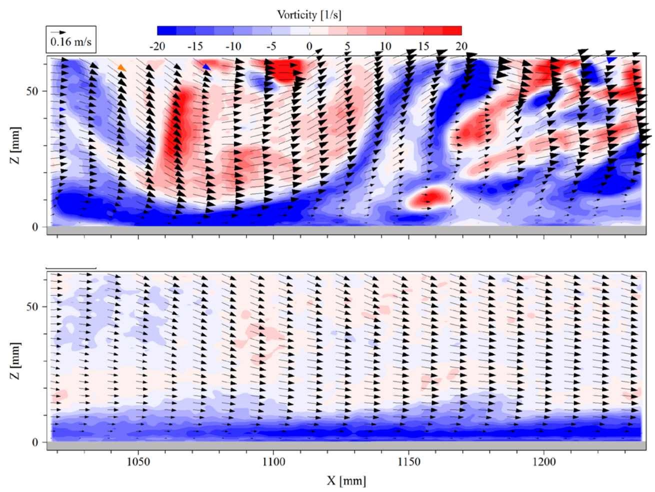

Figure 2: Turbulent flow phase (top) and laminar flow phase (bottom) 1.7 seconds later. Vectors are down-sampled 12× vertically, 3× horizontally. Color-coding reflects the out-of-plane vorticity component ω_y

References

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