DY 5: Convection

Time: Monday 10:00–12:45 Location: H3

Invited Talk DY 5.1 Mon 10:00 H3

Direct numerical simulations towards ultimate turbulence — •Richard Stevens[1], Roberto Verzicco[2], and Detlef Lohse[1,3] — [1]Physics of Fluids, University of Twente, Enshede, The Netherlands — [2]University of Rome Tor Vergata, Roma, Italy — [3]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

Both in experiments and simulations of Rayleigh-Bénard (RB) convection it is a major challenge to reach the ultimate regime in which the boundary layers transition from laminar to turbulent. In the ultimate regime the scaling exponent γ in the relation $Nu \sim Ra^{\gamma}$, where Nusselt Nu is the dimensionless heat transport and Rayleigh Ra is the dimensionless temperature difference between the plates, increases. The critical Rayleigh number (Ra^*) for the transition to the ultimate regime has been observed in the Göttingen experiments around $Ra^* \approx 2\times10^{14}$. So far, the highest Ra obtained in direct numerical simulations (DNS) is $Ra = 2 \times 10^{12}$ for aspect ratio $\Gamma = 0.5$ (Stevens, Lohse, Verzicco, JFM 688, 31 (2011)). Here we present a comparison between the Göttingen experiments and DNS up to $Ra = 10^{13}$. We find perfect agreement between experiments and simulations, both for the heat transfer and for the mean and temperature variance profiles close to the sidewall. In addition, we discuss simulations for $\Gamma = 0.23$ up to $Ra = 10^{14}$, which agree well with measurements by Roche et al., NJP 12, 085014 (2010). In addition, we discuss the influence of the aspect ratio on the heat transfer and flow structures in high Rayleigh number convection.

DY 5.2 Mon 10:30 H3

Boundary layers and scaling relations in natural thermal convection — •Olga Shishkina — Max Planck Institute for Dynamics and Self-Organization, Am Fassberg 17, 37077 Göttingen, Germany

Classical setups to study natural thermal convection are vertical convection (VC), where the fluid is confined between two differently heated vertical walls, horizontal convection (HC), where the fluid is heated at one part of the bottom plate and cooled at some other part, and Rayleigh-Benard convection (RBC). Here we consider the boundary-layer (BL) equations in natural thermal convection and derive for some flow configurations the mean flow characteristics and the scaling relations of the Nusselt and Reynolds numbers (Nu, Re) with the Rayleigh and Prandtl numbers (Ra, Pr). For VC the scaling relations are obtained directly from the BL equations (Shishkina, Phys. Rev. E 93 (2016)), while for HC they are derived by extending the Grossmann-Lohse theory for RBC (J. Fluid Mech. 407 (2000)) to the case of VC (Shishkina, Grossmann, Lohse, Geophys. Res. Lett. 43 (2016)).

The work is supported by the Deutsche Forschungsgemeinschaft (DFG) under the grant Sh 405/4 - Heisenberg fellowship.

DY 5.3 Mon 10:45 H3

Experimental analysis of superstructures in large-aspect-ratio Rayleigh Bénard convection — Christian Kästner, •Christian Resagk, and Jörg Schumacher — Institute of Thermodynamics and Fluid Mechanics, TU Ilmenau, Ilmenau

We report about measurement and analysis of horizontal velocity fields in a square Rayleigh-Bénard convection cell at an aspect ratio Gamma = 10 with compressed air and sulfur hexafluoride as working fluid. 2D3C horizontal cuts through the convective flow were obtained from stereoscopic particle image velocimetry (SPIV) measurements. Optical access for laser light sheet and PIV cameras was provided by transparent side-walls and a transparent heating plate. The application of a transparent heating plate, a glass plate coated with a transparent and electrically conductive metal oxide (TCO), allowed first time experimental observation of horizontal velocity fields in turbulent thermal convection at large aspect ratio. The horizontal cuts were taken in mid-plane of the convection cell and below the cooling plate at a Rayleigh number ranging from Ra = 10^4 - 10^7. Spatial and transient analysis of the velocity fields revealed superstructures, steadily increasing in size with increasing Rayleigh number. Hence the present experimental approach and results provide further insights into large-scale coherent flow pattern formation in turbulent thermal convection.

DY 5.4 Mon 11:00 H3

Resolved energy budget of superstructures in Rayleigh-Bénard convection — •Gerrit Green[1,2], Dimitar Vlaykov[1,3], Juan-Pedro Mellado[4], and Michael Wilczek[1] — [1]Max-Planck-Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Faculty of Physics, University of Göttingen, Germany — [3]University of Exeter, Exeter, England — [4]Max-Planck-Institute for Meteorology, Hamburg, Germany

The dynamics of turbulent Rayleigh-Bénard convection exhibits a complex interaction between coherent large-scale flow patterns, so-called superstructures, and small-scale fluctuations. In this contribution we employ direct numerical simulations to investigate the interaction between scales and clarify the impact of turbulence on large-scale patterns. A filtering approach is used to separate the superstructures and turbulent fluctuations. It complements spectral analysis techniques by retaining physical space information. This allows us to study the energy budget at the scale of superstructures and to characterize the different contributions, such as the power input due to buoyancy, the direct dissipation and the energy transfer between scales. We find that the energy transfer in the bulk differs significantly from the one close to the walls. In the bulk, most of the energy input in the superstructures is balanced by the energy transfer between scales, which acts primarily as a dissipation for the large scales. Close to the wall, there is a layer in which the energy transfer is up-scale, driving the superstructures. Our investigations therefore provide insights which will help to derive an effective description of turbulent superstructures.

DY 5.5 Mon 11:15 H3

The evolution of the large-scale flow in magnetoconvection — •Till Zürner[1], Felix Schindler[2], Tobias Vogt[2], Sven Eckert[2], and Jörg Schumacher[1] — [1]Institute of Thermodynamics and Fluid Mechanics, Technische Universität Ilmenau, Postfach 100565, 98684 Ilmenau — [2]Department Magnetohydrodynamics, Institute of Fluid Dynamics, Helmholtz-Zentrum Dresden-Rossendorf, Bautzner Landstraße 400, 01328 Dresden, Germany

We investigate the effect of a vertical magnetic field on the flow properties of turbulent Rayleigh-Bénard convection. The large-scale flow of a low-Prandtl number liquid metal alloy in a cylindrical convection cell of aspect ratio 1 is reconstructed by a combination of temperature and direct velocity measurements, using ultrasound Doppler velocimetry (UDV). In accordance to theory and simulations the flow strength is reduced by the induced Lorentz forces. With increasing magnetic field strength a transition from the turbulent one-roll large-scale circulation to a weakly non-linear cell-like structure is observed. Increasing the field strength even further finally supresses the flow in the centre of the cell almost completely. However, even at such high fields significant flows can still be observed near the side walls of the cell, far above the critical Hartmann number of the Chandrasekhar limit for the onset of magnetoconvection for a fluid layer without lateral boundaries. This destabilising effect of non-conducting side walls was predicted by theory and simulations, and is here confirmed by experiments for the first time.

292,314,312,321

DY 5.6 Mon 11:45 H3

Rotating turbulent Rayleigh-Bénard convection at very large Rayleigh numbers — •Marcel Wedi[1], Dennis van Gils[2], Stephan Weiss[1], and Eberhard Bodenschatz[1] — [1]Max-Planck-Institut for Dynamics and Self-Organization, Göttingen, Germany — [2]Twente University, The Netherlands

Thermal convection in astro- and geophysical systems is both, highly turbulent and strongly influenced by Coriolis forces caused by the rotation of their celestial body. We aim to study the influence of rotation on the heat transport and the temperature field at very large thermal driving in the High Pressure Convection Facility (HPCF) in Göttingen. The facility consists of a cylindrical cell with a diameter of 1.10 m and a height of 2.20 m that can be filled with pressurized sulfur hexafluoride (SF_6) or Helium at up to 19 bar. The height of the cell and the large density of SF_6 enables us to reach large thermal drivings with Rayleigh numbers up to 2×10^{15}. The cell is mounted on a rotating table and connected to the non-rotating world via water feed-throughs and slip rings. We reach Ekman numbers down to 10^{-8}, possibly entering the geostrophic regime. At very high rotation rates the Froude number increases and centrifugal forces may not be negligable. The effects of rotation and applied temperature settings are looked at in the temperature field. In our talk, we discuss these effects and the behavior of the flow field as well as the heat transport.

DY 5.7 Mon 12:00 H3

Non-Oberbeck-Boussinesq effects and flow structures in Rotating Rayleigh–Bénard convection in pressurized SF_6 — •Xuan Zhang and Olga Shishkina — Max Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, 37077 Göttingen

Rotating Rayleigh–Bénard convection (RBC) in pressurized sulfur hexafluoride (SF_6) in a cylindrical cell of the diameter-to-height aspect ratio 1/2 is studied using our finite-volume code Goldfish. The results based on direct numerical simulations (DNS) at Prandtl number 0.8, Rayleigh number 10^8 to 10^{10} and Rossby number 0.02 to 50 are presented. Non-Oberbeck-Boussinesq effects are studied by considering temperature dependence of the fluid properties, and the results are compared to those under Oberbeck-Boussinesq approximation. Effects of rotation on the flow structures are investigated in terms of the global heat transfer, dynamics of large-scale circulation, long-term bulk temperature statistics and local historical temperature signals.

Funding Acknowledgment: The work is supported by the German Research Foundation under the grant SH405/8 and Heisenberg fellowship SH405/4. We acknowledge the Leibniz Supercomputing Centre (LRZ) for providing computing resources on SuperMUC.

DY 5.8 Mon 12:15 H3

Inclined thermal convection in liquid metals — •Lukas Zwirner and Olga Shishkina — Max Planck Institute for Dynamics and Self-Organization, Am Faßberg 17, 37077 Göttingen

Any tilt of a Rayleigh-Benard convection (RBC) cell against gravity changes the global flow structure inside the cell. Recent experiments by Vasil'ev et al. (2015, Tech. Phys. 60) and Frick et al. (2015, Europhys. Lett. 109) with liquid sodium (Prandtl number Pr<<1) demonstrated that the heat transport in low-Prandtl number fluids is especially sensitive to the inclination angle. Our study is based on direct numerical simulations of inclined convection in a cylindrical cell of diameter-to-height aspect ratios 1 and 1/5 and we consider Prandtl numbers down to Pr=0.0083. We demonstrate that the global flow structure like the large scale circulation is influenced by both the inclination angle and the lateral confinement of the cell. For inclined convection we observe the formation of two system-sized plume columns, a hot and a cold one, that impinge on the opposite boundary layers (Zwirner and Shishkina, 2018, J. Fluid Mech. 850). In RBC the confined cell supports the formation of multiple rolls on top of each other.

The work is supported by the German Research Foundation under the grant SH405/7 and Heisenberg fellowship SH405/4. We acknowledge the Leibniz Supercomputing Centre (LRZ) for providing computing resources on SuperMUC.

DY 5.9 Mon 12:30 H3

Heat and momentum transport in symmetric horizontal convection — •Philipp Reiter, Mohammad Emran, and Olga Shishkina — Max Planck Institute for Dynamics and Self-Organization, Am Fassberg 17, 37077 Göttingen, Germany

Horizontal convection (HC) is a paradigm system to study natural turbulent convection, in which heating and cooling is applied solely to one horizontal surface of a fluid layer. This type of convection is relevant in different geophysical and astrophysical systems, e.g., in the meridional-overturning circulation of the oceans. Recent progress in understanding of the scaling relations of the mean heat and momentum transport has been done theoretically (Shishkina et al., Geophys. Res. Lett 43(2016)) and numerically, but further investigations are required.

Here, using an advanced version of the computational code goldfish, we investigate a modified symmetric elongated HC setup, where heat is applied to the central part of the bottom plate and cooling to both ends of the HC cell. Such meridional symmetry bypasses some difficulties that arise in the measurements in the classical configuration and it leads to a more natural setup with less artificial constraints. For the modified and classical HC, we compare global flow structures and their time evolution, as well as the scaling relations, over a wide range of Rayleigh numbers.

This work is supported by the DFG grants Sh405/10 and Sh405/4.