DY 16: Focus: Fundamental aspects of turbulent convection

Thermal convection, i.e. a flow driven by a thermal gradient, is frequently encountered in nature and technological applications. It is a fundamental mechanism to effectively transport heat. Convection flows in nature are usually highly turbulent and as such challenging to measure experimentally, simulate numerically, and model theoretically. In this session we discuss current developments and open questions from different branches of turbulent convection research. Experimentalists, theoreticians and, numericists will come together in order to discuss recent results covering the range from large-scale geo- and astrophysical systems down to laboratory size model systems.

Organized by M. Wilczek, S. Weiss and J. Schumacher

Time: Tuesday 9:30–13:15 Location: ZEU 118

Invited Talk DY 16.1 Tue 9:30 ZEU 118

The Geostrophic Branch of Rotating Convection — •Stephan Stellmach[1], Meredith Plumley[2], Keith Julien[2], and Philippe Marti[2] — [1]Institut für Geophysik, Westfälische Wilhelms-Universität, Münster, Germany — [2]Department of Applied Mathematics, University of Colorado, Boulder, USA

Rotating convective flows are ubiquitous in nature. They generate planetary magnetic fields, cause deep mixing in the Mediterranean Sea and possibly drive the zonal winds observed on Jupiter. Unfortunately, laboratory experiments and direct numerical simulations (DNS) fail to reach a dynamical regime in which the convection is strongly turbulent but still dominated by Coriolis forces on all scales of interest. This so-called geostrophic branch of rotating convection is thought to be relevant in many natural systems. A possible way to explore this regime are simulations based on asymptotically reduced model equations that are expected to hold in the limit of rapid rotation. In this talk, I will discuss the predictive power of these models in detail, with a particular focus on the role of boundary layers, inverse energy cascades and the possibility to numerically simulate flows in parameter regimes beyond what can be reached in laboratory experiments and direct numerical simulations today.

DY 16.2 Tue 10:00 ZEU 118

Turbulent convection in planetary interiors — •Ulrich Hansen and Claudia Stein — Institut für Geophysik, Unii Münster, Correnstrasse 24, 48149 MuensterGermany

The dynamics of planetary mantles is largely governed by convection. The Earth's mantle for example, extends from 100 km to about 3000 km depth and consists mostly of silicate rocks. Phenomena like plate tectonics and hot-spot volcanism are intimately coupled to processes within the boundary layers of the convective system. Due to the high viscosity of the material, mantle convection is characterized by a virtually infinite Prandtl number, i.e. mechanical inertia is unimportant for the flow. At the same time the Rayleigh number is high (Ra > 107) , such that thermal advection dominates by far the transport of heat. Under such conditions numerical experiments reveal typical features of turbulent convection. For constant material properties a large scale flow (l.s.c) typically evolves, stipulated with instabilities of smaller scales. These instabilities develop within the thermal boundary layer of the l.s.c. and their interaction with the large scale wind give rise to chaotic fluctuations. In particular, we observe reversals of the l..s.c. without any external triggering Since the experiments are performed under stress free conditions, also counter-flows can be excluded to trigger the reversals. In planetary interiors non-Boussinesq effects complicate the dynamics, especially the strong dependence of the viscosity on temperature.At large viscosity contrasts a viscous lid self consistently develops, which overlies a region of turbulent convection.

DY 16.3 Tue 10:15 ZEU 118

Stellar convection models with Kramers-type opacity law — •Petri Käpylä — Leibniz-Institut für Astrophysik, Potsdam, Germany — ReSoLVE Centre of Excellence, Department of Computer Science, Aalto University, Finland

We present first results from three-dimensional hydrodynamic simulations of stratified convection in a slab geometry applying a Kramers-type opacity law. We show that in such models the depth of the convection zone is not a priori fixed as the opacity law is sensitive to temperature and density. This is in contrast to the overwhelming majority of models presented in the literature where either a fixed profile of the heat conductivity or the boundary conditions dictate the depth of the convective layer.

Furthermore, we also show that a substantial portion of the mixed layer is stably stratified according to the Schwarzschild criterion. In particular, we find an extended layer where both the enthalpy flux and the vertical gradient of specific entropy are positive which cannot be explained by the usual counter-gradient parametrization. Such weakly sub-adiabatic layers are also potentially crucial for solving some of the current issues in stellar differential rotation and dynamo modeling.

DY 16.4 Tue 10:30 ZEU 118

The effect of a horizontal magnetic field on weakly turbulent Rayleigh-Benard convection — Vogt Tobias[1], Ishimi Wataru[2], Tasaka Yuji[2], Yanagisawa Takatoshi[3], and •Eckert Sven[1] — [1]Helmholtz Zentrum Dresden-Rossendorf (HZDR), Dresden, Germany — [2]Laboratory for Flow Control, Hokkaido University, Sapporo, Japan — [3]Japan Agency for Marine-Earth Science and Technology (JAMSTEC), Yokosuka, Japan

MHD Rayleigh-Bénard convection was studied experimentally using the eutectic metal alloy GaInSn inside a box having a square horizontal cross section and an aspect ratio of length/height = 5/1. Systematic flow measurements were performed by means of ultrasound Doppler velocimetry that can capture time variations of instantaneous velocity profiles. Applying a horizontal magnetic field organizes the convective motion into a flow pattern of quasi-two dimensional rolls arranged parallel to the magnetic field. If the Rayleigh number (Ra) is increased over a certain threshold Ra/Q, whereby Q is the Chandrasekhar number, the convection flow undergoes a transition to turbulence. Besides the primary convection rolls the flow measurements reveal regular flow oscillations arising from 2D and 3D deformations of the rolls, Ekman-pumping induced flow as well as smaller side vortices that develop around the convection rolls. The experiments are accompanied by direct numerical simulations. The comparison between the DNS and the flow measurements shows a very good agreement.

DY 16.5 Tue 10:45 ZEU 118

Numerical studies of turbulent convection in liquid mercury and sodium — •Jörg Schumacher[1] and Janet D. Scheel[2] — [1]TU Ilmenau, Germany — [2]Occidental College Los Angeles, USA

Statistical properties of turbulent Rayleigh-Bénard convection at low Prandtl numbers Pr, which are typical for liquid metals such as mercury or gallium at Pr=0.021 and liquid sodium at Pr=0.005, are investigated in high-resolution, three-dimensional and massively parallel spectral element simulations in a closed cylindrical cell with an aspect ratio of one. These results are compared to previous turbulent convection simulations in air. In detail, we compare the scaling of global momentum and heat transfer with existing experiments or other simulations. Low-Prandtl-number flows are characterized by a significantly enhanced momentum transfer compared to convection in air. Thus we also investigate the dynamics of near-wall structures in the transient velocity boundary layers of this class of convection flows and their connection to critical points of the skin friction field. These findings are related to turbulent boundary layers in channel flows without temperature differences.

DY 16.6 Tue 11:00 ZEU 118

Turbulent heat transport in low-Pr number fluids — •Lukas Zwirner and Olga Shishkina — MPI Dynamik und Selbstorganisation, Göttingen

Turbulent convective heat transport is ubiquitous in nature. Rayleigh-Benard convection (RBC), where a fluid layer is confined between a lower heated plate and an upper cooled plate, is a classical model system to investigate turbulent convective heat transport. With any tilt of a RBC cell against gravity, the global flow structure in the convection cell changes, which leads to a change of the heat transport.

The purpose of the present work is to investigate by means of direct numerical simulations how heat and momentum transport, represented, respectively, by the Nusselt number and Reynolds number, depend on the main input parameters of the convective system. Those are the Rayleigh number Ra, Prandtl number Pr and the inclination angle of the convection cell. Thereby, the focus is set on convective flows in cylindrical containers of a small diameter-to-height aspect ratio Γ, $\Gamma = 1/5$, and $Pr \leq 1$. For each studied combination of Ra, Pr and Γ, an optimal inclination angle of the convection cell, providing maximal heat flux is determined. Furthermore, for the particular case of RBC (with zero inclination angle of the cell), different possible (e.g. single- or double-roll) states of the large scale circulation are studied in detail, including their influence on global heat transport in the system.

15 min. break

Invited Talk DY 16.7 Tue 11:30 ZEU 118

Convection rolls and fingers in double diffusive convection — •Andreas Tilgner — Institute of Geophysics, Göttingen

Double diffusive convection with a stabilizing temperature and a destabilizing salt gradient occurs in large areas in the oceans. Convection is possible even if the net density stratification is stable owing to the very different diffusivities of heat and salt. The typical flow pattern in this case are so called salt fingers. According to some observations, they can organize into layers separated by standard convection rolls. The transport of heat and salt greatly depends on whether fingers form. This contribution will present experiments which used an electrodeposition cell to sustain a destabilizing concentration difference of copper ions in aqueous solution between the top and bottom boundaries of the cell. The resulting convecting motion is analogous to Rayleigh- Bénard convection at high Prandtl numbers if the cell is kept at spatially uniform temperature. However, if a stabilizing temperature gradient is imposed across the cell, double diffusive fingers appear even for thermal buoyancy two orders of magnitude smaller than chemical buoyancy. It is found that the fingers obey several simple scaling laws. The control parameters can also be chosen such that fingers and convection rolls coexist in vertically stacked layers.

DY 16.8 Tue 12:00 ZEU 118

Droplet nucleation in two-phase thermal convection: A laboratory study — •Prasanth Prabhakaran[1], Stephan Weiss[1], Alexei Krekhov[1] und Eberhard Bodenschatz[1,2,3] — [1]Max Planck Institute f. Dynamics and Self-Organisation — [2]Institute f. Nonlinear Dynamics, University Göttingen — [3]Laboratory of Atomic and Solid-State Physics and Sibley School of Mechanical Aerospace Engineering, Cornell University, Ithaca (USA)

We investigate the nucleation and growth of liquid droplets in a Rayleigh-Bénard convection system, i.e., a horizontal fluid layer heated from below and cooled from above. The fluid consists of a mixture of sulfur hexafluoride (SF_6) and helium (He). Temperature and pressure are such that SF_6 exists in both, the vapor and the liquid phase while He is in the gas phase. Hot SF_6 vapor that rises from the bottom condenses inside the colder gaseous He/SF_6 mixture by homogeneous nucleation and forms small droplets that form clouds. We study the condensation process, as well as the dynamics of the droplet motion inside the gas phase visually using a high-speed camera. We found several instances, where droplet condensation occurs in the cold wake of larger falling droplets. This observation may suggest an additional mechanism for nucleation of droplets in atmospheric clouds.

DY 16.9 Tue 12:15 ZEU 118

Prediction of the temperature profiles in Rayleigh-Bénard convection. — •Mohammad Emran and Olga Shishkina — Max-Planck Institute for Dynamics and Self-Organization, Göttingen, Germany.

Experiments and numerical simulations of Rayleigh-Bénard convection (RBC) show that the temperature profiles in RBC systematically deviate from those obtained as solutions of the classical Prandtl-Blasius or Falkner-Skan boundary layer equations. The deviations persist even after rescaling of the profiles in a fixed or dynamical frame. Some improvements have been made by adapting the pressure gradients and buoyancy effects in the classical boundary layer equations. Those improvements mostly influence the prediction of the viscous boundary layer structure, but not the structure of the thermal boundary layer, in particular at large Prandtl number. Here we report a recipe to predict the mean vertical temperature profiles in turbulent Rayleigh-Bénard convection for Prandtl numbers larger than one. It is based on the thermal boundary layer equation from Shishkina et al., Phys. Rev. Lett. 114, 114302 (2015), which incorporates the effect of turbulent fluctuations, and new Direct Numerical Simulations (DNS) of RBC in a cylindrical cell of the aspect ratio 1, for the Prandtl number variation of several orders of magnitude. Our modeled temperature profiles are found to agree with the DNS much better than those obtained with the classical Prandtl–Blasius or Falkner–Skan approaches.

DY 16.10 Tue 12:30 ZEU 118

Horizontal velocity fields in square large aspect ratio turbulent convection cells: comparison between experiment and simulation — •Christian Kästner, Anastasiya Kolchinskaya, Christian Resagk, and Jörg Schumacher — Institute of Thermodynamics and Fluid Mechanics, Technische Universität Ilmenau, Postfach 100565, 98684 Ilmenau

We report a one-to-one comparison of an experimental and numerical analysis of turbulent velocity fields in a square Rayleigh-Bénard convection cell at an aspect ratio ten and air as working fluid. Horizontal cuts through the convective flow were obtained from planar particle image velocimetry (PIV) measurements. Optical access for laser light sheet and PIV camera 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 ratios. The horizontal cuts were taken in mid-plane of the convection cell and below the cooling plate at a Rayleigh number Ra= 500,000. Numerical and experimental results show good agreement and provide new insights into large-scale coherent flow pattern formation in turbulent thermal convection.

DY 16.11 Tue 12:45 ZEU 118

Nonlinear mode decomposition of reversal dynamics in Rayleigh-Bénard convection — •Oliver Kamps[1] and Tim Kroll[2] — [1]Center for Nonlinear Science, WWU Münster, Germany — [2]Institut für Theoretische Physik, WWU Münster, Germany

Complex systems composed of a large number of degrees of freedom can often be described on the macroscopic level by only a few interacting modes or coherent structures. A paradigmatic example for this behaviour is Rayleigh-Bénard convection. In general many turbulent flows seem to be composed of a few coherent structures and it might be possible to find a low dimensional representation of the flow. This has to be done in most cases by means of data analysis methods since it is not possible to derive the low dimensional model from the basic equations of the complex system.

Based on ideas developed in [1,2] we present a nonlinear decomposition method that is able to extract coherent structures and their dynamics from data of turbulent flow fields. We apply this method to reversal dynamics in Rayleigh-Bénard convection in order to derive a low dimensional representation of the system. We also show the relation to other decomposition methods like dynamic mode decomposition.

[1] C. Uhl, R. Friedrich, and H. Haken, Zeitschrift für Physik B, 92, 1993

[2] F. Kwasniok, Physica D: Nonlinear Phenomena, 92, 1996

DY 16.12 Tue 13:00 ZEU 118

Heat and momentum transport scalings in horizontal convection — •Olga Shishkina[1], Siegfried Grossmann[2], and Detlef Lohse[3] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Fachbereich Physik der Philipps-Universität, Marburg, Germany, — [3]Department of Science and Technology, Mesa+ Institute, and J. M. Burgers Centre for Fluid Dynamics, University of Twente, Enschede, Netherlands

In horizontal convection heat exchange takes place exclusively through a single (bottom) horizontal surface of a fluid layer. For this type of convective flow configuration in Shishkina, Grossmann and Lohse, Geophys. Res. Lett. 43 (2016) a theoretical model for the heat and momentum transport scaling with the Rayleigh number (Ra) has been suggested, which is an extension of the Grossmann and Lohse theory (2000) to the case of horizontal convection. The model suggests various different scaling regimes, including in particular the Rossby scaling (with the scaling exponent 1/5 in the Nusselt number versus Rayleigh number scaling) and the ultimate scaling (with the scaling exponent 1/3). In the present talk we discuss the Prandtl-number (Pr) dependences of the Nusselt and of the Reynolds numbers for all derived scaling regimes in horizontal convection and also the locations in the Pr-Ra plane of the (smooth) transitions between different scaling regimes.