DY 42: Turbulence

Time: Wednesday 10:00–12:45 Location: BH-N 128

DY 42.1 Wed 10:00 BH-N 128

On the small-scale structures of the turbulent velocity gradient and the resulting pressure field — •Dimitar G Vlaykov and Michael Wilczek — Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany

The non-local nature of the pressure in incompressible flows is at the heart of the complexity of the turbulence problem. Through a Poisson equation it is intimately related to the non-linear structures of the velocity gradient field in fully developed turbulence. To address both issues, we present a statistical characterization of the spatial structure of the second invariant of the velocity gradient tensor in homogeneous and isotropic turbulence. We distinguish regions of different intensity and type – vorticity or strain dominated, and provide estimates on their scales and relative separation. The results inform a comparative statistical study of the dependence of the pressure nonlocality on the local conditions for a range of Taylor-based Reynolds numbers between 123 and 433. It is found that in strongly vorticity-dominated regions a shielding mechanism is responsible for localizing the dominant pressure contributions to a dissipation-scale neighborhood. Moreover, this neighborhood is smaller than the underlying vortex structure. In strain-dominated regions, on the other hand, the same mechanism leads to the pressure statistics being determined on inertial scales. Finally, the well-known long-range pressure correlations stem from the strong non-locality of the contributions to the pressure in regions of low velocity-gradient intensity.

DY 42.2 Wed 10:15 BH-N 128

Scalable exact coherent structures for the turbulent cascade — •Stefan Zammert and Bruno Eckhardt — Philipps-Universität Marburg, Marburg, Germany

Exact solutions of the Navier-Stokes equations play a key role in the formation of subcritical turbulence. The appearance of three-dimensional turbulence was shown to be connected to secondary bifurcations of such structures in various flows. However, an explanation of the evolution of the observed spatial complexity, e.g. the multiple scales of turbulence, is still missing.

We will show different families of exact coherent states of plane Couette flow which can be scaled in their spatial extends to obtain a hierarchy of exact coherent states (*Eckhardt & Zammert: Nonlinearity, to appear*). While one of these families is localized in the center of the channel and independent of the walls, another one is attached to the walls and reminiscent of so-called attached eddies. The structures propose a potential entry to explain the turbulent cascade using exact coherent structures and thus by methods from dynamical systems theory.

DY 42.3 Wed 10:30 BH-N 128

Filtered kinetic energy budget in two-dimensional Rayleigh-Bénard convection — •Gerrit Green[1,2], Dimitar Vlaykov[1], Juan-Pedro Mellado[3], and Michael Wilczek[1] — [1]Max-Planck-Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Georg-August-University Göttingen — [3]Max-Planck-Institute for Meteorology, Hamburg, Germany

The dynamics of turbulent Rayleigh-Bénard convection (RBC) exhibits a complex interaction between coherent large-scale flow patterns, so-called superstructures, and small-scale fluctuations. It is largely unexplained how such superstructures trigger small-scale turbulence and, conversely, how turbulence sustains or inhibits superstructures. In this contribution, we employ two-dimensional direct numerical simulations to investigate the interaction between scales. A filtering approach is used to separate the large and small scales. This allows us to systematically study the distinct contributions to the large-scale kinetic energy budget. Different Rayleigh and Prandtl numbers are explored with this method. We show that most of the energy tranfer between scales occurs near the wall and that in the bulk it is approximately independent of height. The ultimate goal is to find an effective description of turbulent superstructures in RBC, and the presented results will help to understand how to establish such a description.

DY 42.4 Wed 10:45 BH-N 128

Edge states in the climate system: exploring global instabilities and critical transitions — •Valerio Lucarini[1,2,3] and Tamas Bodai[1,2] — [1]Department of Mathematics and Statistics, University of Reading — [2]Centre for the Mathematics of Planet Earth, University of Reading — [3]CEN, University of Hamburg

Multistability is a ubiquitous feature and provides key challenges for our ability to predict a system's response to perturbations. The Earth climate is multistable: present astronomical conditions support two stable regimes, the warm and the snowball climate. We study the global instability giving rise to the snowball/warm multistability in the climate system by identifying the climatic edge state, a saddle embedded in the boundary between the two basins of attraction of the stable climates. The edge state attracts initial conditions belonging to such a boundary and is the gate facilitating noise-induced transitions between competing attractors. We use a simplified yet Earth-like climate model constructed by coupling a primitive equations model of the atmosphere with a simple diffusive ocean. We refer to the climatic edge states as Melancholia states. We study their dynamics, their symmetry properties, and we follow a complex set of bifurcations. We find situations where the Melancholia state has chaotic dynamics. In these cases, the basin boundary between the two basins of attraction is a strange geometric set with a nearly zero codimension, and relate this feature to the time scale separation between instabilities occurring on weather and climatic time scales. We also discover a new stable climatic state characterized by non-trivial symmetry properties.

DY 42.5 Wed 11:00 BH-N 128

Statistical and Dynamical Properties of Covariant Lyapunov Vectors in a Coupled Atmosphere-Ocean Model - Multiscale Effects and Geometric Degeneracy — •Valerio Lucarini[1,2,3] and Stephane Vannitsem[4] — [1]Department of Mathematics and Statistics, University of Reading — [2]Centre for the Mathematics of Planet Earth, University of Reading — [3]CEN. University of Hamburg — [4]Royal Meteorological Institute, Bruxelles

We study a simplified coupled atmosphere-ocean model using the formalism of covariant Lyapunov vectors (CLVs). The model is obtained via a severe truncation of quasi-geostrophic equations for the two fluids, has 36 degrees of freedom, features a chaotic dynamics. One finds 2 positive Lyapunov exponents (LEs), 16 negative LEs, and 18 near-zero LEs. The presence of many near-zero LEs results from the vast time-scale separation between the time scales of the two fluids. The tangent space spanned by the CLVs corresponding to the positive and negative LEs has a non-pathological behaviour, while strong degeneracies are found for the near neutral modes. Our results underline the difficulties in using hyperbolicity as a conceptual framework for multiscale chaotic dynamical systems, whereas the framework of partial hyperbolicity seems better suited, possibly indicating an alternative definition for the chaotic hypothesis. Our results suggest the need for accurate analysis of error dynamics on different time scales and domains and for a careful set-up of assimilation schemes when looking at coupled atmosphere-ocean models.

15 min. break

DY 42.6 Wed 11:30 BH-N 128

Directed locomotion fuelled by turbulent fluid motion — Nicolas Francois, Hua Xia, Horst Punzmann, and •Michael Shats — Centre for Plasmas and Fluids, Research School of Physics and Engineering, The Australian National University, Canberra, ACT 2601, Australia

Chaotic horizontal motion of fluid at the liquid-gas interface is a ubiquitous phenomenon since such a motion can be driven by surface waves. When waves are steep, such motion is not just chaotic. It becomes turbulent in the sense of Kraichnan's two-dimensional turbulence, a state strongly out of equilibrium. We show that a properly shaped floating object on the liquid surface can tap energy of turbulent fluctuations to fuel its self-propulsion along a trajectory which can be viewed as a rectified random walk. If a floating device is fixed at one position on the surface, making a horizontal rotor, it can convert turbulent fluctuations into unidirectional rotation. The effect relies on the momentum transfer from the underlying fabric of the flow to the floating object. The shape of the object controls its ability to become a 'Lagrangian ratchet' that can tap the energy of correlated bundles of fluid trajectories.

DY 42.7 Wed 11:45 BH-N 128

Tuning diffusion of finite size particles in turbulent flows — •Hua Xia, Nicolas Francois, Horst Punzmann, and Michael Shats — Research School of Physics and Engineering, The Australian National University, Canberra, Australia

The motion of a large floater on a liquid surface perturbed by Faraday waves was shown to be erratic and share features similar to the Brownian motion of particles in contact with a thermal bath. In particular a fluctuation-dissipation relationship was uncovered. This similarity with systems at thermodynamic equilibrium seems at odds with the fact that Faraday waves generate turbulent flows, a state strongly out of equilibrium.

Here we show that the law of dispersion in chaotic flows can be widely tuned due to the coupling of diffusing particles with the fabric and memory of the flow. We demonstrate a sharp change in the law of diffusion as a function of scales seen as a transition from *thermal* diffusion at large scales to strongly non-equilibrium regime at small scales. The chaotic flow is dominated by underlying coherent bundles executing random walk. Large particles interact with many bundles, disperse similar to a Brownian particle in a thermal bath. For particles smaller than the characteristic length scale, the coherent bundles push the particles resulting in a much faster dispersion.

DY 42.8 Wed 12:00 BH-N 128

Fluid surface particle control and transition to order in wave-based liquid metamaterials — Nicolas Francois[1], Hua Xia[1], •Horst Punzmann[1], Paul Fontana[2], and Michael Shats[1] — [1]Research School of Physics and Engineering, Australian National University, Canberra, Australia — [2]Physics department, Seattle University, Seattle, USA

This work demonstrates a method of remotely shaping the trajectories of floating particles on a liquid-gas interface through the external control of surface waves. The underlying principle is a combination of rotating waves, created by a superposition of two orthogonal standing waves, and the Lagrangian drift of particles along closed paths in such waves. This mechanism offers a high degree of control over the particle motion and provides the ability to confine particles to a spatially periodic lattice of nested orbits. The key parameter in the transition from ordered to disordered flow (or vice versa) is the temporal phase shift between the two orthogonal standing waves. We present experimental results on the creation and control of such dynamical liquid interface materials, complemented with a theoretical model of particle trajectories based on the wave-driven Lagrangian drift at the surface of an ideal fluid. In analogy of solid metamaterials which guide waves through matter, liquid metamaterials allow the guidance of matter through control of the imposed surface wave topology. By dynamically shaping a fluid interface using rotating waves, it is possible to effectively produce a 2D material with prescribed transport properties [N. Francois, et. al. Nat. Commun. 7, 14325 (2017)].

DY 42.9 Wed 12:15 BH-N 128

The Statistical Properties of Ultra-Strong Turbulence — •Christian Küchler[1], Gregory P. Bewley[2], and Eberhard Bodenschatz[1] — [1]Max Planck Institute for Dynamics and Self-Organization, Göttingen, Germany — [2]Cornell University, Ithaca, USA

How do the two-point statistical quantities of the velocity field depend on the turbulence level? Is turbulence universal? Answering these questions requires access to a sufficiently wide inertial range over which the turbulence can be considered universal. The Variable Density Turbulence Tunnel at the Max Planck Turbulence Facility can reach extremely high turbulence levels under experimentally resolvable conditions. The VDTT is a closed- loop wind tunnel of 80 m^3 volume filled with pressurized sulfur-hexaflouride at 0.5 bar to 15 bar. This allows to change the turbulence levels over two orders of magnitude, while keeping the geometry of the flow the same. The turbulence is generated by an unique active grid consisting of 111 individually controllable flaps. By using nanoscale thermal anemometry probes developed at Princeton University we record ultra long time series of the turbulent velocity field at a single point 9 m downstream of the active grid. Using these techniques we compiled datasets at turbulence levels that hereto-forth could not experimentally resolved. In the talk we report the evolution of two-point statistics as a function of turbulence level and present insights on the inertial range scaling and intermittency effects of turbulent flows.

DY 42.10 Wed 12:30 BH-N 128

The decay of grid-generated wind tunnel turbulence — •Lisa Rademacher, Lars Kröger, Joachim Peinke, Gerd Gülker, and Michael Hölling — ForWind - Institute of Physics, University of Oldenburg, 26111 Oldenburg, Germany

Producing turbulent inflow conditions inside a wind tunnel by passive and active grids is an important measuring tool to simulate real wind conditions. Especially active grids have shown to be indispensable for controlling the inflow turbulence more precisely and reproducing unsteady processes. This is for instance important for examining wind turbines and how they perform in highly intermittent wind fields. Depending on the investigated problem different wind fields are required e.g. shear flows or unsteady flow events to simulate the turbulent atmospheric boundary layer or gusty wind loads. Since turbulence is characterised by its highly chaotic nature the reproducibility and controllability of the inflow conditions are of high importance. Also the invasive character of the grid itself should be as small or short-living as possible to prevent interfering of grid wake and measurement model. Ideally the grid wake should decay fast compared with the decay of the turbulent structures, which should last as long as possible - so the generated turbulence would exist without traces of the generating grid over the most parts of the measuring section. In this contribution the decay of the generated turbulence and the grid wake considering different flap movement patterns of a Makita-designed active grid are examined by the use of PIV.