



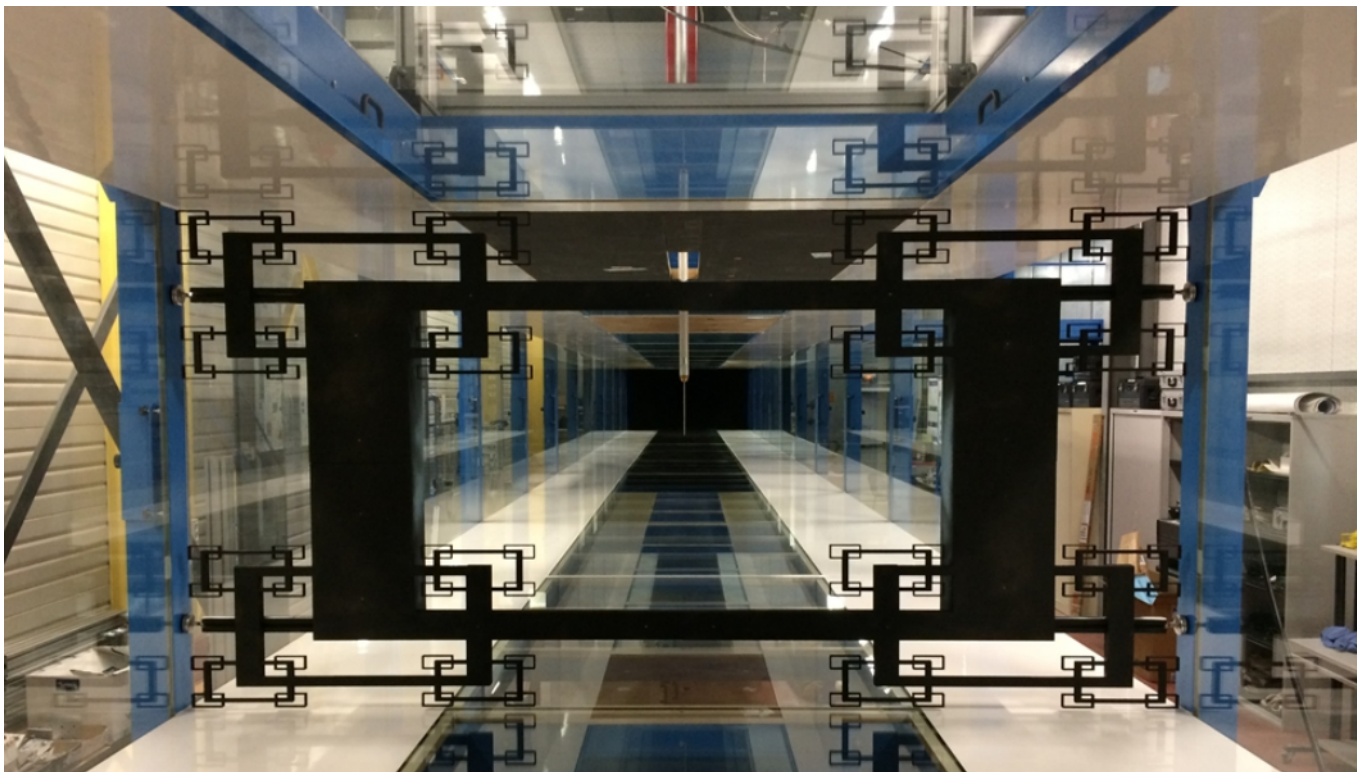
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## LILLE TURBULENCE PROGRAMME 2026

# OPENING WORKSHOP ON TURBULENT FLOWS

Villeneuve d'Ascq, Cité Scientifique, M6 Building  
16-18 June 2026

<https://lmfl.univ-lille.fr/agenda/lille-turbulence-program>



The aim of this workshop is to discuss approaches to turbulent flows which go beyond Kolmogorov equilibrium cascades by taking explicit account of non-stationarity and/or non-homogeneity either in a statistical sense or in the local sense of dynamic intermittency. Kolmogorov equilibrium describes the spatio-temporal average of statistically homogeneous isotropic turbulence. Non-equilibrium is manifest in fluctuations around this equilibrium either in time for spatial averages or in space for time averages and in deviations from such equilibrium by the presence of statistical non-homogeneity and/or non-stationarity/turbulence decay. Non-equilibrium is therefore present in all turbulent flows which implies that various turbulent energy transfer and/or production mechanisms in both scale and physical spaces need to be taken into account to understand turbulence physics, including turbulence cascades, turbulence dissipation and intermittent fluctuations. Different universality classes of non-equilibrium may need to be defined by considering the presence or absence of different types of large-scale coherent structures and different regions of flows in terms of turbulence production, turbulence transport and proximity to the turbulent/non-turbulent interface which is an extreme but ubiquitous instance of local non-homogeneity/intermittency/near-singularity. There are consequences for important leading order properties of a raft of boundary-free turbulent flows including growth rates of turbulent shear flows such as turbulent wakes, jets and mixing layers where approaches based on momentum and force balances need to be confronted with approaches where turbulent energy balances and therefore turbulence dissipation play a leading role. There are also consequences for wall flows such as turbulent channel flows and various types of turbulent boundary layers which need to be elucidated and where both momentum and energy transfers, as well as wall-blocked coherent structures, are key.

## **TUESDAY 16 JUNE 2026**

11:30-12:30 : ARRIVALS

12:30-14:30 WELCOME AND LUNCH

14:30-15:10: SZYMON MALINOWSKI - Turbulent shallow warm marine clouds.

15:10-15:50: RYO ONISHI – Non-equilibrium Turbulence in the Environment; Clouds and Urban Micro-Weather.

15:50-16:30: GUOWEI HE – A toy model and AI approach for learning turbulence.

16:30-17:10: TEA/COFFEE BREAK AND DISCUSSIONS

17:10-17:50: TAKUYA KITAMURA - Effective mean energy dissipation in spectrally truncated Euler equation and its relevance with Navier-Stokes turbulence.

17:50-18:30 : CHRISTOS VASSILICOS – The hypothesis of homogeneous two-point physics in non-homogeneous turbulence.

## **WEDNESDAY 17 JUNE 2026**

8:45-9:25 : HENGDONG XI – Maximum dissipation reduction in bulk polymeric turbulence.

9:25-10:05: SUSUMU GOTO – Multifractality of the hierarchy of coherent vortices in turbulence.

10:05-10:45: CARLOS DA SILVA – New insights into the structure of intense vorticity in isotropic turbulence.

10:45-11:15 : TEA/COFFEE BREAK AND DISCUSSIONS

11:15-11:55: ALBERTO VELA MARTIN – Uncertainty dynamics and the complexity of turbulence.

11:55-12:35: MARTIN OBERLACK – Spatially evolving turbulent round jet flows: DNS, symmetries and scaling laws.

12:35-14:30 : LUNCH

14:30-15:10: YI ZHOU - Surface geometry and entrainment dynamics in TNTI of a temporally evolving jet.

15:10-15:50: JIANGANG CHEN – Characteristics of the temporal evolution of the turbulent/non-turbulent interface in a planar wake..

15:50-16:30: YUTARO MOTOORI - Deformation of a free surface by turbulent wake.

16:30-17:00 : TEA/COFFEE BREAK AND DISCUSSIONS

17:00-17:40: NIKOS BEMPEDELIS, KAIXIN ZHU & KOSTAS STEIROS – Extracting self-similarity from data.

17:40-18:20 SERGIO PIROZZOLI – A spectral framework for the wall-normal distribution of velocity variance in turbulent wall flows.

20:00: *WORKSHOP DINNER, Restaurant Aux Moules de Lille*

**THURSDAY 18 JUNE 2026**

8:45-9:25 : GENTA KAWAHARA – The rigorous ultimate scaling in rapidly-rotating thermal convection.

9:25-10:05: XIAOJUE ZHU - Geostrophic turbulence: scalings and large scale pattern.

10:05-10:45: ALEXANDROS ALEXAKIS - Cascade transitions in geophysical turbulence.

10:45-11:15: COFFEE BREAK

11:15-11:55: MARTA WACLAWCZYK – Scale-by-scale budget of atmospheric moist convection using large eddy simulation data.

11:55-12:35: FILIPPO COLETTI - Turbulence along a free surface does not cascade.

12:35-14:30: CLOSING BUFFET LUNCH

## **Turbulent shallow warm marine clouds**

S. Malinowski

Institute of Geophysics, University of Warsaw

Warsaw, Poland

By principle, shallow warm marine clouds and cloud systems, common around the globe in low latitudes, are simplest to model and investigate. Commonly adopted assumptions of stationarity and horizontal homogeneity almost hold due to a weak diurnal cycle and flat, uniform bottom interface of the modelling domain. No ice microphysics is involved. Despite that, our ability to reproduce such clouds in the virtual reality of the computer is limited and many observed properties are missing. Can we do better? In the talk I will point several weak points of common approaches to be addressed in the next modelling attempts.

## **Non-equilibrium turbulence in the environment; clouds and urban micro-weather**

Ryo Onishi<sup>1</sup>, Yuwei Yin<sup>2</sup>, Taketo Tominaga<sup>2</sup>

1) Supercomputing Research Center, Institute of Integrated Research, Institute of Science Tokyo

2) Department of Mechanical Engineering, Engineering School, Institute of Science Tokyo

Non-equilibrium turbulence is ubiquitous in environmental flows, but its non-equilibrium nature is often neglected in modeling. Here we present two recent efforts to clarify its significance in environmental flow phenomena.

The first one concerns the inertial particle clustering in turbulence, which plays a key role in collisional growth of cloud droplets in cumulus clouds. The clustering intensity, which enhances the mean collision frequency, has been widely modeled; the conventional models, however, rely on numerical results obtained under equilibrium turbulence conditions. We demonstrate that such modeling can introduce significant errors under realistic non-equilibrium conditions.

The second topic concerns the wake behind fractal trees in urban microclimate/micro-weather. Due to the combined effect of global warming and the urban heat-island, extreme heat in urban streets has become a major social concern. Planting street trees is a common mitigation strategy, and many numerical studies have assessed their impact of trees on wind and heat environments. However, these numerical studies typically assume equilibrium dissipation scaling. We show that non-equilibrium dissipation persists over distances of several tree heights downstream in the wake region. This indicates that conventional equilibrium-based models may fail to represent flows in streets lined with trees.

## **A toy model and AI approach for learning turbulence**

Guowei He

Institute of mechanics, Chinese Academy of Sciences Beijing 100190, China

In this talk, I will introduce our recent work on a toy model for space-time correlations of scalar turbulence and an AI approach for wall modeling of large-eddy simulation. In the first parts, a toy model for space-time correlation of passive scalar advected by turbulent flows is proposed. This (TK) model is the combination of Taylor's frozen-flow model and Kriachnan's random-sweeping and white-noise models and leads to the exact solution of space-time correlation. These results are used to demonstrate the scale invariance of space-time correlations and the self-similarity of iso-correlation contours. In the second part, we propose a knowledge-integrated additive (KIA) learning approach for learning wall models in large-eddy simulations. The additive learning capability of KIA without catastrophic forgetting is demonstrated via training the model sequentially using the data of different flows. The models obtained are used to the flows over periodic-hill and the 2-D Gaussian bump with good agreement with DNS and experiments.

# **Effective mean energy dissipation rate in spectrally truncated Euler equation and its relevance with Navier-Stokes turbulence**

Takuya Kitamura

Graduate School of Integrated Science and Technology, Nagasaki University,  
Nagasaki, Japan.

Turbulence is a ubiquitous phenomenon observed across a wide range of scales, from quantum to geophysical and even astrophysical scales, and its fundamental understanding remains one of the central challenges in classical physics. The mean energy dissipation rate is a key physical quantity that determines the decay law of turbulent kinetic energy, turbulent diffusion, mean velocity profiles, and drag. A deeper understanding of this quantity may lead to improved insight into turbulent phenomena, including the picture of the energy cascade.

In this study, we consider the dynamics of the spectrally truncated Euler equations as a minimal model for describing turbulent flow, and discuss how similarities with Navier–Stokes (NS) turbulence can be identified. Furthermore, through the analysis of the dynamics of the spectrally truncated Euler equations which exhibit behavior analogous to that of NS turbulence, we aim to discuss the law of energy dissipation in both equilibrium and non-equilibrium turbulence.

## **The hypothesis of homogeneous two-point physics in non-homogeneous turbulence**

Christos Vassilicos  
CNRS, LMFL, Lille, France

I will present the hypothesis of homogeneous two-point physics in non-homogeneous turbulence and derive its turbulence cascade implications for a number of turbulent flows. This will require the definition of various classes of turbulence non-homogeneity. The Kolmogorov scale-by-scale equilibrium cascade is the special case where the turbulence is homogeneous and stationary.

## **Maximum dissipation reduction in bulk polymeric turbulence**

Hengdong Xi

Northwestern Polytechnic University, XI'an, Shaanxi, China

We present an experimental study of the flow regime and vortex structure in bulk polymeric turbulence through three-dimensional velocity measurements with unprecedented high spatial resolution. We demonstrate that, as the polymer concentration increases, the effect of polymers on the fluid energy dissipation rate can be categorized into two distinct regimes: the dissipation reduction regime and the maximum dissipation reduction (MDR) regime, and in the latter the effect of polymers saturates. We reveal that the MDR regime occurs when the scale range affected by the polymer additives extends up to the integral length scale, rather than the generally accepted Lumley scale. This finding enables us to map out the phase diagram of the flow regimes of polymeric turbulence on Reynolds number and Weissenberg number. Furthermore, we demonstrate that in the MDR regime, sheet-like vortex and strain structures dominate, which is traced to the fact that polymer stress stabilizes shear layers and reduces perturbation to shear instability. These results suggest that the MDR regime is a universal flow state in bulk polymeric turbulence and is the counterpart of the maximum drag reduction regime in wall-bounded flows. Our findings emphasize the significance of sheet-like vortex structures and offer new insights into predicting the critical conditions for the emergence of various flow regimes in viscoelastic fluids.

## **Multifractality of the hierarchy of coherent vortices in turbulence**

Susumu Goto

Graduate School of Engineering Science, The University of Osaka, Osaka, Japan

To investigate the relation between the hierarchy of coherent vortices in turbulence and the multifractal nature of turbulence statistics, we analyze numerical data of turbulence in a periodic cube at high Reynolds numbers (about 1700 based on the Taylor length). We employ scale decomposition with Fourier bandpass filters to identify coherent vortices at each length scale in the inertial range, and then their axes are objectively identified using the low-pressure method. The fractal dimension of the identified hierarchy of vortex axes is always 3, implying that they are space-filling (Tsuruhashi et al. 2021). In contrast, when we identify the set of vortex axes for a given Hölder exponent  $h$ , its capacity dimension can be easily evaluated to capture the spatial intermittency. The evaluated multifractal dimension  $D(h)$  agrees well with the one estimated from experimental data of the scaling of the velocity structure functions. Furthermore, it is interesting to note that there are qualitative differences in the hierarchy of the identified coherent vortices depending on whether the Hölder exponent  $h$  is greater than or less than  $1/3$ . In my presentation, I will report on the findings regarding the impact of these differences in coherent vortices for each Hölder exponent  $h$  on turbulence statistics.

## **New insights into the structures of intense vorticity in isotropic turbulence**

Carlos da Silva

Instituto Superior Tecnico, Universidade de Lisboa

Lisbon, Portugal

One of the most distinctive characteristics of turbulent flows is the presence of a large range of eddy structures, defined loosely as regions of concentrated vorticity and low pressure, with a life time which is large compared with the characteristic timescale of the flow (for the biggest of these structures). The smallest existing eddies where the most intense vorticity of the flow is concentrated, are usually called 'worms' or intense vorticity structures (IVS). Their relevance in turbulence is connected with their relation with the viscous dissipation mechanism, internal intermittency, and with small scale mixing, notably to the so-called 'nibbling' mechanism which ultimately causes the turbulent entrainment. Recent direct numerical simulations (DNS) and an new innovative time tracking algorithm allows the time tracking of a very large number of IVS, and a detailed characterisation of their kinematic and dynamic features from 'birth' to 'death'. The presentation will focus on the dynamics of the 'death' of these structures and on its possible relation with some of the characteristics of these structures. Possible implications for the ability to control the entrainment and mixing rates in turbulent flows are discussed.

## Uncertainty dynamics and the complexity of turbulence

Alberto Vela-Martin

Universidad Carlos III de Madrid, Spain

Turbulence is a canonical example of chaotic dynamics for which the governing equations are known and can be simulated. Current computational resources and numerical methods enable fully resolved direct numerical simulations (DNS) of turbulence, providing an unprecedented amount of high-quality data. Despite capturing the full dynamics, standard single DNSs are limited because they fail to directly address the intrinsic unpredictability of turbulence, hiding its true complexity.

This talk will emphasize the limitations of viewing turbulence through the strict determinism of DNS, and the opportunities that arise when we let uncertainty emerge naturally through massive collections of simulations, recasting a single DNS as a distribution of possible outcomes.

We will see how this approach applies to two complementary problems. First, introducing uncertainty into the prediction of extreme events in two-dimensional turbulence reveals large fluctuations in predictability, showing that similar extreme events can emerge from causally distinct regions with different structures [1]. This reflects causal uncertainty, whereby the same extreme event may arise from different initial conditions, increasing the complexity of predictive algorithms and imposing a strict lower bound on the minimum model size required for accurate forecasts [2]. Second, at high Reynolds numbers, the problem will be formulated as determining the best possible prediction of the flow given an initially small uncertainty [3]. We will see how this prediction is limited by the propagation of uncertainty from small to large scales, in a process that is dynamically analogous to the energy cascade, reflecting a “flow” of uncertainty across scales which exhibits key features of the classical energy cascade [4].

Finally, we will argue that these two examples demonstrate that explicitly accounting for un-certainty is central not only to understanding turbulence, but also to enabling robust and scalable data-driven turbulence modeling.

- [1] Vela-Martín, A., & Avila, M. (2024). Large-scale patterns set the predictability limit of extreme events in Kolmogorov flow. *Journal of Fluid Mechanics*, 986, A2.
- [2] Vela-Martín, A. (2024). Complexity of extreme-event prediction in turbulent flows. *Physical Review Fluids*, 9(10), 104603.
- [3] Vela-Martín, A. (2024). Predictability of isotropic turbulence by massive ensemble forecasting. *Physical Review Fluids*, 9(12), L122601.
- [4] Vela-Martín, A. (2025). The uncertainty cascade in isotropic turbulence. *Journal of Fluid Mechanics*, 1021, A8.

## **Spatially evolving turbulent round jet flows: DNS, symmetries and scaling laws**

Martin Oberlack

Technische Universität Darmstadt, Germany

A spatially evolving turbulent round jet is analyzed using Lie symmetry methods and validated with direct numerical simulations (DNS) of the Navier–Stokes equations. Simulations at Reynolds numbers  $Re = 3500$  and  $7000$  include a passive scalar at  $Pr = 0.71$  in a domain of  $z/D = 75$ . Self-similarity is achieved by prescribing turbulent pipe flow as inflow, leading to rapid convergence. High-quality statistics are obtained, e.g., via ensemble averaging over 200 washouts at  $Re = 3500$ . Mean velocities, Reynolds stresses, and moments of velocity and scalar show scaling up to order 10 with similarity coordinate  $\eta = r/z$ . Probability density functions (PDFs) of axial velocity  $U_z$  are Gaussian on the jet axis, becoming skewed with heavy tails away from it. We have also developed a symmetry-based argument explaining the origin of the well-known Gaussian behaviour for the mean velocity as a function of the scaled radius  $\eta$ . This approach can also be used to generate refined approximations.

# Surface geometry and entrainment dynamics in TNTI of a temporally evolving jet

Yi Zhou

Nanjing University of Science and Technology, Nanjing, China

The turbulent/non-turbulent interface (TNTI) governs the exchange of mass, momentum, and scalar quantities between turbulent and non-turbulent regions. Using high-resolution direct numerical simulations of a temporally evolving turbulent plane jet, we investigate the three-dimensional surface characteristics and temporal evolution of the TNTI. The total surface area is found to remain approximately constant throughout the self-similar period, which is caused by a near-exact balance between the stretching term and the curvature/propagation term. An interesting and perhaps important self-similarity is identified in the TNTI geometry, that is, the probability density function of the shape parameter, the two-dimensional line length density, and the three-dimensional surface area density all collapse onto profiles when properly normalized. This observation implies that the interface evolves in a self-similar manner when the flow reaches a fully developed state. In particular, the ratio of the three-dimensional to two-dimensional wrinkling factors converges to a constant value close to the isotropic stereological limit of  $4/\pi$ . The geometric dependence of the entrainment and detrainment processes is also discussed. The present results are expected to be of relevance to the modeling of the TNTI.

# Characteristics of the temporal evolution of the turbulent/non-turbulent interface in a planar wake

Jiangang Chen <sup>1</sup> and Oliver R. H. Buxton <sup>2</sup>

<sup>1</sup> Institute of Extreme Mechanics, School of Aeronautics, Northwestern Polytechnical University, Xi'an, China

<sup>2</sup> Department of Aeronautics, Imperial College London, London, United Kingdom

An essential feature of turbulent flow is that it continuously entrains and mixes with the surrounding environmental fluid. The local rate of entrainment of the environmental fluid into the turbulent region depends in the first place on the local dynamics of the interfacial layer, usually referred to as the turbulent/non-turbulent interface (TNTI), which undergoes intensive spatial-temporal evolution during the development of the turbulent flow. How the local dynamics of the TNTI evolves over time, and how such evolution is related to the dynamics of the turbulence in the bulk region remain open questions. A better understanding of the associated physics is of practical importance, such as for developing more accurate models to predict the downstream expansion of the wake of a wind turbine.

In the present work, we experimentally investigated the characteristics of the temporal evolution of the TNTI in a planar wake. In the experiment, a vertically arranged circular cylinder was electrically towed through a quiescent water flume at a constant speed  $U_D = 0.6m/s$ , corresponding to a global Reynolds number  $Re (\equiv U_D d/\nu$  where  $d$  is the cylinder diameter) of about 6000. A fluorescent dye (Rohdamine 6G) was released from the rear surface of the cylinder to mark the turbulent wake (figure 1a). A simultaneous measurement of the velocity field and the dye concentration field was performed using a two-camera planar particle image velocimetry (PIV) system and a planar laser-induced fluorescence (PLIF) system, respectively (figure 1a). The fields of view of the two PIV cameras were combined to form a larger one of  $9d$ -by- $3d$  (figure 1b). The sampling frequency of the PIV and PLIF systems was 200Hz.

Some results are shown in figures 2 and 3. The identified TNTI at different time instants is displayed in figure 2, where  $t^* \equiv tU_D/d$  is the non-dimensional time. Note that  $t^* = 0$  is loosely defined as the moment when the cylinder passes through the measurement plane. It is clear that the TNTI spreads towards the environmental fluid as  $t^*$  increases. As expected, the magnitude of the vorticity of the wake decays as the TNTI spreads. A natural question arises that how the decay of the bulk turbulence is related to the temporal evolution of the TNTI. The characteristic of the evolution of the TNTI is first reflected in the variation of its spatial location with respect to time, which is shown in figure 3(a).  $\langle y_{I,exact} \rangle$  represents the mean location of the TNTI over one PIV image. It is observed that  $\langle y_{I,exact} \rangle(t^*)$  is characterized by three distinct stages: (i)  $t^* < T1$ ,  $\langle y_{I,exact} \rangle$  is almost constant in this stage; (ii)  $T1 < t^* < T2$ ,  $\langle y_{I,exact} \rangle$  increases rapidly with  $t^*$ ; (iii)  $t^* > T2$ ,  $\langle y_{I,exact} \rangle$  increases at a much slower rate than that in stage (ii) with a sharp transition at  $t^* = T2$ . It is interesting to see that the instants  $T1$  and  $T2$ , which distinguish the three stages of the temporal evolution of the TNTI of the wake, almost exactly demarcate the different decay behavior of the turbulent kinetic energy in the bulk region of the flow (figure 3b). The physics behind the observed correlation between the evolution of the TNTI and the decay of the turbulence in the bulk region will be investigated in detail in the presentation.

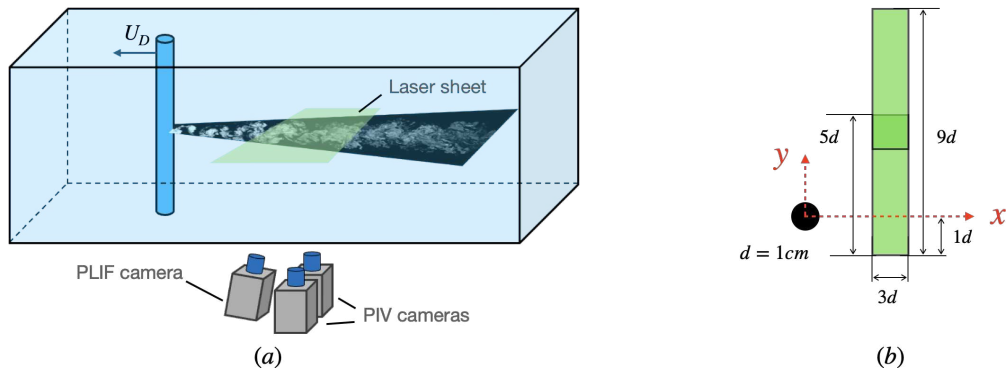


Figure 1: (a) *Skematic setup of the experiment;* (b) *the arrangement of the cylinder and the field of view of the PIV cameras.*

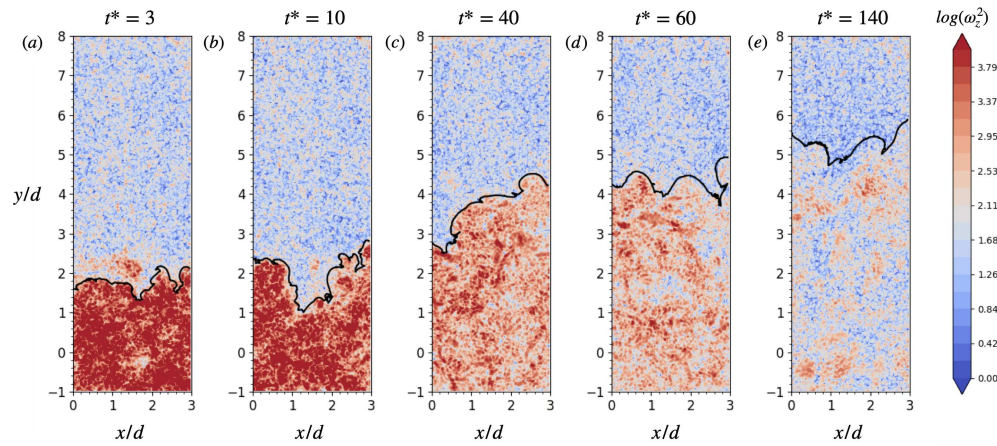


Figure 2: *The turbulent/non-turbulent interface between the wake and the environmental fluid at different time instances.*

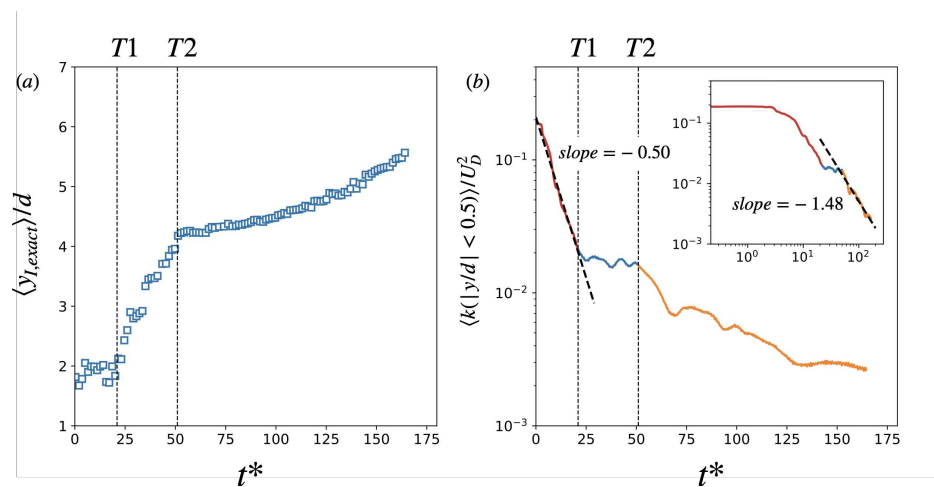


Figure 3: *Evolution of the (a) mean turbulent/non-turbulent interface location and (b) turbulent kinetic energy over time.*

## Deformation of a free surface by turbulent wake

Yutaro Motoori

Graduate School of Engineering Science

University of Osaka, Osaka, Japan

In this workshop, we present results on turbulent wakes with a free surface obtained from two experimental configurations in a recirculating open channel apparatus. (i) In one configuration, we place a thin flat plate beneath the free surface, and examine the turbulence behind it. Even at the same plate depth, the free-surface shape and the turbulent state can differ qualitatively depending on how the plate is brought to the depth, namely, whether the plate is lowered gradually from near the free surface or raised from a deeper position. We quantify this bistability by measuring the velocity field and the force acting on the plate. We then describe the condition under which the bistability occurs using a Froude number based on the plate depth. (ii) In the other configuration, we fix a circular cylinder beneath the free surface, and examine the free-surface deformation caused by the cylinder wake. In the upstream region, the free surface develops large-scale troughs parallel to the cylinder and small-scale crests perpendicular to the cylinder. We quantitatively show that these structures are formed directly by multiscale vortices in the turbulent wake. In contrast, the free-surface deformation produced upstream propagates as gravity waves downstream. We explain this qualitative change in the origin of the free-surface deformation between the upstream and downstream regions using a Froude number based on the free-surface height.

## Extracting self-similarity from data

Nikos Bempedelis<sup>1</sup> , Kaixin Zhu<sup>2</sup> and Kostas Steiros<sup>3</sup>

1) QMUL, London, UK

2) ICL, London, UK

Identifying self-similarity is key to understanding and modelling a wide range of phenomena in fluid mechanics. However, this is not always possible to perform formally in highly complex flows. We propose a data-driven methodology to extract self-similarity, without prior knowledge of the governing equations or boundary conditions, based on an optimisation problem and symbolic regression. The method is first applied to single-scale self-similar problems, including a laminar boundary layer, Burgers' equation, a turbulent wake, and a collapsing cavity, for which the self-similarity expressions are accurately recovered. It is then extended to two-scale self-similar problems, namely turbulent channel flow and homogeneous decaying turbulence, where both inner and outer self-similarity are identified successfully. In the intermediate ranges of these two problems, the algorithm reveals the independence of similarity expressions to both inner and outer scales, leading to the emergence of the well-known scaling laws: the logarithmic law in turbulent channel flow and the  $-5/3$  law in homogeneous decaying turbulence.

# **A spectral framework for the wall-normal distribution of velocity variance in turbulent wall flows**

Sergio Pirozzoli

Dipartimento di Ingegneria Meccanica e Aerospaziale, Sapienza Università di Roma,  
Roma, Italy

We investigate the wall-normal distribution of the streamwise velocity variance in turbulent wall-bounded flows through a spectral analysis of DNS data over a wide range of Reynolds numbers. Building on recent findings on the near-wall influence of large-scale motions (Pirozzoli, 2024), the analysis is formulated in terms of a partition of spectral space into regions associated with distinct physical mechanisms. By constructing simple models for each spectral region and integrating their contributions, we derive predictive expressions for the velocity variance as a function of wall distance and Reynolds number. The results show that the near-wall variance arises from the combined effect of nearly universal small-scale contributions and Reynolds-number-dependent intermediate scales associated with wall-attached eddies. In particular, the emergence of the outer peak is shown to be a direct consequence of the increasing contribution of these intermediate scales, rather than of the largest outer motions. The framework provides a unified interpretation of velocity variance scaling and rationalises the defect power-law behaviour identified in previous studies. Extrapolation to very high Reynolds numbers suggests a bi-modal asymptotic distribution, with inner and outer peaks of comparable magnitude.

Pirozzoli, S. 2024 On the streamwise velocity variance in the near-wall region of turbulent flows. *J. Fluid Mech.* Vol. 985, A5.

## **The rigorous ultimate scaling in rapidly-rotating thermal convection**

Genta Kawahara

The University of Osaka, Osaka, Japan

High-Rayleigh-number asymptotic forms of the Nusselt number and the Reynolds number are given analytically for rapidly-rotating Rayleigh-Benard convection to theoretically discuss the diffusion-free heat and momentum transfer in the so-called ultimate regime. Motivated by Grooms' (2015) rigorous upper and lower bounds on the Nusselt number, we perform an asymptotic analysis for a class of exact "single-mode" solutions to the three-dimensional Boussinesq equations and energy equation. This is my joint work with Dr. Gabriel Hadjerci and Dr. Shingo Motoki.

## **Geostrophic turbulence: scalings and large scale pattern**

Xiaojue Zhu

Max Planck Institute for Solar System Research, Goettingen, Germany

Geostrophic turbulence is a fundamental regime of rapidly rotating convection and plays an important role in geophysical and astrophysical flows. In this talk, I will present recent numerical results that clarify how turbulent transport changes across rotationally constrained regimes and how these changes are tied to the emergence of coherent large-scale flow structures. The simulations reveal that rapidly rotating convection does not pass directly from orderly columnar motion to fully developed turbulence. Instead, it moves through a sequence of distinct regimes, each with its own transport behavior and characteristic flow morphology. As the driving increases, the flow evolves from organized vortical structures to geostrophic turbulence and eventually to large-scale vortices and other domain-scale patterns. These large-scale structures are not simply by-products of the turbulence, but active features that reflect

the underlying balance between rotation, buoyancy, and dissipation. I will also discuss how the nature of the boundaries influences both the transition between regimes and the interpretation of transport laws. In particular, I will show that heat-transfer behavior alone is not always sufficient to identify geostrophic turbulence, since other flow properties can still retain a strong signature of viscous effects even when transport appears asymptotically turbulent. Together, these results provide a more complete picture of geostrophic turbulence by linking scaling behavior, regime transitions, and the formation of large-scale patterns, with implications for convection in planetary interiors and other rapidly rotating natural systems.

## **Cascade transitions in geophysical turbulence**

Alexandros Alexakis

CNRS, ENS Paris, France

Many geophysical and astrophysical flows—such as atmospheric jets, ocean currents, and planetary interiors—exhibit turbulent dynamics strongly influenced by rotation, stratification, and confinement. Unlike classical three-dimensional turbulence, where energy cascades to small scales, these systems often display inverse or bidirectional energy cascade, leading to the formation of large-scale coherent structures.

In this talk, we interpret these behaviors as distinct phases of turbulence, focusing on transitions between forward and inverse cascades. Using examples from rotating and quasi-two-dimensional flows, we show how control parameters can trigger sharp transitions, as well as intermediate regimes such as split cascades. This perspective aims to provide unified framework to understand the emergence of large-scale organization in geophysical turbulence and highlights deep connections with phase transitions in out-of-equilibrium systems.

# **Scale-by-scale budget of atmospheric moist convection using Large Eddy Simulation data**

Marta Waclawczyk

Institute of Geophysics, University of Warsaw, Warsaw, Poland

Moist convection in the atmosphere refers to the vertical transport of heat and moisture driven by buoyancy. Warm, moist air rises, cools, and condenses to form clouds and precipitation. Moist convection is a multiscale phenomenon in which large, coherent thermals ascend, generating cascades of small-scale turbulent eddies while simultaneously undergoing self-aggregation that merges them into larger-scale systems. Using the Kármán–Howarth–Monin–Hill (KHMH) framework, we relate these observations to the phenomenon of the bidirectional cascade. For this, we use a large-eddy simulation dataset describing shallow trade-wind cumulus convection from the BOMEX modeling benchmark. We show that, within clouds, part of the energy injected into the system via buoyancy forcing cascades toward progressively smaller eddies, while another part is transferred to larger scales, allowing these structures to persist and grow.

## **Turbulence along a free surface does not cascade**

Filippo Coletti

ETC Zurich, Switzerland

The energy of fluid turbulence is transported, on average, to smaller and larger scales in three-dimensional and two-dimensional flows, respectively. The motion along the flat free surface of a turbulent liquid shares similarities with both classes of flows, and therefore the direction of the energy cascade along it is ambiguous.

We investigate the problem experimentally, by tracking millions of microscopic particles along the surface of turbulent water stirred by jets randomly pulsing at depth, with negligible small interfacial deformations. We characterize the topology and inter-scale energy transfer of the surface velocity field, and find the local divergence to be crucial to the dynamics: expansive motions, associated with flow upwelling towards the surface, transfer energy to larger scales; while compressive motions, associated with fluid plunging into the bulk, do the opposite. The net inter-scale energy flux is therefore vanishingly small, in stark contrast with homogeneous turbulence in both two- and three-dimensional systems. Moreover, we find that rare and intense compressive/expansive events are chiefly responsible for the instantaneous inter-scale fluxes, which are much stronger than their counterparts at depth.

The result of such net-zero turbulent cascade along the free surface has strong implications for the Lagrangian transport. In particular, the ratio of the forward-in-time and backward-in-time pair separation rate (which is smaller and larger than unity in three- and two-dimensional turbulence, respectively) depends strongly on the distance between particle pairs.

## Information about the workshop

The 3 days workshop will take place at the LMFL

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Lille is easily accessible by fast train from Paris (1h), Brussels (30mn) and London (1h30) or directly through Lille-Lesquin airport from several European cities

Metro :

