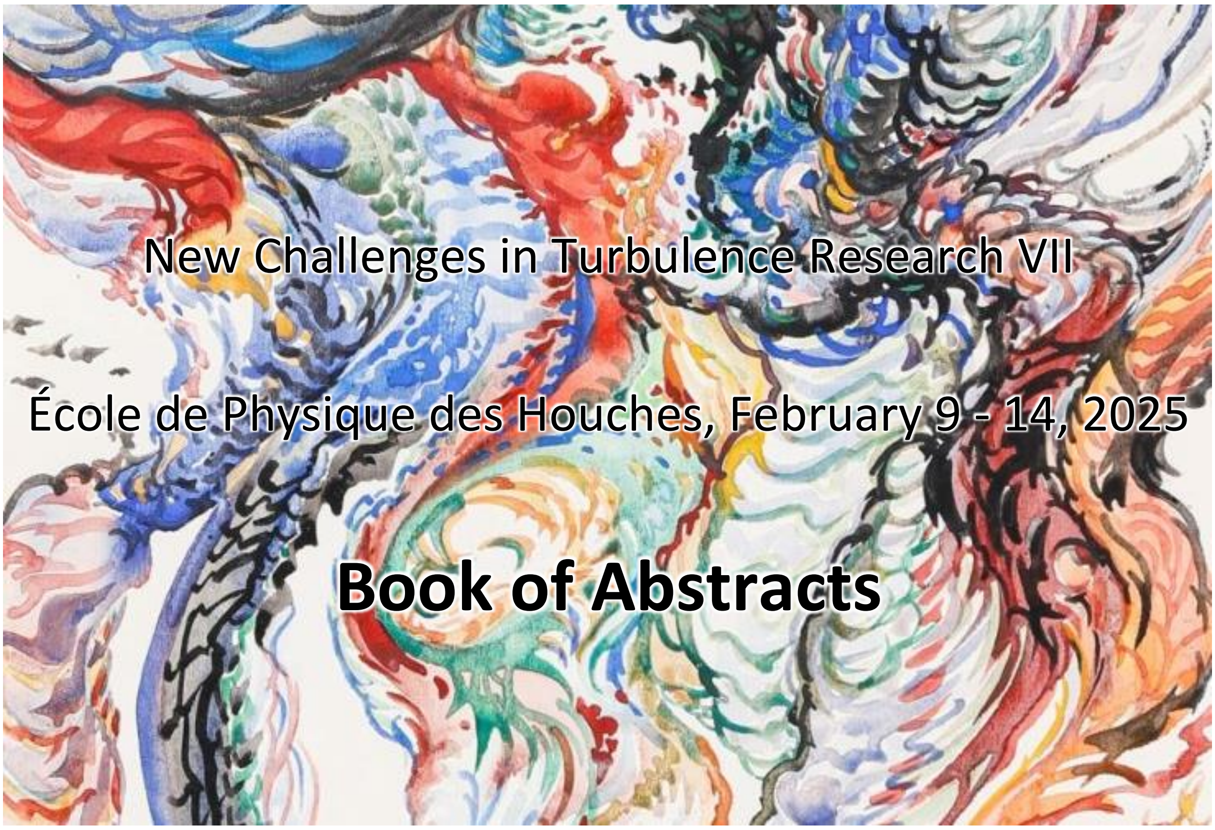

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	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday
8h45-10h15		Léonie Canet	Davide Faranda	Romain Volk	Luminita Danaila	Ivana Vinkovic
10h15-10h45		Coffee Break	Coffee Break	Coffee Break	Coffee Break	Coffee Break
10h45-12h15		Szymon Malinowski	Camille Lique	Christophe Brun	Detlef Lohse	Benjamin Leclaire
12h30-14h		Lunch	Lunch	Lunch	Lunch	Lunch
14h-15h45		Free	Free	Free	Free	Departures
15h45-17h15	Arrivals	Louis Couston		Participants		
17h15-17h45		Coffee Break	Coffee Break	Coffee Break	Coffee Break	
17h45-19h15		Poster (ends at 19h)	Participants	Poster	Participants	
19h30	Diner	19h Welcome drink 19h30 Diner	Diner	Diner	Diner	

Invited lectures

Christophe Brun – LEGI – Turbulence in the stable atmospheric boundary layer over alpine terrain: an application to katabatic winds on steep slopes

We are interested here in the turbulent properties of the atmospheric boundary layer in its surface layer in Alpine relief, on the scale of a local Alpine slope. We focus on the case of a stable atmospheric layer in an anticyclonic meteorological situation characteristic of winter and night-time episodes of thermal inversion. This lecture will be divided into three parts: first, we will define the atmospheric boundary layer (ABL) and its stratification; second, we will derive the set of Reynolds Averaged Navier-Stokes (RANS) equations that apply to flat and sloping terrain; third, we will discuss in situ measurements and numerical modeling results for the case of katabatic winds on a steep alpine slope.

1. Firstly, general knowledge will be provided to define the diurnal cycle of net radiation budget at the earth's surface and its impact on the turbulent ABL energy balance at the ground. The ABL stability will also be defined on the basis of the vertical profile of potential temperature and induced background stratification (Brunt-Väisälä frequency). Hydrostatic and adiabatic conditions will be described to design the complete ABL model to be considered.

2. We will derive the RANS equations for fluid dynamics on flat surface in the ABL. We will describe the buoyancy terms in the momentum equation under conditions of the Boussinesq approximation. We will write down the potential temperature budget that describes the non-isentropic nature of the ABL. We will focus on the turbulent kinetic energy budget (TKE) to represent the variance of the velocity field and the turbulent potential energy budget (TPE) to represent the variance of the temperature field. The TKE budget will be used to discuss the Prandtl mixing length model for stable ABL and its correction for buoyancy effects. The Monin-Obukhov similarity theory will be explained and the turbulent flux Richardson number defined. In this context, we will describe how the classical logarithmic laws of velocity and temperature in the turbulent boundary layer are modified by buoyancy effects. The RANS equations for a steep slope configuration subject to katabatic wind will then be repeated. Prandtl's (1949) model coupling stratification and buoyancy and its variants in turbulent conditions will be described. Finally, we will focus on the turbulent boundary layer below the jet maximum, which we will show to be a non-constant-flux layer forced by gravity terms. We will show how the Monin-Obukhov scale has little impact in this surface gravity jet context, and we will discuss entrainment/detrainment in the direction perpendicular to the surface.

3. The focus will be on the instrumentation used to characterize in situ turbulence in the katabatic jet, both dynamically and thermally. Essentially, we will be describing the principle of the sonic anemometer, which enables us to reconstruct the complete Reynolds tensor and the whole turbulent sensible heat flux with suitable temporal resolution. We will also be looking at the implementation of a high spatial resolution profiler for a 3D pitot with very high temporal resolution. Initial results from the ongoing katabatic wind observation campaign in the Austrian Alps, part of the European TeamX project, will be analyzed. Some numerical approaches to modeling turbulent boundary layer processes in katabatic wind and the laws of the wall derived from them will also be presented.

Léonie Canet – LPMMC – Space-time dependence of correlation functions in turbulence and related models

Calculating, from Navier-Stokes equation, the statistical properties of homogeneous and isotropic fully developed turbulence, in particular intermittency effects, which are deviations from standard scale invariance and Kolmogorov 1941 theory, remains an unsolved issue. The theoretical challenge to overcome is that correlation functions are determined by an infinite hierarchy of coupled equations that needs to be closed. The functional renormalisation group (FRG), offers an efficient theoretical tool to tackle this problem and achieve a controlled closure in the limit of large wavenumbers. The RG, as conceived by Wilson in the seventies, has been pivotal in understanding critical phenomena at equilibrium. Although it was intimately linked with perturbation theory at its origin, it has deeply evolved since then into a modern formulation, the FRG, which allows for both functional and non-perturbative implementations of the RG procedure.

In this lecture, I will first briefly review what is known about the statistical properties, in particular the temporal behaviour, of Eulerian correlation functions in fully developed turbulence. I will then briefly introduce the FRG, and show how it allows one to obtain exact analytical results on the space-time dependence of generic multi-point correlation functions of the turbulent velocity in the limit of large wavenumbers. I will compare these predictions with available results from direct numerical simulations and experiments. In a second part, I will explore related simplified models of turbulence, such as Kraichnan's model for passive scalar turbulence, or the stochastic Burgers equation, and show that a universal behaviour emerges in the temporal decay of correlation functions at large wave-numbers, and that its origin can be traced down to common underlying extended symmetries which I will discuss.

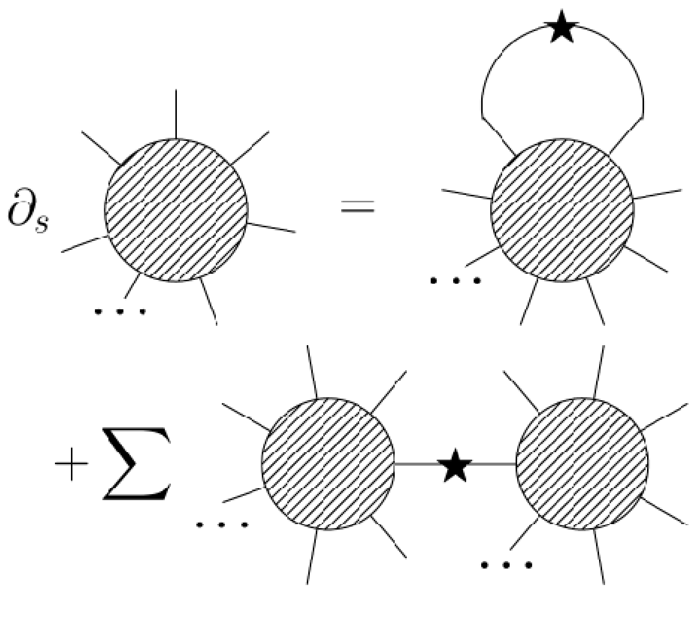


Figure: L. Canet, Journal of Fluid Mechanics, Perspectives, 950, 1 (2022)

Louis Couston – LPENSL – How quickly does ice melt in seawater?

This lecture will introduce the physics of ice melting in seawater, highlighting the role of turbulence. We will review the range of ocean conditions and ice geometries encountered in nature, focusing on polar seas adjacent to marine-terminating glaciers in Greenland and ice shelves fringing the Antarctica coastline. Comparing observations and predictions, we will show that we do not always know how quickly ice melts in seawater.

The melting of horizontal ice boundaries in a background flow leads to double diffusive convection or shear-driven wall turbulence, with weak to strong background density stratification depending on the strength of the mean current. We will review the scaling laws for momentum, heat and salt fluxes in these different regimes, and discuss whether they are in good agreement with state-of-the-art parametrizations for ocean-driven melt in large-scale ocean models. We will then explore the dynamics of meltwater plumes, which are thought to drive large melt rates in the critical grounding-line region where glaciers go from grounded to afloat. The melting of tilted ice-ocean interfaces produces fresh and buoyant seawater layers near the ice that can rise upslope rapidly depending on background conditions. We will discuss the interplay between ice melting, background entrainment and boundary friction that controls meltwater plume properties and review state-of-the-art parametrized models of their evolution along the ice base. Time permitting, we will review current challenges related to observations, simulations and experiments of ice melting in seawater, and offer some perspectives on how to make progress towards addressing in full the question "How quickly does ice melt in seawater?".

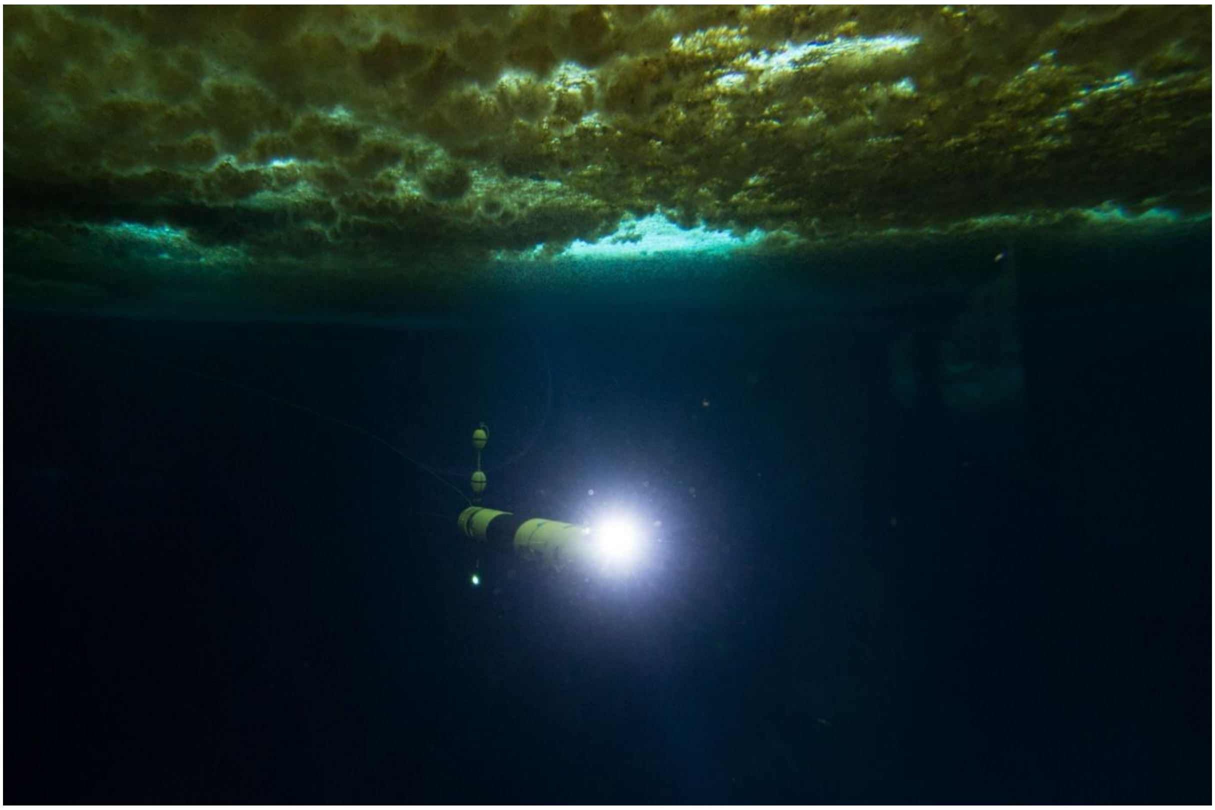


Figure: credit: ICEFIN Robot - B. Schmidt Lab.

Luminita Danaila – M2C – Temperature and wind statistics in the context of heat waves

Recent studies reveal two-way interactions between large-scale atmospheric structures and local near-surface features like temperature and wind. Focusing on the 2003 summer heat wave, we analyze temperature and wind statistics from the surface to the top of the atmosphere over the Northern Hemisphere using ERA5 data, combined with WRF (Wheather Research & Forecast) simulations. We employ Dynamical Mode Decomposition (DMD) to decompose the flow into mean (zonal jet), quasi-periodic variations (waves), and random fluctuations (eddies). By computing the Probability Density Function (PDF) of extreme temperature values across different spatial scales, we emphasize their significance and analyze the second, third, and fourth-order moments of temperature and wind—reflecting variance, interaction directions, and extreme event probabilities. Using the sign of the third-order mixed structure function, we identify both direct and inverse energy cascades along different spatial directions. These cascades reveal how energy transfers between scales inhibit the zonal advection of temperature anomalies, leading to the trapping of heat over Europe. This study underscores the complex turbulent interactions and directional energy transfers that lead to major heat wave events, emphasizing their intricate nature and predictability limitations.

This work is conducted in collaboration with M. Fossa, K. Hussain, C. Blervacq, N. Massei, and M. Ghil.

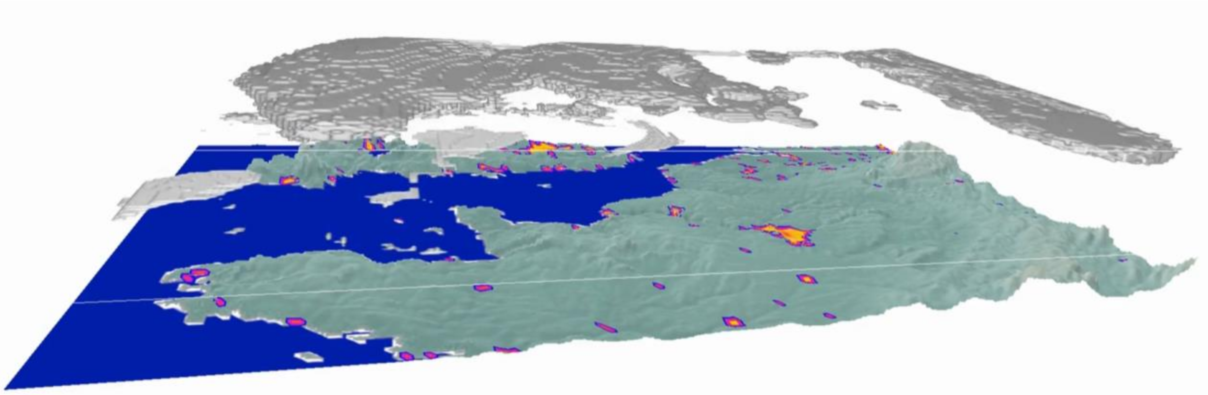


Figure. Precipitations over northern France, computed with WRF (Wheather Research & Forecast).

Davide Faranda – LSCE – Quantifying the Impact of Atmospheric Turbulence on Aviation Operations

Addressing aircraft turbulence not only enhances passenger comfort but also helps reduce fuel consumption and environmental impact, supporting aviation sustainability. This talk investigates how changing atmospheric circulation due to climate change affects in-flight turbulence over Europe. We show how reveal significant climate anomalies, with increasing turbulence intensity over the UK and Northern Europe, where most incidents involve clear air turbulence. This type of turbulence occurs unexpectedly and without warning, especially at high altitudes. Additionally, we discuss how distinct seasonal patterns in moderate-to-severe turbulence encounters, which are most frequent and intense in winter. This is largely influenced by wind shears related to the position of the subtropical jet over the Southern Mediterranean. Our approach builds on previous research by analyzing changes in individual atmospheric circulation patterns and their effects on turbulence-related factors. This provides insights into how anthropogenic influences on atmospheric dynamics may contribute to increased aircraft turbulence. We present specific examples of extreme events (windstorms) that have affected aviation in the last years. This is a joint work with Tommaso Alberti, Lia Rapella, Erika Coppola, Fabio Lepreti, Berengere Dubrulle, Vincenzo Carbone and Philippe Drobinsky.

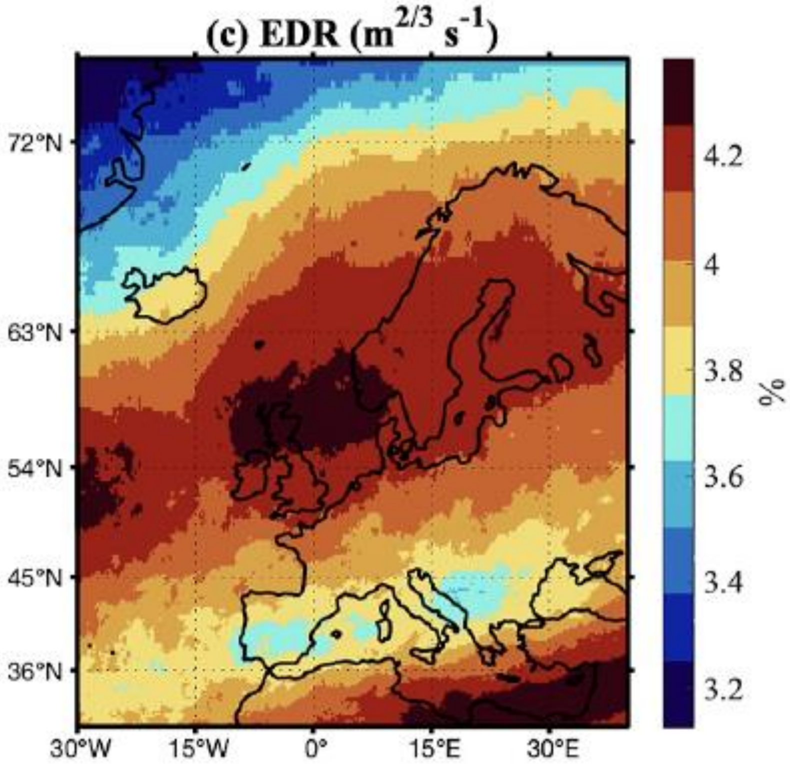


Figure. Eddy dissipation rate (EDR) map in the atmosphere from Alberti et al., Geophysical Research Letters, 51, 2024.

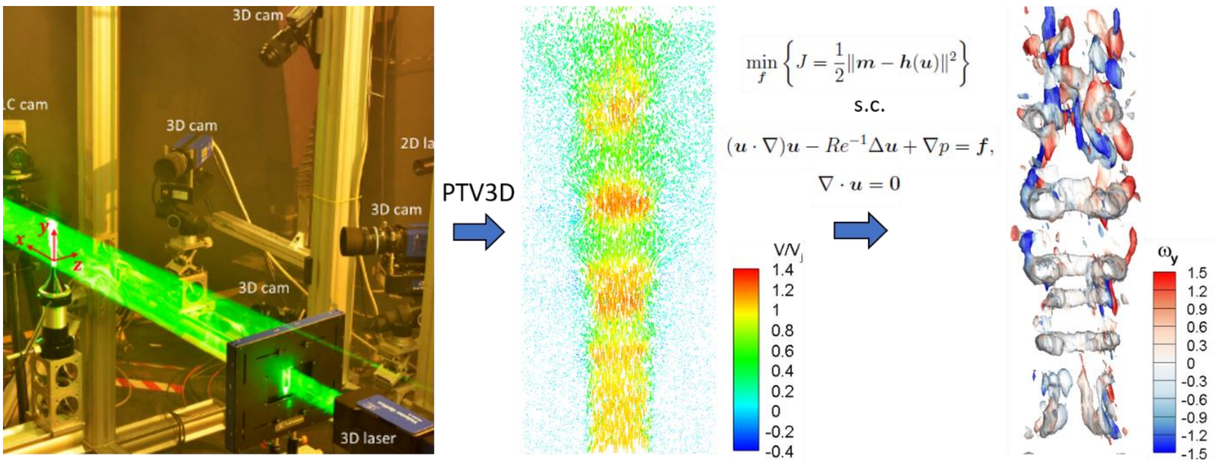
Szymon P. Malinowski – University of Warsaw – Turbulence in clouds and in the Atmospheric Boundary Layer: nonstationary, anisotropic and inhomogeneous. What can we do?

We live on a bottom of a highly turbulent medium. Turbulence is a key transport mechanism governing exchange of momentum, heat, and moisture between the Earth's surface and upper (above the Atmospheric Boundary Layer, ABL) atmosphere, where quasi-2D atmospheric circulations redistribute them on larger, even global scales. Understanding these processes, and more, understanding interactions between turbulence, thermodynamics and radiative transport (in particular related to cloud processes), is crucial to properly describe and model weather and climate. Unfortunately, usual tools used to parameterize turbulence and its effects in meteorological models are based on very simplified description of turbulence. Such problems as turbulence-cloud-convection organization and effects on energy transport between the full span of scales are not adequately addressed

In the course of the lecture, I will briefly sketch major deficiencies resulting from imperfect parameterizations of turbulence in meteorological models and will show possibilities of improvements. In particular we will present new methods to analyze atmospheric experimental data infer on turbulence non-stationarity, inhomogeneity and anisotropy in the ABL and turbulent clouds. Then we will discuss possible improvements of numerical simulations of the atmosphere resulting from the lessons learnt.

Benjamin Leclaire – ONERA – Measuring turbulence using particle imaging: from common practical use to advanced methods

Particle image and particle tracking velocimetry have become among the most popular choices for measuring flows with rich spatio-temporal dynamics. They come nowadays in a number of variants ranging from planar to volumetric, and from low frame rate to fully time-resolved. After having described their common operating principles, we will delve into their practical use for characterizing turbulent flows in wind- or water tunnels, until the extraction of relevant physical quantities thanks to advanced post-processing. Emphasis will be placed in particular on characterizing the methods' performances (spatial and temporal resolutions, error sources and uncertainty quantification). Hybrid experimental and numerical aka data assimilation approaches, which are now frequently used to extend the final flow accuracy and resolution, will finally be introduced.



Camille Lique – LOPS – Ocean mixing and its role for climate

In the global ocean, the mixing of heat, salt, and tracers is driven by a wide variety of dynamical processes that operate across a broad spectrum of scales, ranging from millimeters to several kilometers. These processes play a key role in shaping the large-scale circulation, stratification, and water mass distribution, ultimately influencing the ocean's role in the global climate system. This presentation will consist of three main parts.

Without aiming for a comprehensive review, I will first describe some of the important processes contributing to ocean mixing and turbulence, focusing on how these small-scale dynamics impact larger scales and establish the mean state of ocean conditions and circulation.

Second, I will discuss the various methods used by the scientific community to observe or infer ocean mixing, highlighting both the notable advancements and the remaining challenges.

Finally, I will focus on the Arctic Ocean, which is my main region of interest. In this region, the presence of sea ice and the unique dynamics of the Arctic Ocean create significant specificities in the processes contributing to mixing. These processes include, for example, the life cycle of ocean eddies, vertical mixing and heat fluxes, and surface waves interacting with sea ice. I will also examine how these processes play a critical role in the Arctic's response to climate change, with far-reaching consequences and feedbacks on larger scales.

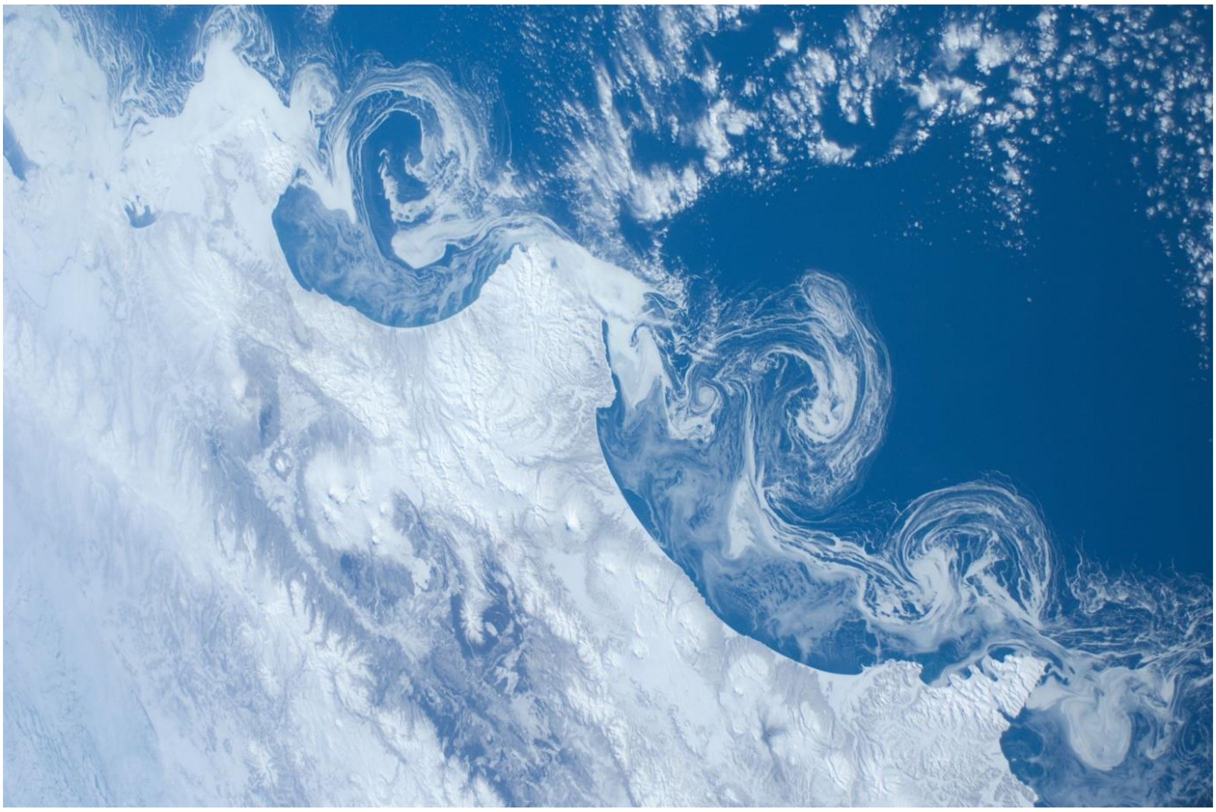
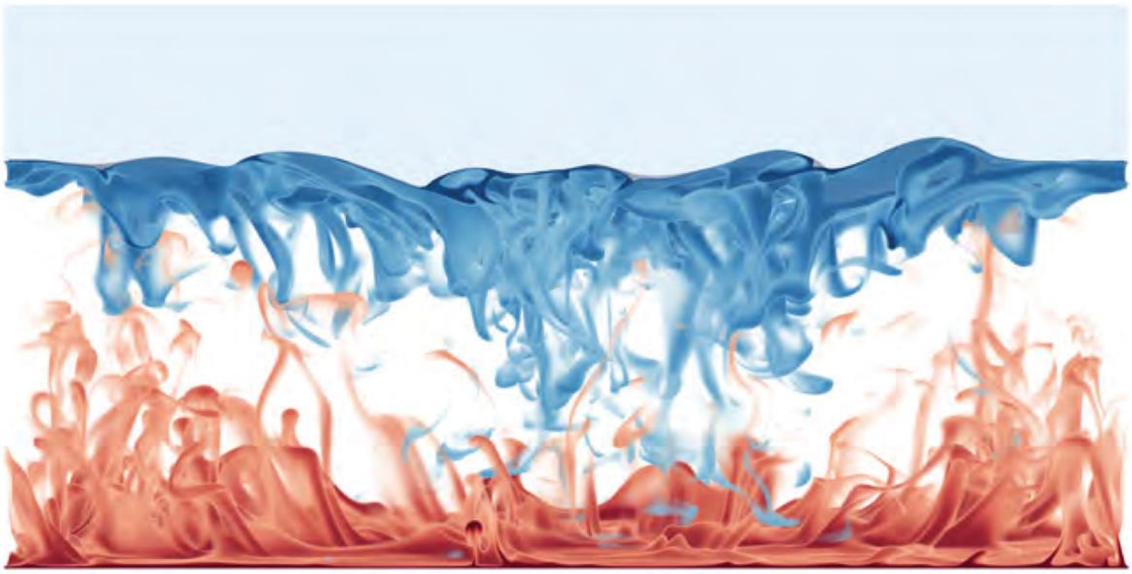


Figure. Picture taken from the International Space Station along the Kamchatka Coastline, Russia on March 15th 2012, showing the signature of ocean eddies on the sea ice distribution. Image courtesy of the Earth Science and Remote Sensing Unit, NASA Johnson Space Center (NASA Photo ID: ISS030-E-162344). Source: eol.jsc.nasa.gov.

Detlef Lohse – University of Twente – Melting of ice

The quantitative understanding of glacial ice melting into the ocean is one of the most outstanding challenges in environmental fluid dynamics. The lack of understanding is on a fundamental level, due to the highly complex multi-scale, multi-physics nature of the problem. The process involves intricate multi-way coupling effects, including thermal convection, salinity, ocean current, and radiation, etc. As ice melts into the surrounding salty water, a decrease in local salt concentration leads to reduced water density, inducing upward buoyant forces and, consequently, upward flow. This flow dynamically interacts with the ice, resulting in a feedback loop of further melting (Stefan problem). Our investigation employs direct numerical simulations with the phase field method. To capture the intricacies of melting dynamics within turbulent flows, we implement a multiple-resolution strategy for salinity and phase field simulations [3]. The versatility of our method is demonstrated through successful applications to diverse melting scenarios, including the formation of melt ponds [2], melting in Rayleigh-Bénard convection [4], vertical convection with fresh water [1], and vertical convection with salty water [3]. In this presentation, we showcase results obtained across these various geometries. This work contributes to advancing our understanding of the complex dynamics involved in glacial ice melting within oceanic environments.



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Ivana Vinkovic – LMFA – Large eddy simulation of particle transport by environmental turbulent flows

Large eddy simulation has become a well-established tool for predicting turbulent flows in a wide variety of engineering and environmental applications. In the past twenty years it has been extensively used for simulations of the atmospheric boundary layer and is currently applied to river flows. The main idea behind this modelling is to reduce the computational cost by low-pass (often grid) filtering the Navier – Stokes equations and therefore removing the smallest (subgrid) scales of the flow. The effect of these subgrid scales on the filtered flow field is then modelled. This task is an active area of research when small (subgrid scales) play a crucial role such as in near-wall or multiphase flows frequently encountered in environmental applications. This conference will deal with particle transport in LES and its application to turbulent boundary layer flows over rough beds in river flows or street canyons. Lagrangian particle tracking will be addressed. Modelling issues related to the turbulent flow but also to particle transport will be discussed in light of ongoing research. Applications of a simple modelling approach coupling LES and Lagrangian particle tracking will be presented in the case of sediment transport over a rough river bed with boulders and for particle or droplet dispersion over a street canyon in a turbulent boundary layer. Results and conclusions will be discussed as well as future studies and related research progress.

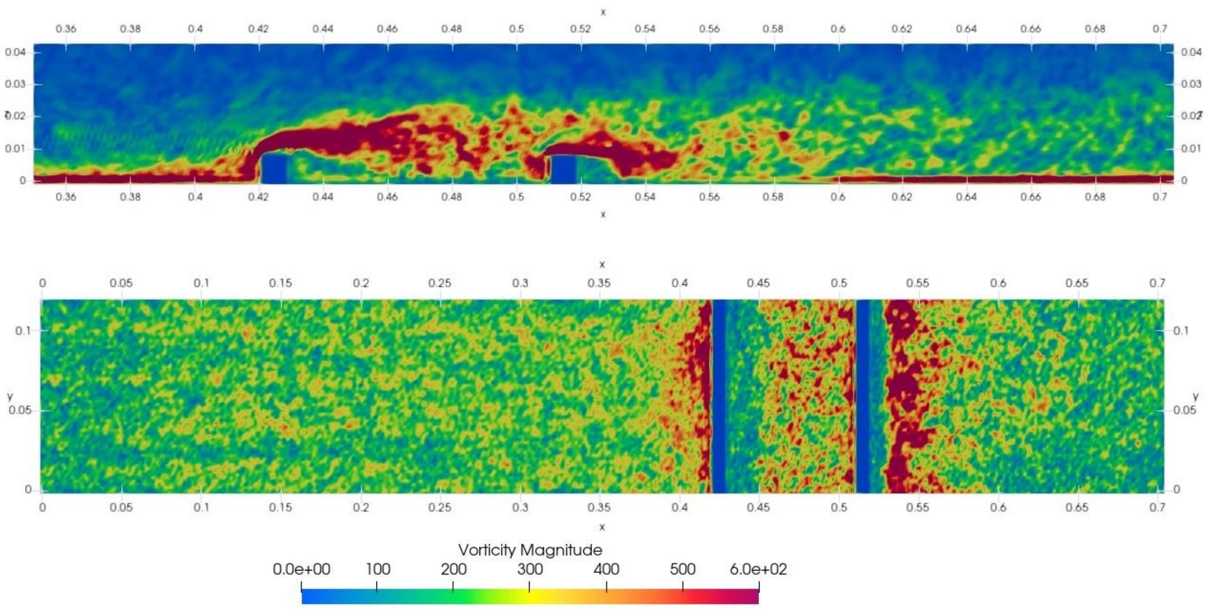
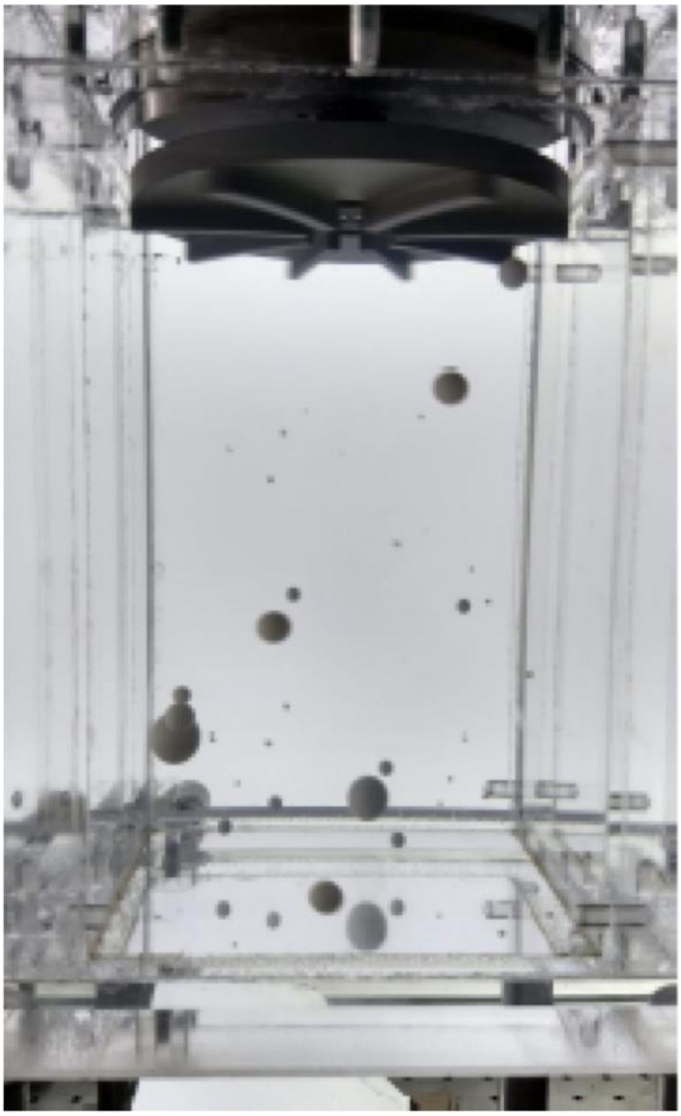


Figure. Vorticity magnitude obtained by large eddy simulation of a street canyon with 8 opening (H is the height of the obstacles) within a turbulent boundary layer, side view (top) and top view (bottom).

Romain Volk – LPENSL – How turbulent flows transport inertial and finite-size particles?

Many practical situations found in nature and industry involve the transport of objects by turbulent flows. Predicting the dynamics of such particles is challenging because it is influenced not only by their physical properties but also by their ability to respond to flow fluctuations. For very small particles, the dynamics are mainly governed by inertia, while the dynamics of particles much larger than the smallest eddy in the flow are more and more affected by their size as it approaches the flow integral scale. This leads to unexpected effects such as trapping in specific regions of the flow depending on the mean flow structure, with long-time dynamics resembling the ones of Brownian particles trapped in a two-well potential. In this lecture, I will review the basic properties of inertial and material particle transport in turbulent flows. Increasing the particle size from the dissipative scale to the integral scale, I will show how material particles respond to flow fluctuations and how their long-time dynamics build up when increasing the Reynolds number of the flow. Heat/mass transfer from such large objects will also be discussed in the example of ice spheres melting in forced convection.



Participant talks

Tuesday

Sofia Angriman – University of Twente – Melting Dynamics of Ice Objects: Collective Effects in Fresh Water

In nature, different factors influence the melting of an iceberg, and to accurately predict its melting rate it is of the utmost importance to understand how all of these aspects are involved. External flows, the difference in temperature with the surroundings, aspect ratio and size of the ice, the presence of salinity in the water, among others, all affect the melting dynamics. Neighbouring ice bodies further complicate the picture, as they can all interact with each other.

In order to disentangle the different phenomena involved, we focus on collective effects, and present an idealised numerical study of two ice bodies that melt close by in fresh water. Two square-shaped objects, with sizes on the order of the centimetres, are immersed in quiescent fresh water at 20 degrees Celsius. By performing two-dimensional Direct Numerical Simulations, and using the phase-field method to model the phase change, the effect of displacing the objects vertically is studied. While the melting of the upper object is mostly unaffected, the melting time and morphology of the lower ice body depends drastically on the initial inter-object distance, highlighting the intricate coupling between natural and forced convection.

Brivaël Collin – LPENSL – Experimental Study of Ocean-Driven Ice-Shelf Melting

We investigate the ocean-driven basal melting of ice shelves and icebergs using a simplified experimental set-up. We use a 40 cm high, 40 cm × 20 cm rectangular tank, which we fill with saltwater 30 cm deep and an overlying freshwater ice cube 10 cm thick. The whole setup is placed in a cold room at approximately 5-8°C to limit thermal exchanges with the surrounding air and a bottom heating plate is used to maintain the saltwater temperature at a prescribed value.

The depth-dependent seawater temperature, the currents, and the melt rates are explored for different bottom plate temperatures and initially homogeneous salinity and temperature conditions (0 g.L^-1 < S_0 < 35 g.L^-1 and 5°C < T_0 < 15°C). The formation of convection cells is observed, with typical thermal Rayleigh number Ra ∼ 10^7 −10^8. We find that the presence of salt creates a two-layer system in the liquid water that inhibits the melting.

The dynamics of our system are investigated using different techniques. We use a shadowgraph set-up to follow the ice-water melting interface and Pt-100 temperature sensors to capture temperature profiles. We also visualize the velocity field through a particle image velocimetry (PIV) setup using a laser sheet illuminating silver coated beads. The image acquisition is done with bursts of 10 images, allowing for an adaptive time-stepping to solidify the PIV results. These techniques provide a relatively comprehensive data set from which we derive a mapping between the average melting rate and the flow statistics (kinetic energy density, dissipation rate, temperature gradient) in a parameter regime of interest to polar oceanography.

Luz Andrea Silva Torres – UML Lab – Concentration and preferential accumulation of small floating particles in a convective ocean mixed layer.

Approximately 20 million tons of plastic enter the ocean each year. The study of the fate and transport of microplastics in the upper layers of the sea is complex since it involves several physical processes at different scales. It is unclear where and under what processes plastic entering the ocean is transported and redistributed. The mechanisms by which these particles are transported, concentrated and clustered along the depth are investigated by extensive direct numerical simulations of small floating particles released in an inhomogeneous turbulent flow. From an idealized 2D convective mixed-layer model, we reproduce some relevant features of the upper ocean flow: at the surface, a well-mixed region where temperature and density gradients almost disappear, and a lower area where a strong stratification in temperature and density develops. This allows a better understanding of particle dynamics in an anisotropic and inhomogeneous turbulent flow. Our objective is to provide a quantitative characterization of the vertical profiles of concentration and preferential accumulation and their dependence on the physical parameters of the fluid flow and particle properties.

Matteo Clementi – ETH Zürich – Experimental characterization of the inception and evolution of Langmuir circulations

The interaction between surface waves and the wind-driven shear current leads to the generation of Langmuir circulations below the surface: counter-rotating elongated vortices roughly aligned in the direction of the wind and waves, believed to play an important role in the exchanges of mass, momentum, and energy between the atmosphere and the ocean.

Here, we experimentally investigate the generation and evolution of Langmuir circulations in a combined wind and water tunnel. It features an 8 m long test section with a 0.8 m air space above 0.6 m deep water, and wave properties are changed by controlling the wind velocity. Particle image velocimetry is performed on the water flow, and the free surface is imaged in space and time by laser-induced fluorescence.

When the wind begins to accelerate from rest over a calm water surface, it creates a shear layer that steadily deepens, following a viscous diffusion scaling. This process continues monotonically until the inception of Langmuir circulations, closely linked to the initial growth of wind waves. These circulations quickly mix horizontal momentum vertically, leading to a deceleration of the surface layer.

Using two-point correlation analysis, we identify vortex length scales and track their evolution to a steady state. Additionally, turbulent kinetic energy dynamics reveal a significant increase compared to shear-driven boundary layer flows, highlighting the enhanced mixing induced by Langmuir circulations.

Wednesday

Caroline Nore – LISN – Numerical investigation of the role of energy transfers in the von Kármán sodium dynamo experiment

We develop a new method to unravel the dynamo mechanism based on a local energy budget that describes dissipation and scale-by-scale energy transfers. This method is motivated by the fact that the dynamo effect is a process that converts kinetic into magnetic energy. It is based on a novel filtering technique that works well with any kind of mesh, including unstructured ones. We use the finite element code SFEMaNS to apply it to data from direct numerical simulations of the von Kármán Sodium setup, which demonstrate dynamo action for two types of impellers (steel or soft iron). The locality of our formalism allows us to trace the origin of the differences between these two types of dynamos: for steel impellers, the dynamo is due to the transfer of velocity energy both in the bulk and in the vicinity of the impellers, whereas for soft iron impellers, the dynamo effect is primarily caused by the rotation of the impeller blades. We explore potential indicators of anomalous dissipative terms that may become significant in the inviscid limit.

Marie Couliou – ONERA – Effect of freestream turbulence on wingtip vortex dynamics

Ambient or freestream turbulence (FST) is a crucial factor for any aircraft, as it encounters atmospheric boundary layer effects during landing and take-off phases, as well as high-altitude turbulence while cruising. The effect of FST on wingtip vortex dynamics was investigated at a chord-based Reynolds number of approximately 100,000. Experiments were performed for turbulence intensities ranging from 0.3% to 12%, generated by an active grid in the 11.1-meter-long wind tunnel at NTNU (Trondheim, Norway). Stereoscopic PIV measurements were conducted from the near field to the far field of a NACA0012 wing, up to 48 chords downstream from the wing's trailing edge. Increasing FST enhances vortex diffusion and amplifies its meandering amplitude. Snapshot proper orthogonal decomposition (POD) of the coherent streamwise vorticity field identified two dominant modes associated with vortex meandering across all FST cases. Furthermore, with increasing FST, POD reveals deformation modes of the vortex structure in the near field that, in no-turbulence cases, only appear in the far field, suggesting that FST accelerates the onset of vortex instabilities. Upstream flow conditions with spatiotemporal modulations of the FST were also tested, with parameters including the amplitude, frequency, and direction of these modulations. Preliminary analyses reveal a phenomenon of vortex oscillation locking into preferential positions for certain vertical modulations of upstream flow velocity.

Jean Le Bris – CEA/SPEC – Reaching sub-Kolmogorov measurements in a turbulent swirling flow

Reaching the sub-dissipative range in direct numerical simulations is challenging, and it is very complicated to obtain decorrelated statistics. Experiments are more suited for such studies. A new prototype of von Kármán experiment, the Giant von Kármán, has recently been developed at CEA as a means to solve this issue. Its sheer size allows us to optically investigate the flow at a smaller scale than ever before over the course of several minutes, at large Reynolds from Re = 10^4 to 10^6. We seed the flow with particles of a radius 5.33µm, and use a laser as a light source. Four cameras then capture the light diffused by the seeding particles in a small volume (50 mm x 45 mm x 6mm) at the center of the experiment. Recent improvements have allowed us to almost triple the attainable seeding density in the volume, while ensuring that we reach low-noise, highly resolved (both spatially, down to η/4, and temporally) velocity field. Reaching such resolutions will allow us to study extensively sub-Kolmogorov phenomena.

Is Navier-Stokes valid below the Kolmogorov scale ?

To study the deviation to Navier-Stokes, we choose, rather than to compute the pressure field, to derive the vorticity fields from the velocity. We introduce $\delta\omega$ the deviation with respect to the vorticity equation at a given scale l. Previous work has highlighted, at resolutions reached in the Small von Kármán setup, the correlation between regions of high $\|\delta\omega\|$ and those of high local energy transfer D_l^I. We'll investigate whether we still have energy transfers hinting at singularities in our measurements below η.

Hyunseok Kim – Max Planck Institute for Dynamics and Self-Organization – An Experimental Study of the Deviation of Particles from Perfect Tracers

In flow visualization studies, it is crucial that particles faithfully follow the flow, i.e. that they are perfect tracers. However, achieving perfect traceability is challenging, especially in gas flow visualization or atmospheric turbulence studies in the field, often requiring compromises. This study investigates the behavior of mildly imperfect tracer particles in high-Reynolds number homogeneous isotropic turbulence using a three-dimensional Lagrangian particle tracking setup. Through this approach, we quantify the effects of tracer particle imperfection on various parameters, providing a deeper understanding of the limitations and adjustments necessary for practical applications.

Thursday

Alinénor Rivière – EPFL – Bubble shape oscillations in turbulence

We study single bubble deformation statistics in an homogeneous and isotropic turbulent flow by means of direct numerical simulations. We consider bubbles at low Weber number (We<3) that have not been broken. We show that we can reproduce bubble deformations with a linear dynamics for each spherical harmonic mode. Inferring the coefficients of the linear model from the DNS data, we find that the natural frequency corresponds to the Rayleigh frequency, derived in a quiescent flow. However, the effective damping increases by a factor 7 compared with the quiescent case, at Taylor Reynolds number Re_λ=55. Looking at the flow structure around the bubble, we argue that the enhanced damping originates from a thick boundary layer surrounding the bubble. We demonstrate that the effective forcing, originating from the turbulent flow forcing on the bubble surface, is independent of bubble deformability. Therefore, the interface deformations are only one-way coupled to the flow. From this model we conclude that bubbles break rather from turbulent fluctuations than from a resonant mechanism. Eventually, we investigate the pressure modes' statistics in the absence of bubbles and compare them with the effective forcing statistics. We show that both fields share the same probability distribution function, characterized by exponential tails, and a characteristic time scale corresponding to the eddy turnover time at the mode scale.

Puneet Sharma – Max Planck Institute for Dynamics and Self-Organization – Particle dynamics in clouds: insights from the zugspitze observatory

The collision-coalescence process in cloud droplets, driven by particle dynamics in turbulent environments, plays a critical role in cloud formation and precipitation. However, this process remains poorly understood due to the complex interactions influenced by turbulence. To study cloud droplet collision rates, we built a particle track-
ing setup at the environmental research station Schneefernerhaus. The setup provides three-dimensional droplet positions and diameters with micrometre precision, enabling analysis of droplet spatial arrangement via the Radial Distribution Function (RDF).
The RDF provides a statistical measure of the probability of finding a droplet at a specific distance from a reference droplet, compared to a uniform distribution. If the value of RDF exceeds 1, it indicates clustering, meaning that droplets are more likely to be found at that
specific distance than in a random, uniform distribution. We derive a general formula of RDF, and compare it with numerical simulations for standard geometries such as spheres, cylinders, cubes, prisms, toroids and cones. We leverage this methodology to study the
clustering behaviour of particles in the observatory. The setup also provides the droplet size information, which can be used to compute parameters related to cloud microphysics and the Stokes number, the dimensionless parameter indicating the droplets' inertia, allowing us to compare our measurements with existing in-situ measurements, numerical simulations and theoretical results.

Florian Lorin – Institut Néel – Triggering quantum turbulence in rotating superfluid helium

Discovered in 1937, superfluid helium — He II — is a key system for studying superfluid dynamics, which remains incompletely understood. Superfluid phases have exotic properties, such as the presence of topological defects known as quantum vortices. Counterflow quantum turbulence, which showcases energy transfer through vortex reconnections happening in vortex tangles, has no classical counterpart.

The study of He II under rotation allows control of the fluid's initial vortex configuration. Our experimental facility – CryoLEM for Cryogenic Lagrangian Exploration Module – is a rotating cryostat that enables direct observation of quantum vortices by injection of micron-sized H2 particles [1]. Temperature-dependent properties can be investigated by pressure regulation.

The hydrodynamical regimes of rotating He II were first studied in [2]. By imposing a heat flux in the fluid, they observed a rise in vortex line density above a flux threshold interpreted as a transition to turbulence. We show that the latter corresponds to the evolution of an oscillating vortex lattice state to a turbulent state and investigate the temperature dependence of this threshold to understand the role played by counterflow in this transition.

[1] Peretti et al. Direct visualization of the quantum vortex lattice structure, oscillations, and destabilization in rotating 4He. Science Advances, 2023.
[2] Swanson et al. Rotation of a tangle of quantized vortex lines in He II. Physical Review Letters, 1983.

<u>Matthieu Chatelain – LPENSL – Lagrangian transport in a Gaussian stochastic turbulent flow</u>

Due to the non-linearity of Navier-Stokes equations, dispersion of particles in atmospheric and oceanic flows remains largely misunderstood and unpredictable. This is to be related to the complexity of the turbulent processes involved and to its temporally and spatially multi-scale characteristics. In this work, we construct a class of stochastic models of turbulent flows with Gaussian multi-scale statistics in time and space and we study the corresponding trajectories of Lagrangian tracers.

The first aim of our work is thus to provide stochastic models that statistically describe turbulence up to the second moment. We start by prescribing the spatial spectrum of a temporally evolving Ornstein-Uhlenbeck process -a simple but rich example of stochastic process- and refine this model to provide temporally differentiable models for its Fourier modes. We then go further building an infinitely differentiable process with Gaussian decreasing Fourier mode's correlation functions in agreement to DNS observations. Eventually, we numerically integrate those stochastic equations with a statistically exact scheme based on a fine analysis of the covariances. Secondly, we will discuss properties of tracers advected by the Eulerian flow, studying the statistics of their acceleration and their velocity increments.

Posters

Monday

Quentin Kriaa – University of Twente – Melting and self-insulation of floating ice shapes in saline water

Most studies analyse ice melting in idealized conditions with a fixed object in a virtually infinite domain. We investigate the specific dynamics of floating ice blocks, focusing on their freedom of motion and on the consequences of confinement due to the presence of a free surface. We conduct laboratory experiments of ice objects melting at the free surface of a water tank of uniform initial ambient temperature 20°C, with a salinity varied from 0 to 35g/kg (seawater salt concentration). Although density anomalies due to salt should dominate over those due to temperature for most of our experiments, quantification of the large-scale flow reveals that fluid motions are always thermally-driven. This is due to the blocking effect of the free surface which prevents the formation of a fast upward plume of fresh meltwater. The analysis of melt rates confirms this driving role of temperature differences. While rotation and capsizing of the ice barely affect the former statistics, the motion of ice impacts its small-scale morphology. We analyse how salt modifies the flow at the ice-water interface, causing the emergence of striations and 'scallop'-like patterns that modify the ice morphology and melt rate. Finally, turbulent entrainment and incomplete mixing between the ambient and the meltwater leads to an accumulation of fresh meltwater below the free surface, creating a cold stratified layer that insulates the ice, delaying melting and modifying the ice morphology.

Corentin PRADOS – IGE/LPENSL – Turbulence in proglacial lakes and ice channels: high-fidelity resolution and impact on ice melting

Proglacial lakes are becoming increasingly common and larger because of climate warming. As a result, downstream communities are more exposed to torrential floods. Lately, large proglacial lakes have been artificially drained through man-made channels at the glaciers' surface. In this work, we model the turbulent dynamics of supraglacial channels and heat transfers, to investigate their stability against their enlargement resulting from phase changes.

We hypothesize that heat exchanges between a supraglacial river and its surrounding environment primarily occur at the bottom ice-water interface. A numerical model with periodic boundary conditions in the horizontal directions is used to analyze the dependence of the Nusselt number on channel slope and density stratification. We take into account the anomaly in the freshwater equation of state. The thermal expansion coefficient is negative at low temperatures, such that both mechanical forcing and thermal effects contribute to turbulent kinetic energy production and enhance heat transfers.

We will compare results from two open-source numerical codes: Dedalus (CPU, spectral) and Oceananigans (GPU, finite volumes). We will analyse the numerical convergence of each code and their carbon footprint. This analysis will shed light on opportunities to reduce the carbon footprint of turbulence research.

Finally, this work will be validated against existing field data and future measurements, resulting from e.g. draining of Tignes Lake.

Axel Tassigny – LEGI – Characterization of internal waves in the Strait of Gibraltar from a large scale realistic physical model

Large amplitude internal waves, propagating eastward are often reported in the Strait of Gibraltar and the Alboran sea, resulting from the interaction between strong tidal currents and topography-driven internal hydraulics.

Laboratory experiments at a high level of realism have been performed reproducing the main forgings, i.e. the bathymetry, the density differences (baroclinic forcing), the Earth's rotation, and the tidal (barotropic) forcing, including spring/neap tides and their modulation. A reduced model of the topography of a region including the Strait of Gibraltar, the west Alboran Sea representing a region of 250kmx150km and the Gulf of Cadiz was mounted on the 13 m diameter Coriolis Platform at LEGI, Grenoble. Experiments are carried out in similarity with respect to the Rossby and Froude numbers at Camarinal Sill, with a Reynolds number of 5,000.

In spring tide conditions, we are able to reproduce the generation and propagation of eastward traveling internal waves in similarity. Two regimes of internal waves, bore-like and soliton-like, are observed. Bore are shown to produce more turbulence and mixing than solitons. Their dichotomy is attributed to a change in the hydraulic criticality of the background flow, and can be predicted by a two-dimensional and two-layers model, despite the intrinsic 3D character of the mean flow in the eastern part of the Strait.

Olivier Coquand – LMPS – Energy cascades in sheared granular flows

Recent numerical simulations have shown that sheared granular flow are governed by scaling equations, describing how the energy flows between the macroscopic scale at which it is injected in the system, and the microscopic scale at which it is dissipated. The values of the exponents however are different from the K41 theory. In this work, we study the possibilities of emergence of new universality classes in fluids, by bridging the gap between continuous models of turbulence in Newtonian liquids, and granular liquids under shear.

Maëlys Magnier – LEGI – Lagrangian study in a stably stratified fluid forced by internal or inertia-gravity waves in a pentagonal domain

This poster presents the implementation of a 3D Particle Tracking Velocimetry (PTV) in the Coriolis facility in LEGI, Grenoble. This Lagrangian measurement system is used to study (stably) stratified turbulence forced by internal gravity waves or inertia-gravity waves. The development of a Lagrangian method to study particle dispersion in a large-scale experiment is particularly complex, due to the large size of the measurement volume (of the order of $1m^3$), to variations in the optical index of the stratified fluid, to vibrations of the structure slightly deforming the free surface and to seeding issues related to sedimentation of the tracers.

Once the images have been recorded, we use the 4D PTV code, available on GitHub and developed by the Physics Laboratory of ENS Lyon. We use 4 cameras to obtain the three-dimensional position of particles as a function of time. One of the special features of this code lies in the efficient method used for 3D matching of lines of sight obtained from each camera, a key stage in the spatial accuracy of particle positioning. After a long exploratory phase in terms of both experiments and choice of data processing parameters, we are now able to obtain measurements of the three-dimensional position of hundreds of particles as a function of time, and hence their velocities. These data will enable us to explore the middle to small scales of wave turbulence, particularly when wave breaking occurs, transferring the energy of the waves to the vortices.

Corentin Bourjaillat – Institut Néel/LEGI – Experiments on the destabilisation of a liquid jet into droplets by a fast gas stream

The destabilisation of a liquid jet into droplets by a fast gas stream is at the heart of many applications, such as in the combustion chamber of a rocket or in oceanic sprays. However, existing models and numerical simulations of these interactions have been validated far from actual conditions. The Cryospray project aims to narrow the gap between predictions from methods such as linear stability analysis and experimental measurements. For this purpose, atomisation experiments are conducted at LEGI with a canonical air/water nozzle to characterise the impact of certain geometrical parameters. In particular, we perform hot wire measurements to inform us about wetting conditions at the nozzle exit, of which the modeling in linear stability analysis currently relies on assumptions. Another set of experiments aims to understand whether the scale of the nozzle impacts fragmentation through the study of homothetic variations of the canonical nozzle. Furthermore, the main objective is to experimentally study jet instabilities and droplet formation in a parameter space larger than in literature and previous experiments. To this end, a liquid nitrogen atomiser cryostat is being developed at Institut Néel using a downscaled version of the canonical nozzle. The low surface tension of liquid nitrogen allows the study of the destabilising mechanisms proposed by Matas et al. [1] over extended ranges of parameters such as the Weber number or the liquid/gas momentum ratio.

[1] Matas, J. P., Delon, A., & Cartellier, A. (2018). Shear instability of an axisymmetric air–water coaxial jet. Journal of Fluid Mechanics, 843, 575-600

Thibault Desaleux – CEA/IMFT – Statistical and extreme events study in internally heated convection

Turbulence in Rayleigh-Benard convection has been widely studied, but turbulence in internally heated convection, common in self-heated fluids, remains underexplored. However, it is crucial to better understand this phenomenology in the nuclear severe accident to apply mitigation strategies. During those events, nuclear fuel melts and mixes with reactor core structures, forming corium—a high-temperature magma (≈3000K) relocating in the vessel lower head due to gravity. The dynamics in this setup, driven by internal heating and vessel wall cooling, are inherently strongly turbulent.

A numerical approach with a simplified geometry - a rectangular box with periodic condition and with no slip conditions in the horizontal and vertical boundary directions - is used to study the dynamic and thermal turbulent structures. Thus, a cooling occurs at the top and bottom with an imposed temperature, while uniform heating is introduced via a source term in the temperature equation. A study with direct numerical simulations is carried out by varying Prandtl (from 0.5 to 5) and Rayleigh (from 106 to 1012) numbers, the dimensionless numbers relevant to the system.

Firstly, standard statistical tools, such as two-point correlations and spectra will be applied to analyze turbulent structures. Secondly, particular attention will be paid to wall heat fluxes and their extreme events which threaten vessel integrity will be carry out.

Noam Bloch – LEGI – Numerical study of hydrodynamic instabilities in pump-turbines at low opening

Reaching the target of carbon neutrality is needed to stabilize the global warming we are facing. For that purpose, in addition to the sufficiency effort in every sector, i.e. reducing the demand, introducing intermittent renewable energy sources in the energy mix appears to be unavoidable. That intermittency leads hydraulic machines to be used increasingly frequently outside their initial design points, as an adjustment variable for grid stability. This is particularly the case for Pumped-Storage Power plants (PSP) using pump-turbine groups (PT). Predicting the performance of these machines, for a wide range of operating conditions, is therefore a crucial issue.

For “out of design” operating conditions, PT can have undesirable effects, due to the development of hydrodynamic instabilities. In pump mode at low discharge, the phenomenon is called the “hump”. It first consists in a rotating stall in the tandem cascade (guide vanes and stay vanes), and then in a backflow from the runner to the cone, this last part being called the “runner hump”.

The goal of my work is to improve the understanding of the runner hump zone, from its appearance and vanishment mechanisms to the quantification of the head drop linked to it. To achieve this objective, Large Eddy Simulations (LES) are performed because they can accurately predict highly unstable and unsteady flows such as those of the operating regimes concerned.

Jiyang He – The Hong Kong University of Science and Technology – Multiple states of two-dimensional turbulence above topography

Through direct numerical simulations, we found that the long-term state of two-dimensional turbulence above topography is strongly dependent on the initial length scale (namely, the initial enstrophy). If the initial length scale is comparable to the domain size, the long-term flow field resembles the minimum-enstrophy state proposed by Bretherton & Haidvogel (J. Fluid Mech., vol. 78, issue 1, 1976, pp. 129–154), with very few topographically locked vortices; the long-term enstrophy is quite close to the minimum value, especially when the energy is no larger than the critical energy level. As the initial length scale becomes smaller, more vortices nucleate and become more mobile; the long-term enstrophy increasingly deviates from the minimum value. Simultaneously, the background PV tends to homogenization, even if the energy is below the critical energy level. These results complement the phenomenology of topographic turbulence documented by Siegelman & Young (Proc. Natl Acad. Sci. USA, vol. 120, issue 44, 2023, e2308018120), by showing that the minimum-enstrophy and background PV homogenization states can be adequately approached by large- and small-scale initial fields, respectively, with relatively arbitrary energy.

Murukesh Muralidhar – LPENSL/CEA SPEC – Extreme events in a random set of bending elastic waves

Rogue waves are exceptionally large & extreme waves that take place in seas and oceans. Traditionally, they are defined as waves with heights exceeding twice the significant height, for a given sea state. These rare, destructive events demand an understanding of their underlying physical mechanism for their prediction, particularly considering their impact on seafaring and structures. This study investigates the existence and characteristics of such extreme waves in a mechanical wave system—a thin, elastic stainless steel plate.

The elastic plate adheres to wave turbulence theory, assuming a 4-wave process. Despite analogies to surface waves, differences exist, notably the absence of an inverse cascade in these elastic waves. For waves longer than the plate's thickness, this dispersive media is considered two-dimensional, governed by a dispersion relation: ω=λk2, with λ as the efficient coefficient measuring the plate's response to external force [Nazarenko, Wave turbulence, 2011]. A large electromagnetic shaker sustains the plate in a steady state of motion, out of equilibrium. Laser vibrometers are used to make point measurements of the displacement and velocity at point of interest and at point of energy injection. Questions arise regarding the system's ability to exhibit extreme states and the physical mechanisms involved. Can occurrences be quantified, and are the same mechanisms applicable to ocean waves? Addressing the effect of forcing frequency and amplitude on extreme wave observation is a primary focus. Determining the proper wave description—geometrical or kinematic—is also crucial.
We present the first experimental observation of “elastic rogue waves”. The displacement spectral density shows a slope of -2 in the low-frequency regime, consistent with energy equipartition below

the excitation frequency. Interestingly, the occurrence of rogue events is not strictly associated with the highest steepness of the waves, which may seem counter-intuitive at first. Another intriguing finding is that the asymptotic value of the percentage of occurrence of these extreme states is independent of the forcing frequency, marking a significant inference. Conditional statistics reveal correlations that further illuminate the underlying physical mechanisms leading to such a state on the elastic plate.

Nicolas Lanchon – CEA SPEC – Event-Based Cameras for Efficient (and Cost-Effective !) PIV Applications
Particle Image Velocimetry (PIV) and Particle Tracking Velocimetry (PTV) are critical techniques for flow visualization in experimental fluid mechanics. However, the implementation of these methods often requires expensive equipment and generates vast quantities of data.

Recently, a new type of camera, known as an “event-based camera” or “neuromorphic camera,” has become available. Unlike conventional cameras, event-based cameras do not record images but instead detect changes in intensity at each pixel asynchronously and independently. This novel approach drastically reduces data volume while achieving an equivalent acquisition rate of 10 kHz. Additionally, these cameras are significantly more affordable, costing approximately ten times less than traditional PIV systems.

In our study, we develop experimental methods and algorithms designed for event-based cameras to measure 2D Eulerian velocity fields. This approach demonstrates the potential of event-based cameras as an efficient, cost-effective alternative for flow visualization in fluid dynamics research.

Wednesday

Jean-Baptiste Gorce – MSC – Decaying Saffman Turbulence

We investigate experimentally the decay of three-dimensional hydrodynamic turbulence, initially generated by the erratic motions of centimeter-size magnetic stirrers in a closed container. Such zero-mean-flow homogeneous isotropic turbulence is well suited to test Saffman's model and Batchelor's model of freely decaying turbulence. Here, we report a consistent set of experimental measurements (temporal decay of the turbulent kinetic energy, of the energy dissipation rate, and growth of the integral scale) strongly supporting the Saffman model. We also measure the conservation of the Saffman invariant at early times of the decay and show that the energy spectrum scales as k^2 at large scales and keeps its self-similar shape during the decay. This Letter thus presents the first experimental evidence of the validity of the connection between the Saffman invariant and the k^2-energy spectrum of the large scales. The final decay regime closely corresponds to Saffman's model when the container size is sufficiently large.

Daniel Boutros – University of Cambridge – An analogue of Onsager's conjecture for the inviscid primitive equations of oceanic and atmospheric dynamics

Onsager's conjecture provides regularity conditions for weak solutions of the incompressible Euler equations to conserve or dissipate energy, which is related to the description of sufficient criteria to rule out the dissipation anomaly in the zero viscosity limit. This conjecture has been fully established in the case of the Euler equations. We consider an analogue of Onsager's conjecture for the hydrostatic Euler equations (also known as the inviscid primitive equations of oceanic and atmospheric dynamics), which are derived by taking the small aspect ratio limit.

The resulting anisotropic and nonlocal structure of these equations coming from this singular limit makes it possible to introduce and consider several new classes of weak solutions and to prove a range of sufficient criteria for energy conservation, which are independent of each other. This means that there probably is a 'family' of Onsager conjectures for these equations. Furthermore, we prove the existence and nonuniqueness of weak solutions to the inviscid primitive equations. These results are joint works with Simon Markfelder and Edriss S. Titi.

Lucas Fery – CEA LSCE – Subgrid-scale modeling of turbulent shear flow with vortons

We introduce a novel subgrid-scale model for shear flows, exploiting the spatial intermittency and the scale separation between large-scale flows and coherent small-scale structures. The model is highly sparse, focusing exclusively on the most intense structures, which are represented by vortons—dynamically regularized quasi-singularities that experience rapid distortion from the large-scale shear. The vortons, in turn, influence the large-scale flow through the subgrid stress tensor. The model displays an interesting transition between two distinct regimes: (i) a laminar regime, where dissipation is entirely attributed to the large-scale flow, and the vortons dynamics is essentially diffusive, and (ii) a turbulent regime, in which most of the dissipation arises from the vortons. These regimes correspond to different scalings of dissipation and the Grashof number as functions of the Reynolds number, with power-law relationships that resemble those observed in classical turbulence.

Adrien Lopez – CEA SPEC – Turbulent boundary layer in Logarithmic Lattices

Introduced in 2019, the Logarthmic Lattice method is an idealized model to simulate fully turbulent fluids, akin to a multidimensional generalization of shell models. It is based on an exponential sampling of the Fourier modes. When calculating nonlinear terms (like the advection terms), the passage to physical space is not possible anymore due to the decimation of modes. Instead, the convolution product is calculated directly in Fourier space. Its complexity is kept in check by a suitable choice of the logarithmic spacing of the sampled modes. This allows to save up memory and computational resources and makes possible simulations with parameters like the Reynolds number in a geophysical or astronomical range.

In its original formulation, it is difficult to accommodate boundary conditions, which are necessary for any relevant geophysical modelling. Indeed, the method is purely spectral and the link with physical space is compromised by the decimation of modes. This new method consists in formulating Navier-slip boundary conditions (where boundary tangential stress is proportional to tangential velocity) in Fourier space. This approach gives a tunable parameter (slip length) to phenomenologically model the properties of a flat boundary (like roughness). By varying this parameter, two regimes are identified in the turbulent limit of high Reynolds number with different scaling laws.

Abhishek Paraswarar Harikrishnan – CEA SPEC – Vortex Reconnection on Logarithmic Lattices

Vortex reconnection is aptly described by Yao and Hussain (2020) as a ''fundamental topology-transforming dynamical event''. Studying its mechanism is important for predicting the behavior of trailing vortices of an aircraft, understanding the turbulence cascade and more importantly, the occurrence of finite-time singularities in Euler or Navier-Stokes equations. Simulations are usually carried out with direct numerical simulations or simplified models based on the Biot-Savart law. While the former becomes computationally expensive for large Reynolds numbers where the number of nodes N scales like $Re^{9/4}$, the latter techniques cannot adequately represent core-flattening processes that occur during reconnection time which are known to significantly dampen vorticity amplification (see Moffatt and Kimura (2019) and Yao and Hussain (2020)). In this talk, we will first discuss a simplified model developed by Campolina and Mailybaev (2021) where the velocity fields are defined on discrete multi-dimensional logarithmic lattices in Fourier space. Similar to other shell models of turbulence, this configuration allows us to reach very high Reynolds numbers with few modes. Since it also uses the full Navier-Stokes equation but on a simplified configuration space, numerous aspects of reconnection including core-flattening and bridge formation are preserved. The initial configuration, reconstruction of physical space from lattice variables and qualitative aspects of reconnection are discussed in a later part of the talk.

Federica Gucci – University of Cologne – Directionality of the turbulent exchange of momentum: an eigen-decomposition approach

Existing formulations of near-surface turbulence were developed for flat and horizontally homogeneous terrain, which is not representative of most of the Earth's land surface. There is evidence that including the information on the directionality of the turbulent exchange of momentum (anisotropy), represented by the eigenvalues of the stress tensor, may improve the empirical formulations used in weather and climate models and allow their extension to complex orography.

The present contribution explores how specific sets of eigenvalues (determining the shape of anisotropy) and eigenvector's directions are related to particular components of momentum exchange in the coordinate system widely applied in turbulence studies. The approach investigates the uniqueness of the relation between eigenvalues and momentum exchange and if the eigenvectors' direction is physically constrained (e.g., by atmospheric stability, height above ground), as this could give insights for turbulence models. Two datasets from a relatively flat terrain and a glacier site are used to answer these questions. It is shown that eigenvectors' direction depends on the examined site, and other factors are not straightforward to isolate.

Elliot Bes – LEGI – Quantum turbulence simulations using the vortex filament model.

When helium-4 is cooled down near absolute zero, it reaches a superfluid state, where it can flow with virtually no viscosity. Because of quantum mechanical constraints, any rotational motion of the fluid will generate quantum vortices, which possess a quantified circulation and a atom sized radius. These vortices can reconnect with one another, and when many vortices interact with each other, a state known as quantum turbulence may appear. This state has been shown to display similar properties to turbulence in classical fluids, including the emergence of Kolmogorov's 1941 laws. We show preliminary results from numerical simulations of quantum turbulence using the vortex filament model (VFM) in the zero temperature limit. In the VFM, quantum vortices are represented as three-dimensional space curves that interact through the Biot-Savart law. Our results show the same power laws for the energy spectrum and the variance of velocity circulation observed in classical turbulence.

Mano Grunwald – Max Planck Institute for Dynamics and Self-Organization – Large-scale 3D Lagrangian particle tracking using soap bubbles

Field measurements of atmospheric turbulence are challenging to conduct, not only because flow conditions are constantly changing in space and time, but also because of the high Reynolds numbers and thus the large range of scales present in the turbulence. Among the most challenging techniques is Lagrangian particle tracking, which is used to investigate turbulent mixing and dispersion behaviour. The ability to conduct highly-resolved Lagrangian measurements in the atmosphere is of interest to a wide range of applications including wind turbine flows, the spreading of pollutants and urban fluid dynamics.

This study is motivated by the desire to investigate coherent structures in the wakes of wind turbines. These flow structures are too small to be adequately captured by large-scale measurement techniques like LIDAR and remote sensing. However, they require fields of view significantly larger than those achieved in laboratory-scale experiments. Here, we explore soap bubbles as atmospheric tracer particles. We use Phantom high-speed cameras for data acquisition and a shake-the-box code for reconstructing the particle tracks. The long-term goal of this work is to image the largest possible field of view in order to study the flow behind wind turbines and other large-scale structures.

Lorenn Le Turnier – Max Planck Institute for Dynamics and Self-Organization – Lagrangian particle tracking in a high Reynolds number wind turbine wake

Wind turbines operate at high diameter-based Reynolds numbers which leads to wakes dominated by highly turbulent flows. As these turbulent wakes have a direct impact on the performances of the downstream wind turbines, understanding their evolution process is important. The wakes of wind turbines are characterized by the presence of coherent structures like tip vortices that affect mixing phenomena at the wake-freestream interface. Studying the wake dynamic from a Lagrangian perspective gives insight into the transport characteristics and mixing characteristics directly related to the wake recovery.

Here, we present Lagrangian Particle Tracking (LPT) [1,2] measurements of a wind turbine wake. LPT allows for volumetric measurements of highly turbulent flows by following tracer particles within a predefined volume over an extended period of time. The LPT setup has been developed in the Variable Density Turbulence Tunnel (VDTT) [3] at the Max Planck Institute for Dynamics and Self-Organization. This wind tunnel uses pressurized SF_6 to achieve full-scale Reynolds numbers on a small-scale turbine. To obtain turbulent inflow conditions, the velocity fluctuations are modified using an active grid. Illumination is provided by a 300W laser, while high temporal resolution is achieved using four

Phantom high-speed cameras. As such, the experimental setup presented here allows spatial and temporal investigation of wind turbine wakes in real-world flow conditions.

[1] C. Küchler, A.I. Landeta, F. Nordsiek, J. Molacek, E. Bodenschatz. "Lagrangian Particle Tracking at Large Reynolds Numbers". 2022. https://doi.org/10.48550/arXiv.2404.04215
[2] C. Küchler. "Measurements of Turbulence at High Reynolds Numbers". Diss. Georg-August University School of Science (GAUSS) Göttingen. 2021. http://dx.doi.org/10.53846/goediss-8490
[3] E. Bodenschatz, G.P. Bewley, H. Nobach, M. Sinhuber, and H. Xu. "Variable density turbulence tunnel facility." Review of Scientific Instruments 85.9. 2014. https://doi.org/10.1063/1.4896138

<u>Yuna Hattori – Max Planck Institute for Dynamics and Self-Organization – Experimental study of a wind turbine wake in a convective boundary layer</u>

Wind turbines are interacting with the flow in the lowest part of the atmospheric boundary layer, which is directly affected by the temperature of the Earth's surface. During daytime, the surface is mostly warmer than the air above, causing convection. The flows interacting with wind turbines are strongly turbulent and complex, making the prediction of wind turbine electricity production difficult. Laboratory studies allow us to study the effect of surface heating in a controlled environment. We use the Prandtl Wind Tunnel (PWT) at the Max Planck Institute for Dynamics and Self-Organization in Göttingen, Germany. The PWT is equipped with an active grid and heated plate, which we use to create convective, turbulent boundary layer flows. Here we present systematic measurements of velocities behind a wind turbine model, over different magnitudes of surface heating, inflow velocities, and turbulence intensities. We then discuss some implications of our results on the effect of convection on the wakes of wind turbine flows.

<u>Claudia Brunner – Max Planck Institute for Dynamics and Self-Organization – Effect of inflow conditions on tip vortex breakdown in a wind turbine wake</u>

Wind turbines are exposed to widely varying inflow conditions that depend on the local boundary layer meteorology. These inflow conditions are characterised by varying degrees of mean velocity shear and turbulence intensity, which affect the performance and durability of the turbine as well as the downstream evolution of the wake. These effects are challenging to study in the field due to the large scales involved, and most wind tunnel experiments are conducted at low Reynolds numbers. The near wakes of wind turbines are dominated by vortices shed from the tips of the blades. As they advect downstream, the tip vortices form a helical structure with three convoluted spirals. Here, we investigate the effect of the inflow turbulence, inflow shear, and tip speed ratio on their breakdown. We present results from high Reynolds number experiments in the Variable Density Turbulence Tunnel (VDTT) at the Max Planck Institute for Dynamics and Self-Organization. This wind tunnel uses pressurized SF6 as the working fluid to achieve a diameter-based Reynolds number of Re_D = 3 x 10^6. An active grid with 111 individually-controllable paddles is used to generate inflow profiles with varying degrees of velocity shear and turbulence intensity. Streamwise hot-wire measurements at multiple downstream positions quantify the breakdown of the tip vortices behind a MoWiTo 0.6 model turbine.

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