FLUCTUATIONS IN RAYLAIGH-BÉNARD CONVECTION

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Abstract The aim of the internship is to simulate Rayleigh-Bénard convection at $Ra \sim 10^7 \div 10^9$ to study the behaviour of the fluctuations. Statistics of temperature, velocity, and heat transport will be in particular investigated. The goal would be to find out a scaling law for the heat transport near the wall.

General Purpose. The statistical properties of temporal fluctuations of "global quantities", i.e. spatially averaged, are of interest in various fields including turbulence, granular media, phase transitions, etc. For example, the fluctuations of the injected power necessary to drive a turbulent flow, the injected or dissipated power in a granular gas excited by vibrating a piston, the current in the asymmetric exclusion process, the magnetization in a XY model, the mean velocity in growth processes, have been studied recently. Furthermore, understanding fluid motion and heat transport in turbulent thermal convection is crucial for progress in industrial, geophysical and environmental applications. While a large proportion of previous studies on turbulent thermal convection (Rayleigh-Bénard) focuses on the estimate of average heat transfer, very few studies are devoted to fluctuations. We want to investigate the temporal fluctuations of heat flux at the wall and possibly to validate a scaling law proposed after experimental measurements[1].

To this aim, we will perform Direct Numerical Simulations (DNS)[2] of Rayleigh-Bénard convection in a flow configuration close to that of the experiments. Our numerical simulations provide combined data of velocity, temperature, and heat transport dynamics which can be used as reference/benchmark data to tune and explain experimental results. In particular, the scaling of the skewness will be investigated.

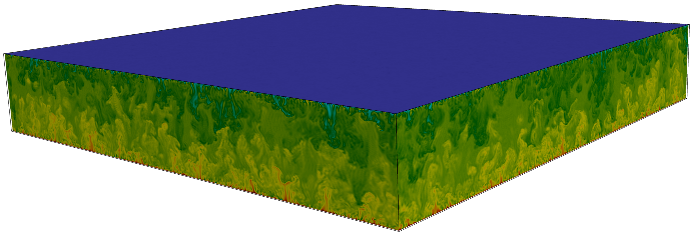

Figure 1. Temperature distribution for $Ra = 10^9$. Red indicates regions of high temperature, whereas blue indicates regions of low temperature.

Theoretical model We consider an incompressible and Newtonian turbulent flow of water confined between two rigid boundaries. The bottom wall is kept at uniform high temperature (θ_h), whereas the top wall is kept at uniform low temperature (θ_c). Mass, momentum and energy equations in dimensionless form and under the Boussinesq approximation are:

$$\nabla \cdot \mathbf{u} = 0, \tag{1}$$

$$\frac{\partial \mathbf{u}}{\partial t} + (\mathbf{u} \cdot \nabla)\mathbf{u} = -\nabla p + 4\sqrt{\frac{Pr}{Ra}}\nabla^2 \mathbf{u} - \delta_{i,3}\theta, \tag{2}$$

$$\frac{\partial \theta}{\partial t} + (\mathbf{u} \cdot \nabla)\theta = +\frac{4}{\sqrt{PrRa}}\nabla^2 \theta, \tag{3}$$

where u_i is the i^{th} component of the velocity vector, θ is temperature, p is pressure, $\delta_{1,3}\theta$ is the buoyancy force (acting in the vertical direction only) that drives the flow. Eqs. (1)-(3) have been obtained using $L_{ref} = h$ as reference length, $u_{ref} = \sqrt{g\beta\Delta\theta/2h}$ as reference velocity, $\theta_{ref} = \Delta\theta/2$ as reference temperature and $p = \rho g\beta\Delta\theta/2h$ as reference pressure. Density ρ, kinematic viscosity ν, thermal diffusivity k and thermal expansion coefficient β are evaluated at the mean fluid temperature $\theta_m = 29^o C$. Two dimensionless numbers appear in Eqs. 1-3: the Prandtl number $Pr = \nu/k$ and the Rayleigh number $Ra = (g\beta\Delta\theta(2h)^3)/(\nu k)$.

References

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