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2025 *Activity Report*

RESEARCH CENTRE: **Inria Centre at Université Côte d'Azur**

IN PARTNERSHIP WITH: **CNRS**

Project-Team

CALISTO

Stochastic Approaches for Complex Flows and Environment

In collaboration with Centre de Mise en Forme des Matériaux (CEMEF)

Project-Team CALISTO

Creation of the Project-Team: 2020 November 01

Each year, Inria research teams publish an Activity Report presenting their work and results over the reporting period. These reports follow a common structure, with some optional sections depending on the specific team. They typically begin by outlining the overall objectives and research programme, including the main research themes, goals, and methodological approaches. They also describe the application domains targeted by the team, highlighting the scientific or societal contexts in which their work is situated. The reports then present the highlights of the year, covering major scientific achievements, software developments, or teaching contributions. When relevant, they include sections on software, platforms, and open data, detailing the tools developed and how they are shared. A substantial part is dedicated to new results, where scientific contributions are described in detail, often with subsections specifying participants and associated keywords. Finally, the Activity Report addresses funding, contracts, partnerships, and collaborations at various levels, from industrial agreements to international cooperations. It also covers dissemination and teaching activities, such as participation in scientific events, outreach, and supervision. The document concludes with a presentation of scientific production, including major publications and those produced during the year.

Keywords

Computer sciences and digital sciences

A5.10.6. – Swarm robotics

A6. – Modeling, simulation and control

A6.1. – Methods in mathematical modeling

A6.1.1. – Continuous Modeling (PDE, ODE)

A6.1.2. – Stochastic Modeling

A6.1.3. – Discrete Modeling (multi-agent, people centered)

A6.1.4. – Multiscale modeling

A6.1.5. – Multiphysics modeling

A6.1.6. – Fractal Modeling

A6.2. – Scientific computing, Numerical Analysis & Optimization

A6.2.1. – Numerical analysis of PDE and ODE

A6.2.2. – Numerical probability

A6.2.3. – Probabilistic methods

A6.2.4. – Statistical methods

A6.2.6. – Optimization

A6.2.7. – HPC for machine learning

A6.3. – Computation-data interaction

A6.3.1. – Inverse problems

A6.3.2. – Data assimilation

A6.3.3. – Data processing

A6.3.4. – Model reduction

A6.3.5. – Uncertainty Quantification

A6.4. – Automatic control

A6.4.1. – Deterministic control

A6.4.2. – Stochastic control

A6.4.3. – Observability and Controlability

A6.4.4. – Stability and Stabilization

A6.4.5. – Control of distributed parameter systems

A6.4.6. – Optimal control

A6.5. – Mathematical modeling for physical sciences

A6.5.1. – Solid mechanics

A6.5.2. – Fluid mechanics

A6.5.3. – Transport

A6.5.4. – Waves

A6.5.5. – Chemistry

A9.2. – Machine learning

A9.5. – Robotics and AI

A9.11. – Generative AI

Other research topics and application domains

B2.2.7. – Virtual human twin

B2.7.3. – Medical robotics

B3.2. – Climate and meteorology

B3.3.2. – Water: sea & ocean, lake & river

B3.3.4. – Atmosphere

B4.3.2. – Hydro-energy

B4.3.3. – Wind energy

B5.6. – Robotic systems

B9.5.2. – Mathematics

B9.5.3. – Physics

B9.5.4. – Chemistry

B9.5.5. – Mechanics

Contents

1 Team members, visitors, external collaborators

Research Scientists

- Mireille Bossy [Team leader, INRIA, Senior Researcher, HDR]
- Jérémie Bec [CNRS, Senior Researcher, HDR]
- Laetitia Giraldi [INRIA, Researcher, HDR]
- Christophe Henry [INRIA, ISFP, HDR]

Faculty Member

- Simon Thalabard [Université Côte d'Azur, Associate Professor, Institut de Physique de Nice]

Post-Doctoral Fellows

- Chiara Calascibetta [INRIA, Post-Doctoral Fellow]
- Long Li [CNRS, Post-Doctoral Fellow, from Nov 2025]
- Christian De Jesus Reartes [INRIA, Post-Doctoral Fellow, from Sep 2025]
- Ciro Sobrinho Campolina Martins [CNRS, Post-Doctoral Fellow, until Feb 2025]

PhD Students

- Eduardo Nelson Gutiérrez-Turner [Universidad de Valparaíso, Chile, from Sep 2025 until Nov 2025, First visit from Feb 2025 to Mar 2025. Second visit]
- Paul Maurer [INRIA]
- Lucas Palazzolo [INRIA]
- Guirec Peyrot [EDF R&D, CIFRE, from May 2025]
- Nicolas Valade [INRIA, until Sep 2025]

Interns and Apprentices

- Bernhard Eisvogel [INRIA, Intern, from May 2025 until Oct 2025]
- John Alexander Osorio Henao [INRIA, Intern, from Apr 2025 until Aug 2025]

Administrative Assistants

- Quentin Campeon [INRIA, from Jul 2025 until Aug 2025]
- Marylène Fontana [INRIA, from Sep 2025]
- Stéphanie Verdonck [INRIA, until Jun 2025]

Visiting Scientists

- Kerlyns Martínez Rodríguez [University of Concepción, Chile, until Mar 2025]
- Héctor Olivero-Quinteros [University of Valparaiso, Chile, from Feb 2025 until Mar 2025]
- André Luis Peixoto Considera [IMPA, Brazil, from Oct 2025]

External Collaborators

- Christophe Brouzet [CNRS, Institut de Physique de Nice]
- Eric Simonnet [CNRS, Institut de Physique de Nice]

2 Overall objectives

CALISTO is a research team centered on the study of complex flows and the transport of complex particles. By integrating insights from physics, mathematics, and engineering, CALISTO develops and refines numerical models and computational tools to:

- Advance the fundamental understanding of the underlying physics of complex flows;
- Predict large-scale environmental and industrial phenomena, such as the dispersion of inert particles (like dust, pollens or microplastics);
- Control and optimize the locomotion and navigation of active particles, whether as isolated individuals or within swarms.

Targeted applications are pursued in collaboration with both national academic partners (e.g., OCA Nice, IRPHE Marseille, ENS Lyon, INRAE Rennes) and international ones (e.g., TU Dresden, IIT Bombay, IMPA Brazil, Univ. Valparaíso Chile), as well as industrial partners (e.g., EDF, CEA, Roboté).

Complex particles in complex flows

A key challenge in our research is addressing the highly out-of-equilibrium and multi-scale nature of the studied flows. We begin by studying fully developed turbulent flows in idealized settings and progressively extend our approaches to more realistic environments, such as the atmosphere, oceans, and rivers, where small-scale modeling is essential. For applications in medical microrobotics, the dominant role of viscosity introduces complexity due to rheology and strong confinement.

Another challenge arises from interactions with boundaries, which often involve complex geometries, particle-wall interactions, and inter-particle interactions, each presenting specific modeling difficulties.

A third challenge lies in capturing the diversity of particle sizes, shapes, and material properties (e.g., mechanical, chemical) as well as the variability of wall surface characteristics (such as roughness, adhesion, and geometric complexity). Our goal is to develop simple yet effective models that faithfully capture these complexities.

The team's diverse expertise enables a thorough and robust approach, integrating physical, mathematical, and numerical perspectives, and, to address these scientific objectives, CALISTO relies on the expertise of its permanent members, covering a wide range of approaches, including:

- The statistical study of small-scale phenomena, combining direct numerical simulations and laboratory experiments (Axis A, Axis C).
- The mathematical analysis of theoretical models, including singularity formation, spontaneous stochasticity in infinite Reynolds number flows, and intermittency theories (Axis A, Axis D).
- The development, numerical approximation, and mathematical analysis of stochastic models that result from or are designed to be consistent with macroscopic computational fluid dynamics (CFD) approaches (Axis B, Axis D).
- The design of optimization methods, machine learning techniques, deep learning strategies for optimization, Bayesian learning for uncertainty quantification, and model reduction techniques (Axis C, Axis D, Axis E).

3 Research program

Calisto structures its research around five key axes. While all team members contribute to these areas, we highlight below the permanent researchers most involved in each.

Axis A – Complex flows and particles: from fundamental science to applied models – Jérémie Bec, Mireille Bossy, Christophe Brouzet, Laetitia Giraldi, Christophe Henry, Simon Thalabard.

Axis B – Particles and flows near boundaries – the entire team.

Axis C – Active agents and active fields – Laetitia Giraldi, Jérémie Bec, Eric Simonnet.

Axis D – Non-equilibrium physics: from models to mathematics – Jérémie Bec, Mireille Bossy, Eric Simonnet, Simon Thalabard.

Axis E – Modeling uncertainties in fluctuating environments – Jérémie Bec, Mireille Bossy, Christophe Henry, Eric Simonnet, Simon Thalabard.

3.1 Axis A – Complex flows and particles: from fundamental science to applied models

This axis focuses on advancing the understanding and modeling of realistic dispersed, multiphase turbulent flows. In situations where basic mechanisms are still not fully apprehended, this axis aims at bringing out the underlying physics by identifying novel effects and quantifying their impacts.

Our overall objective here is to design, validate and apply new efficient modeling and simulation tools for fluid-particle systems that account for relative particle motions, two-particle interactions and complex flow geometries. This involves the following four subtopics.

Modeling polydisperse, complex-shaped, deformable particles

Particles encountered in industrial/environmental applications are generally difficult to model due to their range of sizes, shapes and properties (deformations). The goals here are: (a) To give a precise and systematic description of the transport properties of non-ideal, non-spherical, flexible particles; (b) To design efficient reduced dynamical models based on approximations of the Lagrangian gradient dynamics; (c) To validate them against fine-scale numerical experiments. An important outcome will be to provide reduced macroscopic models for flexible, non-spherical particles that incorporate some internal degrees of freedom (e.g., based on trumbbells or articulated chains).

The particle interactions and size evolution

Particles suspended in a fluid have complex interactions with each other, collide and can even stick together to form aggregates that can later fragment into smaller clusters. The evolution of particle sizes is generally addressed in large-scale situations using models based on mean-field kinetics. These models are derived from a well-mixed assumption and thus fail to account for local spatial inhomogeneities in the population and its environment. The objective here is to raise our understanding of particle interactions to a new level, allowing for effective mesoscale models for the resulting population dynamics.

The transfers between the dispersed phase and its environment

Particles often deposit or stick to the walls (e.g., sand/sediment settling on the floor/seabed), where they accumulate to form complex structures. Resuspension is the reverse process, whereby deposited particles are detached under the action of the flow. We aim here at developing reliable models for the deposition/resuspension phenomena that accurately capture the relationship between particle motion and the fine-scale flow structures (possibly including correlated effects).

Accounting for a Non-Newtonian fluid rheology

Many natural fluids (e.g., blood, toothpaste) are non-Newtonian and exhibit shear-thinning properties. The key challenge is to understand and write a model accounting for the dynamics of particles in such non-Newtonian fluids. In fact, this question is still open even in the simplest case of spherical and rigid particles immersed in such flows.

3.2 Axis B – Particles and flows near boundaries

This research axis focuses on understanding and modeling the dynamics of flows and suspended particles near boundaries. In fact, in many practical applications, suspended particles are moving close to surfaces (like sand/dust/pollen in the atmospheric boundary layer) or even on surfaces themselves (like gravels rolling on riverbeds).

The challenges here are twofold: first, near-wall flows are highly anisotropic and structured, leading to rich and complex particle dynamics and transport regimes; second, particle-surface interactions are governed by short-range physico-chemical forces, making accurate modeling of deposition, resuspension, and near-surface transport particularly demanding. These challenges motivate the development of advanced modeling tools tailored for near-boundary flow-particle systems.

Wall-induced fluctuations and singularities

Interactions between flows and boundaries generate intense fluctuations, often leading to singular behaviors. In particular, boundary-layer separation in the presence of adverse pressure gradients can trigger small-scale instabilities and vorticity injection, acting as a dominant source of turbulence. Recent studies within the team highlight how singularities in Prandtl's boundary layer equations can drive spontaneous stochasticity, where infinitesimal perturbations lead to macroscopic differences in flow evolution. These effects are especially relevant in confined or rough-wall environments, where wall-induced instabilities strongly influence transport dynamics, turbulence generation, and energy dissipation. Understanding these mechanisms is crucial for improving predictive models of near-wall particle transport and flow separation in natural and industrial settings.

Lagrangian approaches for large-scale simulations

This activity is related to the modeling of environmental flows, such as atmospheric boundary layer (ABL) or river/marine systems. The challenge is to develop coherent approaches to solve the fluid and the particle phase. In this framework, CALISTO works on both (i) moment (Eulerian) approaches for the flow with Lagrangian for particle phase and (ii) Lagrangian fluid-particle approaches for the flow and Lagrangian for particle phase. The latter combination – called here Lagrange-Lagrange approaches – appears to be particularly interesting for developing a fully coherent model of a turbulent flow, of particles embedded in it, as well as their interactions. To that extent, we are currently improving stand-alone Lagrangian models for the fluid phase and its interaction with complex terrains while accounting for canopy-induced effects, buoyancy effects and modeling of active scalars (like temperature or salinity).

Lagrangian models for correlated near-wall dynamics

The near-wall dynamics of particles is further enriched by the complex interactions with the surfaces, leading to phenomena like deposition, saltation, splashing and resuspension. Yet, as particles accumulate on surfaces, they build up complex deposits and interact strongly with each other, leading to interesting correlated motion. In terms of modeling, the aim is to understand how to integrate microscopic and memory phenomena to obtain Lagrangian (Markovian) dynamics enriched by the effects of turbulent structures (near-edge residence time) and anisotropy (shear effect).

3.3 Axis C – Active agents and active fields

This research axis focuses on the study of self-propelled particles that convert internal or ambient free energy into motion. These active agents include microorganisms, such as bacteria and plankton, as well as artificial devices designed for micro-manufacturing, toxic waste cleanup, targeted drug delivery, or localized medical diagnostics. Effective control of these microswimmers movement requires addressing several key questions, particularly within complex flow environments characterized by inhomogeneities, fluctuations, obstacles, boundaries, or non-Newtonian rheological properties.

The study and optimization of these microswimmers displacements typically involves two main steps. First, a *locomotion strategy* is developed, which focuses on selecting the appropriate composition, shape, and deformation for an efficient swimming. The second step is the definition of a *navigation strategy*, aimed at minimizing the energy needed to reach a target in a given environment. CALISTO brings together cross-disciplinary expertise in optimal control, small-scale fluid-structure interactions, statistical modeling, and large-scale turbulent transport, offering a unique opportunity to address both locomotion and navigation simultaneously. Below, we summarize the main ongoing research lines in this axis.

Mathematical modeling of micro-swimmers

This section focuses on the mathematical models used to simulate the dynamics of micro-swimmers, leveraging different levels of physical fidelity. The goal is to develop and compare a hierarchy of models, from high-fidelity approaches solving the full Navier-Stokes equations in an ALE (Arbitrary Lagrangian-Eulerian) framework, to simplified models capturing dominant hydrodynamic effects. At the highest fidelity, we consider Full fluid-structure interaction models based on the ALE formulation of the Navier-Stokes equations. We include Boundary Element Methods (BEM), particularly effective in the low Reynolds number regime where fluid motion is governed by the Stokes equations. As the physical complexity is reduced, lower-fidelity models are employed, focusing only on dominant hydrodynamic interactions. These include methods like Resistive Force Theory (RFT), designed to approximate swimmer-fluid interactions without explicitly solving the surrounding flow. This modeling framework supports a wide range of swimmer types — natural, artificial, deformable, elastic, or flagellated — and enables systematic studies of key physical properties, such as boundary effects on motility or the hydrodynamical interaction on collective patterns.

Control and optimal navigation in complex flows

We investigate control and optimal path planning strategies for microswimmers, focusing on both natural self-propelled swimmers controlled via body deformation and artificial bio-inspired swimmers driven by external fields. CALISTO addresses controllability and optimization challenges using geometric control theory, with models ranging from ODEs to PDEs, depending on system complexity. To mitigate computational costs, surrogate models such as Gaussian process regression are explored for efficient prediction and optimization. Additionally, we study optimal navigation in complex, time and space-varying flows, where swimmers must overcome chaotic advection and trapping in vortices. Building on recent advances in machine learning for smart swimming, we aim to extend these strategies to more realistic scenarios, incorporating additional control parameters, swimmer-fluid interactions, and hydrodynamic interactions between swimmers.

Optimal control of microswimmer swarms

Coordinating the collective motion of a swarm of microswimmers without controlling each one individually presents a significant challenge. To address this, we start with simplified interaction models, such as the Vicsek alignment model, which generates rich collective behaviors. Using reinforcement learning, we aim to design optimal strategies that modify pattern formation and the spatial organization of micro-swimmers to achieve prescribed displacements. Additionally, we plan to apply macroscopic fluctuation theory (MFT) to these active systems, providing a powerful tool to understand how collective behaviors emerge from individual uncertainties. This will offer deeper insights into the role of fluctuations in driving critical phenomena and guide the development of models for better control of phase transitions. However, models like the Vicsek model may not fully capture the complexities of realistic swimmer interactions. To evaluate its relevance, we will compare its predictions with direct numerical simulations of various swimmer types, such as squirmers and undulatory swimmers, identifying the conditions under which the model remains valid. This approach will enable the transfer of optimal control strategies from simplified models to realistic systems for practical applications.

3.4 Axis D – Non-equilibrium physics: from models to mathematics

Calisto is developing a toolbox of mathematical analysis methods to address fundamental questions in non-equilibrium systems. These tools support the central challenge of unifying the description of the infinite Reynolds number limit, which is central to most real-world cases of developed turbulence. A key aspect of this effort is the ability to analyze and gain insight from simplified toy models that capture essential features of turbulent transport. Stochastic analysis plays a pivotal role across all axes of the team, providing a common language for modeling complex dynamics and guiding numerical approaches. The new modeling strategies proposed—especially in Axis A and Axis B—introduce new challenges in the analysis and discretization of stochastic differential equations (SDEs), calling for both theoretical advances and innovative computational methods. This section outlines some of the key questions we are addressing.

Fundamental aspects of turbulence in the infinite Reynolds limit

In the infinite Reynolds number limit, turbulence exhibits extreme sensitivity to initial conditions, leading to *spontaneous stochasticity*, where arbitrarily small perturbations can result in vastly different flow evolutions. This phenomenon challenges traditional deterministic descriptions and suggests an intrinsically probabilistic nature of turbulence at high Reynolds numbers. A key open question is to determine constraints on the limiting flow, which may arise from statistical conservation laws, such as generalized versions of Kelvin's theorem and geometrical zero modes, or from anomalies, including the persistence of energy dissipation in the inviscid limit and the breakdown of scale invariance. By integrating insights from statistical mechanics, non-equilibrium physics, probability theory, and the analysis of partial differential equations, our goal is to develop theoretical frameworks capable of capturing these effects.

Solvable models and stochastic transport in turbulence

A complementary approach to understanding the limit of infinite Reynolds numbers lies in the study of solvable models, where probabilistic methods provide rigorous insight into transport and mixing properties. Passive scalar advection by turbulent flows exemplifies how spontaneous stochasticity arises, with tracer particles following non-unique trajectories in the vanishing diffusivity limit. In simplified settings, such as Gaussian random flows or shell models, explicit calculations reveal how anomalous dissipation, intermittency, and memory effects shape the statistical structure of turbulence. By using tools from stochastic processes, measure theory, and ergodic dynamics, our objective is to explore how these features persist in more realistic turbulent systems. These models serve as ideal testbeds for refining probabilistic descriptions of turbulent transport and for elucidating the interplay between Lagrangian chaos, conservation anomalies, and statistical closures.

SDEs and related computational methods

Stochastic differential equations (SDEs) are widely used in macroscopic descriptions of the Lagrangian dynamics of particles in turbulent flows (see Axis A and Axis B). For decades, SDEs driven by Brownian motion have been employed to describe single-point particle dynamics. However, the subject remains far from fully explored, as existing tools for accurately modeling interactions with walls or other particles, as well as capturing shape and deformability effects, are still quite limited in macroscopic modeling. Our goal here is to extend the analysis to new forms of SDEs, incorporating a family of driven noises that include jump noises, spatio-temporal noises, and non-Markovian stochastic integrals associated with long-range memory effects. This is particularly relevant in connection with intermittency phenomena, while also accounting for nonlinear wall conditions and particle-particle interactions. Such mathematical analysis is crucial for developing robust models and innovative efficient numerical integration schemes.

3.5 Axis E – Uncertainties in fluctuating environments: models & simulations

Calisto aims to develop a unified framework for modeling, analyzing, and simulating uncertainties in complex fluctuating environments. This effort goes together with the advances made in Axis A, Axis B, and Axis C. Each of these domains features high levels of variability and unpredictability—whether due to rough flow fields, particle interactions, or inherent model ambiguities. Axis E proposes a complementary approach combining macroscopic modeling, reduced toy models, and advanced numerical simulations to tackle these challenges. By bridging the gap between detailed physical mechanisms and coarse-grained descriptions, this axis seeks to quantify uncertainty, evaluate model predictability, and guide model refinement. Multi-fidelity methods, meta-modeling, and data-driven strategies will be used to adaptively calibrate and optimize models across scales, enabling robust simulations under uncertainty.

Sources and mechanisms for uncertainties

Rough dynamical systems are inherently unpredictable, from the evolution of individual trajectories to probability measures, with spontaneous stochasticity arising both in low-dimensional settings and in complex systems with many degrees of freedom. Within the framework of macroscopic fluctuation theory (MFT) for particle systems, it can originate from the interplay between noise and small-scale singularities in long-range interaction kernels or from the ill-posed nature of mesoscopic hydrodynamic equations. To clarify these mechanisms, we plan to first analyze low-dimensional toy models before extending our study to more complex systems. These insights will enable the development of quantitative methodologies to characterize uncertainty propagation, determine predictability limits in singular flows, and refine statistical models for fluctuating hydrodynamic systems.

Uncertainty quantification

Models must also be designed with calibration capabilities, which are essential for simulations and validation. Although numerical integration is inherently part of this process, turbulence modeling presents a unique challenge, with numerous competing models and no clear consensus. In this context, sensitivity analysis (SA) and uncertainty quantification (UQ) methods play a crucial role in evaluating how uncertainties in model inputs affect variations in model outputs. One of the key challenges in macroscopic and engineering models is to represent increasingly complex flow scenarios while accurately reproducing refined statistics. Our goal is to use meta-modeling tools and surrogate models to support and enhance expert-driven modeling in this task.

Meta-modeling and multi-fidelity

We aim to develop a methodology to tackle high-dimensional optimization problems arising from real-world applications. In this context, high-fidelity models are extremely costly and must be used sparingly. To address this, we adopt a multi-fidelity framework, where low-fidelity models guide the exploration, and high-fidelity evaluations are used selectively to refine solutions. Uncertainty quantification, based on Bayesian optimization techniques, will be used to dynamically switch between fidelity levels, balancing computational cost and precision to improve efficiency and accuracy. In addition, we explore hybrid approaches combining machine learning techniques to support adaptive fidelity selection in complex optimization workflows.

4 Application domains

Environmental challenges: predictive tools for particle transport and dispersion

Particles are omnipresent in the environment:

- formation of clouds and rain results from the coalescence of tiny droplets in suspension in the atmosphere;
- fog corresponds to the presence of droplets in the vicinity of the Earth's surface, reducing the visibility to below 1 km [25];
- pollution corresponds to the presence of particulate matter in the air. Due to their impact on human health [33], the dispersion of fine particulate matter (PM) is of primary concern: PM1, PM2.5 and PM10 (particles smaller than 1, 2.5 or 10 μm) and Ultra Fine Particles (UFP, smaller than 0.1 μm) are particularly harmful for human respiratory systems while pollen can trigger severe allergies;

- the dispersion of radioactive particles following their release in nuclear incidents has drawn a great deal of attention to deepen our understanding and ability to model these phenomena [39];
- plastic contamination in oceans impacts marine habitats and human health [27];
- suspension of real micro-swimmers [19] such as sperm cell, bacteria, and in environmental issues with animal flocks attracted intrinsic biological interest [29];
- accretion of dusts is responsible for the formation of planetesimals in astrophysics [28].

These selected examples show that the presence of particles affects a wide range of situations and has implications in public, industrial and academic sectors.

Each of these situations (deposition, resuspension, turbulent mixing, droplet/matter agglomeration, thermal effect) involves specific models that need to be improved. Yet, one of the key difficulties lies in the fact that the relevant phenomena are highly multi-scale in space and time (from chemical reactions acting at the microscopic level to fluid motion at macroscopic scales), and that consistent and coherent models need to be developed together. This raises many issues related both to physical sciences (i.e. fluid dynamics, chemistry or material sciences) and to numerical modeling.

Next generation of predictive models for complex flows

Many processes in power production involve circulating fluids that contain inclusions, such as bubbles, droplets, debris, sediments, dust, powders, micro-swimmers or other kinds of materials. These particles can either be inherent components of the process, for instance liquid drops in sprays and soot formed by incomplete combustion, or external foul impurities, such as debris filtered at water intakes or sediments that can obstruct pipes. Active particles, seen as artificial micro-swimmers, have attracted particular attention for medical applications since they can be used as vehicles for the transport of therapeutics or as tools for limited invasive surgery. In these cases, optimization and control requires monitoring the evolution of their characteristics, their trajectories (with/without driving), and their effects on the fluid with a sufficiently high level of accuracy. These are very challenging tasks given a numerical complexity of the numerical models.

These challenges represent critical technological locks and energy companies are devoting significant design efforts to deal with these issues, increasingly relying on the use of macroscopic numerical models. This framework is broadly referred to as "Computational Fluid Dynamics" (CFD). However, such large-scale approaches tend to oversimplify small-scale physics, which limits their suitability and precision [21]. Particles encountered in industrial situations are generally difficult to model: they are polydisperse, not exactly spherical but of any shape, and deform; they have complex interactions, collide and can agglomerate; they usually deposit or stick to the walls and can even modify the very nature of the flow (e.g. polymeric flows). Extending present models to these complex situations is thus key to improve their applicability, fidelity, and performance.

Models operating in industry often incorporate rather minimalist descriptions of suspended inclusions. For instance, they rely on statistical closures for single-time, single-particle probability distributions, as is the case for the particle-tracking module in the open-source CFD software Code_Saturne developed and exploited by EDF R&D. The underlying mean-field simplifications do not yet allow to account for complex features of the involved physics that require higher-order correlation descriptions and modeling. Indeed, predicting the orientation and deformation of particles requires suitable models of the fluid velocity gradient along their trajectories [41] while concentration fluctuations and clustering depend on relative particle dispersion [35, 26]. Estimates of collision and aggregation rates should also be fed by two-particle dynamics [34], while wall deposition is highly affected by local flow structures [36]. Improving existing approaches is thus key to obtain better prediction tools for multiphase flows.

New simulation approach for microswimmer and active particles

The study and optimization of microswimmer locomotion have a wide range of applications spanning biomedical engineering, biophysics, microfluidics, and robotics. In biomedical contexts, microswimmers are envisioned as microrobotic agents for targeted drug delivery, minimally invasive diagnostics, and therapeutic interventions within complex biological environments. From a fundamental perspective, microswimming models provide insight into the locomotion strategies of microorganisms such as bacteria, spermatozoa, and algae, and contribute to a deeper understanding of transport processes at low Reynolds numbers. In engineering and microfluidic applications, microswimmers enable active transport and manipulation at the microscale, where conventional flow control techniques are ineffective. Beyond these domain-specific applications, microswimming also serves as a valuable testbed for advanced numerical simulation, multi-fidelity optimization, and high-performance computing methodologies, with transferable impact on a broad class of complex, multiscale physical systems.

In turbulent flow regimes, microswimming and active particle dynamics play a key role in a variety of environmental, engineering, and fundamental physics applications. Active microorganisms (such as plankton, bacteria, or algae) interact with turbulent fluctuations in oceans and atmospheric flows, affecting dispersion, clustering, and transport processes that are central to biogeochemical cycles and ecosystem dynamics. From a modeling perspective, the competition between active swimming, turbulent advection, and rotational diffusion leads to complex multiscale dynamics that challenge classical transport theories. Studying microswimmers in turbulent flows also provides a valuable framework for developing stochastic Lagrangian models, investigating intermittency and anomalous transport, and assessing the impact of small-scale flow structures on particle dynamics. These questions are highly relevant for environmental modeling, scalar transport, and the design of efficient numerical and high-performance computing methodologies for turbulent multiphase systems.

New simulation approach for renewable energy and meteorological/climate forecast

A major challenge for sustainable power systems is the integration of climate and meteorological variability into both operational and medium- to long-term planning processes [24]. As wind, solar, and marine or river-based energies gain importance, the demand for accurate forecasts across multiple time horizons continues to grow [23, 32, 22].

A key difficulty lies in achieving refined spatial descriptions. In wind energy, production forecasts are strongly affected by turbulence in the near-wall atmospheric boundary layer, which increases flow variability and impacts interactions with turbines, terrain, and surface roughness. While advanced computational fluid dynamics tools are already used in this sector [37, 31], the question of how to enrich and refine wind simulations—by combining meteorological forecasts, large-scale information, and local measurements—remains largely open.

Similar challenges arise for hydro and marine energy systems, particularly in river and tidal turbine farms, where turbulence, complex geometries, and limited measurement availability complicate forecasting and operational safety. In this context, the evaluation of uncertainty becomes crucial, especially for long-term planning under climate change. Recent studies, such as those of the European QUICS project [38], highlight the need to quantify uncertainties in hydropower forecasts, which stem from the nonlinear and delayed relationship between meteorological forcing, hydrological response, and electricity generation [30].

5 Highlights of the year

Originally structured as as joint team with CNRS/CEMEF UMR7635, the year 2025 is marked by a reconfiguration of Calisto as a joint team with Institut de Physique de Nice (InPhyNi), UMR7010, Université Côte d'Azur and CNRS.

While Calisto's core scientific focus remains unchanged– integrating microscopic & fundamental perspectives to inform macroscopic & engineering models– its transition into a joint team with InPhyNi further strengthen this distinctive trait. This new configuration enhances the team's expertise in the fundamental and theoretical aspects of complex flows while also expanding its engagement in experimental research.

A key strength shared by all team members is the development and application of numerical tools, ranging from algorithm design to high-performance computing. Our methodologies include finite-element methods, spectral approaches, particle-based simulations, stochastic Monte Carlo techniques, and machine-learning.

Although still awaiting official signatures, this change in the team is already effective on a daily basis. The year 2025 is therefore marked by this major development.

6 Latest software developments, platforms, open data

6.1 Latest software developments

6.1.1 SDM_brine

Keyword: Computational Fluid Dynamics

Scientific Description: We develop specialized numerical methods designed to model and analyze the behavior of brine discharges in three-dimensional fluid domains with complex bathymetric features. Developed in line with methodologies like those outlined in the WINDPOS project, SDM-Brine aims to incorporate computational fluid dynamics (CFD) techniques to solve the governing equations of fluid motion following a stochastic Lagrangian approach consistent with Navier-Stokes equations. The idea is to couple fluid motion equations with a fluid particle feature vector, including information on salinity, temperature, or density-driven properties.

Functional Description: A numerical method designed to model and analyze the behavior of brine discharges in three-dimensional fluid domains with complex bathymetric features.

Release Contributions: prototyping initial version

URL: https://project.inria.fr/swam/work-in-progress/stochastic-lagrangian-approach-for-brine-discharge-simulations/

Contact: Mireille Bossy

Participant: Mireille Bossy

7 New results

7.1 Axis A – Complex flows: from fundamental science to applied models

7.1.1 Book on the progress in the modeling of discrete particle dynamics in turbulent flows

Participant: Christophe Henry.

The purpose of this book is to present the statistical description of turbulent poly-disperse two-phase flows based on the probability density function (PDF) approach. Adopting the point of view of the physicist, the presentation focuses on the analysis of the physical content of stochastic formulations used to model the dynamics of discrete particles in non-fully resolved turbulent flows. We follow a step-by-step approach to introduce this multi-scale and multi-physics topic, and bring out current challenges to emphasize not only how but why PDF models are developed. By investigating state-of-the-art models, the book also invites researchers to address the open issues presented and, to that effect, new ideas are proposed. Starting with examples from daily situations and covering the basic equations as well as going through the reasons calling for a statistical treatment, this book can serve as an introduction for readers not yet familiar with the topic. Since we provide detailed accounts of the specific challenges we are faced with when considering statistical descriptions of discrete particle dynamics in random media with non-zero time and space correlations, the book is also intended for practitioners in the field. Finally, new ideas and cutting-edge formulations are developed in the hope to overcome present limitations and embolden specialists to pursue their own views.

This work is a collaboration with Jean-Pierre Minier (EDF R&D, MFEE, Chatou, France) and Martin Ferrand (EDF R&D, MFEE, Chatou and CEREA laboratory, Ponts ParisTech). It has been published in Springer in April 2025 as an open-source publication [6].

7.2 Axis B – Particles and flows near boundaries

7.2.1 Dynamics and collisions of spheroidal particles near surfaces

Participants: Mireille Bossy, Christophe Henry.

In this study, we develop a new model for the dynamics of spheroidal particles in turbulent wall-bounded flows. In particular, the model takes into account the effect of interactions between surfaces on the translational velocity and rotational velocity of particles. The model bridges the gap between approaches based on the Coulomb law, which take into account friction between two surfaces in contact, and approaches based on coefficients of restitution, which account for rolling and griping effects.

Preliminary results have been presented at the 12th International Conference on Multiphase Flow (ICMF2025) that took place in Toulouse (France) in May 2025.

7.2.2 Bridging lubrication and solvation forces for spherical particles moving near a surface

Participants: Laetitia Giraldi, Christophe Henry, John Alexander Osorio Henao.

During the internship of John A. Osorio Henao, we worked on the modeling of short-range lubrication forces that arise when a solid body immersed in a liquid nears a solid surface. We compared the results obtained using two models: (i) precise models to explicitly solve lubrication forces, which are based on a finite-size particle approximation (whereby the fluid flow is solved around each spherical particle) and (ii) large-scale models based on the integration of the particle motion including an approximation of the lubrication force. As the distance between the two objects nears zero, lubrication forces are known to diverge. We attempted to combine existing models for lubrication forces to the solvation forces developed at molecular scales.

Our work shows that, when the particle size is small enough, we can define a minimum separation distance between the two objects. This provides a hint towards finding physical arguments to justify the introduction of cutoff distances in large-scale simulations of particles nearing boundaries in a fluid.

7.2.3 Population-based model for marine ecology

Participants: Christophe Henry, Isidora Avila Thieme *(Univ Mayor, Chile)*, Kerlyns Martínez Rodríguez *(Univ Concepcion, Chile)*, Hector Oliveiro-Quinteros *(Univ Valparaiso, Chile)*.

As part of the SWAM Associated Team research programme, we have studied the dynamics of kelp populations. In the context of marine ecosystems where multiple species are suspended in water, an interesting species is the Chilean kelp, a type of large brown algae that grows near coastlines.

Our goal here is to analyze the interplay between different species including algae, consumers and producers (sessiles and non-sessiles) especially when subject to harvesting by fishermen and how the effects of non-compliance are propagated to the network. For that purpose, we rely here on an Allometric Trophic Network (ATN) model that has been recently developed by colleagues from Chile [20]. This model describes the evolution in the biomass of a community of interacting species. This sort of population-based model takes into account the prey/predator interactions (e.g. herbivores feeding on algae), the competition for space between sessile species, the birth/death rates as well as harvesting by fishermen and how the effects of non-compliance are propagated to the network (through stochastic models). Perspectives on this topic, which will be explored in 2026, cover control problems as well as analysis of spatial dynamics and long-term dynamics.

7.3 Axis C – Active agents and active fields

7.3.1 Harnessing swarms for directed migration of interacting active particles via optimal global control.

Participants: Jérémie Bec, Chiara Calascibetta, Laetitia Giraldi.

This study investigates the use of global control strategies to enhance the directed migration of swarms of interacting self-propelled particles confined in a channel. Uncontrolled dynamics naturally leads to wall accumulation, clogging, and band formation due to the interplay between self-organization and confinement. This work explores whether a uniform global control, such as magnetic field acting on all particles, can optimize collective transport. Using a discrete Vicsek-like model, it is found that simple global alignment controls, optimized via reinforcement learning, efficiently suppress unfavorable configurations and significantly increase the net particle flux along a prescribed channel direction. These results highlight that coarse, system-level observations are sufficient to achieve near-optimal control, even in regimes with strong fluctuations or partial ordering. This is a collaborative work that has been submitted to EPL (Europhysics Letters) (see [10]).

7.3.2 Non-locally controllable but trackable magnetic head flagellated swimmer

Participants: Lucas Palazzolo, Laetitia Giraldi.

Unlike macroscopic swimmers, microswimmers operate in a low-Reynolds-number regime dominated by viscous forces. This paper investigates the controllability of a magnetic microswimmer composed of a spherical magnetic head and an elastic, non-magnetic flagellum. The swimmer evolves in a Stokes flow and is modeled using the resistive force theory. We prove that, under planar motion, the system is not small-time locally controllable and numerically identify regions that remain inaccessible. Nevertheless, simulations show that trajectory tracking can still be achieved via Bayesian optimization, though it requires large-amplitude transverse deformations.

This is a collaborative work with Michael Binois (Inria, Team Acumes). The paper [12] has been submitted.

7.3.3 Parametric shape optimization of flagellated micro-swimmers using Bayesian techniques

Participants: Lucas Palazzolo, Laetitia Giraldi.

Understanding and optimizing the design of helical micro-swimmers is crucial for advancing their application in various fields. This study presents an innovative approach combining Free-Form Deformation with Bayesian Optimization to enhance the shape of these swimmers. Our method facilitates the computation of generic swimmer shapes that achieve optimal average speed and efficiency. Applied to both monoflagellated and biflagellated swimmers, our optimization framework has led to the identification of new optimal shapes. These shapes are compared with biological counterparts, highlighting a diverse range of swimmers, including both pushers and pullers.

It is part of the research conducted by Lucas Palazzolo under the supervision of Laetitia Giraldi, funded by the ANR JCJC Nemo. This work was also carried out in collaboration with Mickael Binois and Luca Berti [3]. It has been accepted to Physical Journals of Fluids and presented into the International Conference on Sensitivity Analysis of Model Output [17].

7.3.4 Two-way coupling of fluid-structure interaction for elastic magneto-swimmers: a finite element ALE approach

Participants: Laetitia Giraldi.

Artificial micro-swimmers actuated by external magnetic fields hold significant promise for targeted biomedical applications, including drug delivery and micro-robot-assisted therapy. However, their dynamics remain challenging to control due to the complex nonlinear coupling between magnetic actuation, elastic deformations, and fluid interactions in confined biological environments. Numerical modeling is therefore essential to better understand, predict, and optimize their behavior for practical applications. In this work, we present a comprehensive finite element framework based on the Arbitrary Lagrangian-Eulerian formulation to simulate deformable elastic micro-swimmers in confined fluid domains. The method employs a full-order model that resolves the complete fluid dynamics while simultaneously tracking swimmer deformation and global displacement on conforming meshes. Numerical experiments are performed with the open-source finite element library Feel++, demonstrating excellent agreement with experimental data from the literature. The validation benchmarks in both two and three dimensions confirm the accuracy, robustness, and computational efficiency of the proposed framework, representing a foundational step toward developing digital twins of magneto-swimmers for biomedical applications.

It is part of the research conducted by Laetitia Giraldi in collaboration with Christophe Prud'Homme, Vincent Chabannes, Agathe Chouippe, and Céline Van Landeghem (all affiliated with the University of Strasbourg). The work has been submitted for review.

7.4 Axis D – Non-equilibrium physics: from models to mathematics

Stochastic analysis, and related numerical analysis, together with improved statistical descriptions of highly-nonlinear dynamics are central topics in Calisto. This research axis encompasses activities aiming, either (a) at strengthening our understanding on the origin and nature of fluctuations that are inherent to turbulent flows, or (b) at providing a coherent framework in response to the various mathematical challenges raised by the development of novel models in other research axes. Addressing these two fundamental aspects concomitantly to more practical and applied objectives is again a hallmark of the team.

7.4.1 Anomalous dissipation and spontaneous stochasticity in deterministic surface quasi-geostrophic flow

Participants: Jérémie Bec, Simon Thalabard, Nicolas Valade.

Surface quasi-geostrophic (SQG) theory describes the two-dimensional active transport of a scalar field, such as temperature, which – when properly rescaled – shares the same physical dimension of length/time as the advecting velocity field. This duality has motivated analogies with fully developed three-dimensional turbulence. In particular, the Kraichnan – Leith – Batchelor similarity theory predicts a Kolmogorov-type inertial range scaling for both scalar and velocity fields, and the presence of intermittency through multifractal scaling was pointed out by Sukhatme & Pierrehumbert [40], in unforced settings.

In the paper published in Journal of Fluid Mechanics in 2025 [4], we refine the discussion of these statistical analogies, using numerical simulations with up to $16\,384^2$ collocation points in a steady-state regime dominated by the direct cascade of scalar variance. We show that mixed structure functions, coupling velocity increments with scalar differences, develop well-defined scaling ranges, highlighting the role of anomalous fluxes of all the scalar moments. However, the clean multiscaling properties of SQG transport are blurred when considering velocity and scalar fields separately. In particular, the usual (unmixed) structure functions do no follow any power-law scaling in any range of scales, neither for the velocity nor for the scalar increments. This specific form of the intermittency phenomenon reflects the specific kinematic properties of SQG turbulence, involving the interplay between long-range interactions, structures and geometry. Revealing the multiscaling in single-field statistics requires us to resort to generalized notions of scale invariance, such as extended self-similarity and a specific form of refined self-similarity. Our findings emphasize the fundamental entanglement of scalar and velocity fields in SQG turbulence: they evolve hand in hand and any attempt to isolate them destroys scaling in its usual sense. This perspective sheds new lights on the discrepancies in spectra and structure functions that have been repeatedly observed in SQG numerics for the past 20 years.

7.4.2 Numerical analysis of stochastic system

On the ε–Euler-Maruyama scheme for time inhomogeneous jump-driven SDEs

Participants: Mireille Bossy, Paul Maurer.

In [1], we consider a class of general SDEs with a jump integral term driven by a time-inhomogeneous random Poisson measure. We propose a two-parameters Euler-type scheme for this SDE class and prove an optimal rate for the strong convergence with respect to the $L^p(\Omega)$-norm and for the weak convergence. One of the primary issues to address in this context is the approximation of the noise structure when it can no longer be expressed as the increment of random variables. We extend the Asmussen-Rosinski approach to the case of a fully dependent jump coefficient and time-dependent Poisson compensation, handling contribution of jumps smaller than ε with an appropriate Gaussian substitute and exact simulation for the large jumps contribution. For any $p \geq 2$, under hypotheses required to control the L^p-moments of the process, we obtain a strong convergence rate of order $1/p$. Under standard regularity hypotheses on the coefficients, we obtain a weak convergence rate of $1/n + \epsilon^{3-\beta}$, where β is the Blumenthal-Getoor index of the underlying Lévy measure. We compare this scheme with the Rubenthaler's approach where the jumps smaller than ε are neglected, providing strong and weak rates of convergence in that case too. The theoretical rates are confirmed by numerical experiments afterwards.

This study is mainly motivated by the simulation of stochastic models, with a focus on investigating Lévy processes, and particularly α-stable processes, arising as the limit distribution of the generalized Central Limit Theorem for independent random variables with infinite variance. We apply this model class for some anomalous diffusion model related to the dynamics of rigid fibers in turbulence studied in [18].

Weak rough kernel comparison via path-dependent PDEs for integrated Volterra processes

Participants: Mireille Bossy, Paul Maurer, Kerlyns Martínez Rodríguez.

Motivated by applications in physics (e.g., turbulence intermittency) and financial mathematics (e.g., rough volatility), in [9], we study a family of integrated stochastic Volterra processes characterized by a small Hurst parameter $H < \frac{1}{2}$. We investigate the impact of kernel approximation on the integrated process by examining the resulting weak error. Our findings quantify this error in terms of the L^1 norm of the difference between the two kernels, as well as the L^1 norm of the difference of the squares of these kernels. Our analysis is based on a path-dependent Feynman-Kac formula and the associated partial differential equation (PPDE), providing a robust and extendible framework for our analysis.

Intermittency in Volterra Processes and Weak Convergence of Markovian Approximations

Participants: Mireille Bossy, Paul Maurer, Kerlyns Martínez Rodríguez, Bernhard Eisvogel.

Multifractal (or intermittent) stochastic processes have been introduced in turbulence to generate processes with long-range correlations, capable of reproducing anomalous observables.

To get even closer to the analysis of intermittency in turbulence and to the multifractal nature of related quantity known as local dissipation, we consider in this work a stationary version of Riemann-Liouville fractional Brownian motion, and its integral, introducing a time scale $T_0 > 0$, and a Hurst parameter $H \in (0, \frac{1}{2})$,

$$\begin{aligned} X_\tau^{H,T_0} &= \int_0^\tau \exp(V_{s+T_0}^{H,T_0}) ds, \ \tau \leq 0, \\ V_t^{H,T_0} &= \nu \int_{t-T_0}^t (t-u)^{H-\frac{1}{2}} dW_u - \frac{\nu^2}{4H} T_0^{2H}, \ t \geq T_0. \end{aligned} \tag{1}$$

The process X admits a well-defined limit as $H \longrightarrow 0$, which takes the form of a multiplicative Gaussian chaos and exhibits local multifractality.

Despite the singular nature of the Volterra kernel, we adapt the techniques developed in [9] to show that the Markovian approximation –constructed via a Laplace transform– is itself locally multifractal and converges weakly to the Volterra solution for $H \in [0, \frac{1}{2})$. The convergence rate is then analyzed through its connection with the convergence rate of an associated quadrature formula.

A Poisson-Alekseev-Gröbner formula through Malliavin calculus for Poisson random integrals

Participants: Paul Maurer, Jérémy Zurcher *(School of Mathematics - Georgia Institute of Technology)*.

In [11], we establish an Alekseev–Gröbner formula for stochastic differential equations (SDEs) driven by a Poisson random measure, which express the global error between a functional of two processes solution of SDEs started at the same initial condition, in terms of the infinitesimal error (i.e, the difference between the SDEs coefficients). In particular, we consider the situation where the flow process is only assumed to be jointly stochastically continuous with respect to space and time. Our proof relies on a new approach for the definition of the Skorohod–Poisson integral to treat the anticipating term appearing in the formula, based on a definition of the Malliavin derivative on a class of smooth random variables, instead of the more standard polynomial chaos approach.

Transport of large rigid fibers in Kraichnan's model

Participants: Paul Maurer, Mireille Bossy, Jérémie Bec.

The dynamics of long, flexible fibers interacting with a flow constitute a well-studied problem in fluid–structure interaction. A classical framework is slender-body theory (SBT), which provides a local anisotropic relationship between the elastic forces acting on the fiber and the hydrodynamic drag forces it experiences.

An SBT-type equation describing fiber dynamics in a turbulent flow has been derived in the literature, in the form of a partial differential equation governing the local fiber length. In this work, we investigate the incorporation of a turbulent fluctuation model into this equation, focusing on the special case of a rigid fiber.

Turbulent fluctuations are introduced through a Kraichnan velocity field, modeled as a Gaussian random field that is white in time and spatially correlated. The resulting model takes the form of an infinite-dimensional stochastic differential equation driven by Stratonovich noise. For this equation, we establish the existence and global uniqueness of solutions.

We further derive the associated Fokker–Planck equation governing the law of the process and identify a reduced finite-dimensional model, in the form of a system of stochastic differential equations, which is equivalent in law to the original formulation.

7.5 Axis E – Modeling uncertainties in fluctuating environments

7.5.1 Non-unique self-similar blowups in shell models: insights from dynamical systems and machine-learning

Participants: Ciro Sobrinho Campolina Martins, Eric Simonnet, Simon Thalabard.

Strong numerical evidence supports a universal blow-up scenario in the Sabra shell model, a widely used cascade model for three-dimensional turbulence, featuring complex velocity variables defined on a geometric progression of scales. The blow-up is conjectured to be self-similar and characterized by finite-time convergence toward a universal profile exhibiting non-Kolmogorov (anomalous) small-scale scaling.

Solving the associated nonlinear eigenvalue problem has, however, proved challenging. Previous insights have mainly relied on the Dombre–Gilson renormalization scheme, which transforms self-similar solutions into solitons propagating over an infinite rescaled time horizon. In this work, we further characterize blow-up solutions in the Sabra model by developing two complementary approaches targeting the eigenvalue problem.

The first approach is based on a formal expansion with respect to a bookkeeping parameter ε, interpreting the self-similar solution as a (degenerate) homoclinic bifurcation. Using standard bifurcation analysis tools, we show that the homoclinic bifurcations identified under finite truncations of the expansion converge toward the numerically observed Sabra solution.

The second approach relies on machine-learning-based optimization techniques to directly solve the Sabra eigenvalue problem. This method reveals a rich and intricate phase space structure, including a continuous family of non-universal blow-up profiles, characterized by different numbers N of pulses and associated scaling exponents α. This work is published in [2].

7.5.2 Calibration under uncertainty of Lagrangian transport models

Participants: Mireille Bossy, Kerlyns Martínez Rodríguez, Hector Olivero-Quinteros, Eduardo Nelson Gutierrez Turner.

As part of the SWAM Associated Team research programme, we have been working this year on the modeling of time series that combine dynamical variables and scalar quantities (such as salinity and temperature), based on a stochastic Lagrangian description of transport phenomena.

The project pursues several objectives:

- Clarify the modeling framework and identify the parameterizations in `SDM_brine` that need to be adapted for salinity;
- Develop a coherent model for the fluctuations of time series at a single measurement point;
- Build, on the basis of this model, a robust methodology for calibration under uncertainty.

The last two objectives involve both mathematical modeling and the statistical analysis of stochastic processes, with the aim of estimating physical model parameters while performing sensitivity analyses to identify potential improvements. We are currently testing the calibration methodology on simulated data, prior to applying it to observational data.

8 Bilateral contracts and grants with industry

8.1 Bilateral Grants with Industry

Participants: Christophe Henry.

Modeling of particle deposition and resuspension in airflow configurations using a hybrid LES/PDF approach. Since May 2025, Christophe Henry supervises the CIFRE PhD project of Guirec Peyrot, in collaboration with the Fluid Mechanics Energy and Environment team from EDF R&D (Martin Ferrand being the co-supervisor). The goal of this project is to develop and implement a new stochastic Lagrangian model for the simulation of particle transport, deposition and resuspension compatible with Large-Eddy Simulations (LES) for the fluid phase.

9 Partnerships and cooperations

9.1 International initiatives

9.1.1 Associate Teams in the framework of an Inria International Lab or in the framework of an Inria International Program

SWAM

Participants: Jérémie Bec, Mireille Bossy, Christophe Henry, Paul Maurer, Kerlyns Martinez Rodriguez.

Title: Sea, Waves, And ecosysteMs: Stochastic models for perturbed marine environments

Duration: 3 years, starting in 2024

Coordinator: Kerlyns Martinez Rodriguez

Partners:

- Universidad de Valparaiso (UV) (Chile)
- Universidad de Concepción (UdeC) (Chile)

Inria contact: Mireille Bossy

Summary: This associated team project brings together a multidisciplinary team of experts in areas such as stochastic analysis, numerical probabilities, fluid mechanics, ocean engineering, and ecology. The primary objective is to address current challenges related to the installation of desalination plants and their potential impacts on ocean dynamics, thereby affecting the composition and distribution of species in surrounding aquatic ecosystems. The two issues at hand involve different time and space scales.

On the one hand, a large-time scale stochastic model analysis will be conducted to study species potentially at risk in certain coastal areas. On the other hand, desalination plants interact with the marine environment through seawater intake points and brine discharge points into the sea. This discharge process occurs on a much shorter time scale. Nevertheless, it is essential to understand how the brine generated during the internal plant process is dispersed and/or accumulated, and how it may potentially disrupt the current. For this aspect, we intend to develop CFD simulation tools to analyze response variabilities and sensitivity, based on Lagrangian stochastic approach and the code SDM developed at Calisto.

During 2025, the project held weekly online meetings to advance the topics defined in the first year, along with the updated items described below that focus on two main areas.

Regarding the flow modeling part. The calibration process concerns Lagrangian transport models for salt concentration and temperature, considered as scalar quantities. This topic involves both mathematical modeling and statistics of stochastic processes to estimate physical model parameters while conducting sensitivity analysis to target potential improvements (see also Section 7.5.2).

Regarding the ecology/policy modeling part. The extension of the study to marine species beyond the main kelp forest resources already investigated in SWAM. The idea here is to analyze the interplay between different species including algae, consumers and producers (sessiles and non-sessiles) especially when subject to harvesting by fishermen and how the effects of non-compliance are propagated to the network. Perspectives on this topic cover control problems as well as analysis of spatial dynamics and long-term dynamics (see also Section 7.2.3).

9.1.2 STIC/MATH/CLIMAT AmSud projects

CHA2MAN

Participants: Jérémie Bec, Mireille Bossy, Christophe Henry, Paul Maurer, Eric Simonnet, Simon Thalabard.

Title: Stochasticity & Chaos in Multiscale Phenomena

Program: MATH-AmSud

Duration: January 1, 2025 – December 31, 2026

Local supervisor: Mireille Bossy

Partners:

- Alexei Mailybaev (IMPA, Brazil)
- Kerlyns Martínez Rodríguez (Universidad de Concepción, Chile)

Inria contact: Mireille Bossy

Summary: The CHA^{2}MAN (stoCHAsticity & CHAos in MultiscAle pheNomena) project aims to address the complex behaviors of multiscale dynamical systems by incorporating stochastic perturbations to account for inherent uncertainties and randomness. This approach serves as a regularization mechanism when deterministic models fall short.

To this aim, CHA^{2}MAN integrates perspectives from two mathematical disciplines: stochastic modeling & analysis and the study of complex dynamical systems to address specific multiscale phenomena, with chaotic behaviors.

Throughout the year, the team maintained regular scientific interactions through weekly online meetings. In addition, consistent exchanges were ensured via the Calisto seminar, held regularly by Zoom, allowing continuous collaboration among the partners.

Several international mobility actions marked the year. Spring visits were organized in 2025 and 2026 from Chile to France, involving researchers Kerlyns Martínez Rodríguez (University of Concepción) and Héctor Olivero (University of Valparaíso), as well as doctoral student Eduardo Gutiérrez (University of Valparaíso). Francisco Bernal, a Mathematical Engineering student from the University of Valparaíso, visited the Calisto group to take part in the Populate Summer School 2025, with complementary funding from the Associated Team SWAM.

Eduardo Gutiérrez also carried out a three-month doctoral visit from September to the end of November 2025. André Considera, postdoctoral researcher at IMPA, joined the Calisto group for a ten-month visit starting on October 1st, 2025. Mireille Bossy and Paul Maurer from the Calisto group, together with Héctor Olivero from the University of Valparaíso, visited the Mathematics Department at the University of Concepción in December 2025 for a two-week stay, hosted by Kerlyns Martínez.

Further exchanges included visits by Alexei Mailybaev and Luna Lomonaco from IMPA to the Calisto group at INPHYNI, University of Nice Côte d'Azur, and a visit by Jan Kiwi from PUC to several French laboratories in Fall 2025. These activities significantly strengthened scientific collaboration and fostered long-term partnerships between the participating institutions.

9.1.3 Participation in other International Programs

CEFIPRA project "Polymers in turbulent flows"

Participants: Jérémie Bec, Dario Vincenzi *(LJAD, Université Côte d'Azur)*.

Title: Polymers in turbulent flows

Partner Institutions:

- LJAD, Université Côte d'Azur, France
- IIT Bombay, India
- ICTS Bangalore, India

Date/Duration: March 31, 2023 / 3 years

Additionnal info/keywords: This bilateral project aims at studying the dynamics of polymers in turbulent flows, with the idea to use Lagrangian approaches to find links between microscopic scales and the rheology of polymer suspensions and macroscopic continuum models. The french PI is Dario Vincenzi (CNRS-Laboratoire Jean Alexandre Dieudonné) and the Indian PI is Jason Picardo (IIT Mumbai). The CALISTO team is a partner of the project and received funding to support bilateral visits.

9.2 European initiatives

9.2.1 Other european programs/initiatives

COST Action CA24104, Stochastic Differential Equations: Computation, Inference, Applications (STOCHASTICA).

Participants: Mireille Bossy, Paul Maurer.

Started in November 2025, STOCHASTICA is a pan-European network of researchers working under the umbrella of Computational Stochastics. As an EU-funded COST Action, STOCHASTICA brings together applied modelers, theoretical mathematicians, numerical analysts, and statisticians with the goal of making practical and general-purpose tools that empower non-specialist experts to make appropriate and routine use of stochastic differential equation (SDE) models. Mireille Bossy is member of the network Core Group and leads the WP "Stochastic systems and statistical methods".

9.3 National initiatives

9.3.1 ANR PRC TILT

Participants: Jérémie Bec, Ciro Sobrinho Campolina Martins.

The ANR PRC project TILT (Time Irreversibility in Lagrangian Turbulence) started on January 1st, 2021. It is devoted to the study and modeling of the fine structure of fluid turbulence, as it is observed in experiments and numerical simulations. In particular, recall that the finite amount of dissipation of kinetic energy in turbulent fluid, where viscosity seemingly plays a vanishing role, is one of the main properties of turbulence, known as the dissipative anomaly. This property rests on the singular nature and deep irreversibility of turbulent flows, and is the source of difficulties in applying concepts developed in equilibrium statistical mechanics. The TILT project aims at exploring the influence of irreversibility on the motion of tracers transported by the flow. The consortium consists of 3 groups with complementary numerical and theoretical expertise, in statistical mechanics and fluid turbulence. They are located in Saclay, at CEA (Bérengère Dubrulle), in Lyon, at ENSL (Laurent Chevillard, Alain Pumir), and in Sophia Antipolis (Jérémie Bec). Within TILT, Ciro Sobrinho Campolina Martins joined CALISTO in January 2023 until early 2025.

9.3.2 ANR JCJC NEMO

Participant: Laetitia Giraldi, Lucas Palazzolo.

The JCJC project NEMO (controlliNg a magnEtic Micro-swimmer in cOnfined and complex environments) was selected by ANR in 2021, and started on January 1, 2022 for four years. The end is planned on January 31, 2027. NEMO team is composed of Laetitia Giraldi, Mickael Binois and Laurent Monasse (Inria, Acumes).

NEMO aims at developing numerical methods to control a micro-robot swimmer in the arteries of the human body. These robots could deliver drugs specifically to cancer cells before they form new tumors, thus avoiding metastasis and the traditional chemotherapy side effects.

NEMO will focus on micro-robots, called Magnetozoons, composed of a magnetic head and an elastic tail immersed into a laminar fluid possibly non-Newtonian. These robots imitate the propulsion of spermatozoa by propagating a wave along their tail. Their movement is controlled by an external magnetic field that produces a torque on the head of the robot, producing a deformation of the tail. The tail then pushes the surrounding fluid and the robot moves forward. The advantage of such a deformable swimmer is its aptness to carry out a large set of swimming strategies, which could be selected according to the geometry or the rheology of the biological media where the swimmer evolves (blood, eye retina, or other body tissues).

Although the control of such micro-robots has mostly focused on simple unconfined environments, the main challenge is today to design external magnetic fields that allow them to navigate efficiently in complex realistic environments.

NEMO aims at elaborating efficient controls, which will be designed by tuning the external magnetic field, through a combination of Bayesian optimization and accurate simulations of the swimmer's dynamics with Newtonian or non-Newtonian fluids. Then, the resulting magnetic fields will be validated experimentally in a range of confined environments. In such an intricate situation, where the surrounding fluid is bounded laminar and possibly non-Newtonian, optimization of a strongly nonlinear, and possibly chaotic, high-dimensional dynamical system will lead to new paradigms.

9.3.3 ANR PRC NETFLEX

Participants: Jérémie Bec, Mireille Bossy, Laetitia Giraldi, Christophe Henry, Paul Maurer.

The ANR PRC project NEFFLEX (*Tangles, knots, and breakups of flexible fibers in turbulent fluids*) started on January 1, 2022. NETFLEX is a four-years project that aims at advancing our knowledge on the dynamics of long, flexible, macroscopic fibers in turbulent flows, and to understand and model the processes of fiber fragmentation and aggregation. NETFLEX brings together Université Côte d'Azur (Institut de Physique de Nice, Laboratoire Jean Alexandre Dieudonné), Inria (Calisto) and Aix-Marseille University (IRPHE). NETFLEX approach combines three levels of description (micro, meso, and macroscopic) and relies on a synergy between mathematical modeling, numerical simulations, and laboratory experiments. It relies on the development of newly designed experiments and a substantial improvement of the mathematical and numerical tools currently used in the study of fiber dynamics. An overall aim is to develop a new framework able to cope with such intricate effects of turbulence and to reproduce the significant observable features in a macroscopic approach.

Improved modeling of turbulent fluctuations and effective transport models for aggregates are among the key issues to be addressed in order to extend the macroscopic models.

9.3.4 PEPR Numpex AAP SAGE-HPC

Participant: Laetitia Giraldi, Eric Simonnet.

The project, prepared and submitted in 2025, has been selected under the PEPR NumPEx call for proposals. It will start on January 1st, 2027, and will run until the end of 2029.

The SAGE-HPC project aims to develop an open and scalable software platform for multi-fidelity optimization of complex physical problems on exascale HPC systems. By combining low- and high-fidelity models with advanced optimization methods, the project seeks to reduce computational costs while enabling efficient and automated large-scale optimization. The framework is evaluated on benchmark problems drawn from three main application areas: swimmer swarms, aeronautical engineering, and solar composition modeling.

Coordinated by Laetitia Giraldi, who serves as the Principal Investigator, this project brings together a consortium involving Inria (teams Calisto, Acumes, Maasai, and Makutu) and IRMA at Université de Strasbourg.

9.4 Regional initiatives

9.4.1 Thematic Semester POPULATE

Participants: Mireille Bossy, Laetitia Giraldi, Christophe Henry.

The thematic semester POPULATE (*Population dynamics: from fundamental to applied science*) started on June 1, 2024 and ended on December 31 2025. The project was funded by the Academy of "Complex Systems" from University Côte d'Azur. Additional funding were secured from CNRS Mathematics (through the national call for Thematic Schools) as well as local institutions (Doeblin Federation, Inria, INRAE and LJAD).

The main goal of POPULATE was to organize events on the topic of "models for population dynamics". Three main events took place between March 2025 and October 2025: two one-week international conferences and one two-week international summer school (these events are detailed in Section 10.1).

The project was coordinated by Christophe Henry and the committee was composed of researchers from various laboratories in Nice (more details on the website). Laetitia Giraldi was in the Organizing committee of the summer school.

10 Dissemination

10.1 Promoting scientific activities

10.1.1 Scientific events: organization

General chair, scientific chair

- Mireille Bossy is co-chairing, with Nawaf Bou-Rabee (Rutgers) and David Cohen (Chalmers), the Stochastic Computation Workshop at FoCM2026.
- Christophe Henry co-chaired the Spring Conference on Population Dynamics: From Data to Models, held within Inria Center at University Côte d'Azur from March 10 until March 14, 2025. This event was organized within the framework of the Thematic Semester POPULATE.
- Christophe Henry co-chaired the Summer School on Population Dynamics: From Fundamental to Applied Science, held in Grasse from June 16 until June 27, 2025. This event was organized within the framework of the Thematic Semester POPULATE.

Member of the organizing committees

- Christophe Henry was a member of the organizing committee for the Spring Conference on Population Dynamics: From Data to Models, held within Inria Center at University Côte d'Azur from March 10 until March 14, 2025.

- Laetitia Giraldi and Christophe Henry were members of the organizing committee for the Summer School on Population Dynamics: From Fundamental to Applied Science, held in Grasse from June 16 until June 27, 2025.
- Christophe Henry was a member of the organizing committee for the Fall Conference on Population Dynamics: Model Design, Optimization and Control, held within LJAD laboratory at University Côte d'Azur from October 13 until October 17, 2025.

Scientific seminars of the Team. Christophe Henry is organizing the monthly Seminar of Team CALISTO. In 2025, the following researchers were invited to give a presentation (more details on the team website): Paola Cinnella (Institut Jean Le Rond d'Alembert, Paris), Frank Ruffier (CNRS atAix Marseille University) and Atul Varshney (Nice Institute of Physics, Nice).

10.1.2 Scientific events: selection

- Laetitia Giraldi was invited to chair a session and to present at PICOF, Hamamet 2025.

Member of the conference program committees

- Christophe Henry was a member of the scientific committee for the Spring Conference on Population Dynamics: From Data to Models, held within Inria Center at University Côte d'Azur from March 10 until March 14, 2025.
- Laetitia Giraldi and Christophe Henry were members of the scientific committee for the Summer School on Population Dynamics: From Fundamental to Applied Science, held in Grasse from June 16 until June 27, 2025.
- Christophe Henry was a member of the scientific committee for the Fall Conference on Population Dynamics: Model Design, Optimization and Control, held within LJAD laboratory at University Côte d'Azur from October 13 until October 17, 2025.
- Laetitia Giraldi was members of the scientific committee for the School/Conferences on Active Matter: the synergy between Maths and Physics, held in Paris from May 26 until June 13, 2025.
- Mireille Bossy was member of the scientific comittee for "EHF 2025 – The XXI edition of the Jacques-Louis Lions Hispano-French School on Numerical Simulation in Physics and Engineering", which was held in Ciudad Real, Spain, in June 2025.

10.1.3 Journal

Reviewer - reviewing activities In 2025, CALISTO scientific staff have been acting as reviewers for various international journals, listed in the following according to each team member:

- Christophe Henry acted as reviewer for *Applied Physics Letters, Journal of Aerosol Science, Journal of Colloid and Interface Science, Building and Environment, Research & Design of Nuclear Engineering*.
- Mireille Bossy acted as reviewer for *Stochastic Processes and their Applications*, *Journal of Computational Physics*, *FoCM Journal*, *Numerical Algorithms*, IMA Journal.

10.1.4 Invited talks

- Laetitia Giraldi was invited to organize, chair, and present on the Active Matter: the synergy between Maths and Physics conference, June 2025.
- Laetitia Giraldi was invited to give a seminar into IRPHE laboratory in Marseille in November 2025.
- Mireille Bossy was invited to give a talk at the Probability, finance and signal Conference, May 19-23, 2025 at CIRM, France.
- Mireille Bossy was invited to give a talk at the international workshop Milstein's method: 50 years on, Nottingham, July 2025.

10.1.5 Leadership within the scientific community

- Until May 2025, Jérémie Bec was in charge of the Academy of excellence "Complex Systems" of the IDEX Université Côte d'Azur (Decision-making role for funding; Coordination and animation of federative actions; Participation in the IDEX evaluation).
- Since May 2025, Mireille Bossy is in charge, with Claire Michel, of the Academy of excellence "Complex Systems" of the IDEX Université Côte d'Azur.
- Mireille Bossy was Chairing until May 2025 the Scientific Council of the Academy of excellence "Complex Systems" of the IDEX Université Côte d'Azur.

Calisto team members are involved in the scientific/steering committees of several national research networks:

- RT-UQ : Research network on Uncertainty Quantification.
- GdR Défis théoriques pour les sciences du climat on theoretical aspects for climate science.
- GDR Calcul that promotes communication and exchange within the computing community in France.

Calisto team members are also involved as partners in other networks including: GdR Navier-Stokes 2.0 on turbulence, and Euromech (European Mechanics Society).

10.1.6 Scientific expertise

- Mireille Bossy was member of the hiring committee PR 26 at LPMS, Université Paris Cité, and member of the hiring committee PR 26 at LAMA, Université Gustave Eiffel.
- Mireille Bossy reviewed projet proposals for ANID (Chile).
- Mireille Bossy was a jury member for the PhD Price 2025 «Maths Entreprise & Société» of AMIES.
- Christophe Henry reviewed project proposal for:
  - University of Pau (France)
  - PAZY Fondation (Israel).

10.1.7 Research administration

- Christophe Henry is acting as the local correspondent for the yearly activity reports of all Teams within Inria Center at Université Côte d'Azur since September 2023.
- Laetitia Giraldi is member of the Scientific Committee of the Maison de la Simulation et des Interactions (MSI), Université Côte d'Azur since June 2025.
- Laetitia Giraldi is member of the NICE committee for Inria postdoctoral fellowships and Inria delegation positions since 2022.
- Laetitia Giraldi is Scientific Integrity Officer of Inria Center at University Côte d'Azur since December 2025.

10.2 Teaching - Supervision - Juries - Educational and pedagogical outreach

10.2.1 Teaching

Calisto scientific staff have been involved in the following teaching activities:

- Laetitia Giraldi: Assignments (Khôlles) in preparatory schools MPSI, MP* (2h weekly, Centre International de Valbonne).

- Christophe Henry: Advanced models for hydrology, with master students in their fifth year (equiv. M2) within the program "Génie de l'eau" at the engineering school Polytech'Nice (27h).
- Christophe Henry: Chemistry, with 1st year students (equiv. L1) in the Batchelor Program of Centrale Méditerranée (14h).

10.2.2 Supervision

- PhD defense: Paul Maurer defended his PhD on November 2025 entitled "Analysis and approximation of some stochastic differential equations for the modeling of non diffusive phenomenons" [7]; supervised by Mireille Bossy.
- PhD defense: Nicolas Valade defended his PhD on September 2025 entitled "Surface Quasi-Geostrophic turbulence" [8]; supervised by Jérémie Bec and Simon Thalabard (Institut de Physique de Nice, Université Côte d'Azur).
- PhD defense of Celine Van-Landeghem, "Micro-natation dans des environnements complexes" defended in October 2025; co-financed by the ANR Nemo; co-supervised by Laetitia Giraldi and Christophe Prud'Hommes (University of Strasbourg).
- PhD in progress: Guirec Peyrot, "Modeling of particle deposition and resuspension in airflow configurations using a hybrid LES/PDF approach" started in May 2025; CIFRE PhD co-supervised by Christophe Henry and Martin Ferrand (EDF R&D).
- PhD in progress: Lucas Palazzolo, "Using Bayesian optimizian for driving micro-swimmers" started in october 2023; financed by the ANR Nemo; co-supervised by Laetitia Giraldi and Mickael Binois (Inria, Acumes).
- PhD visit: Eduardo Nelson Gutierrez Turner (Universidad de Valparaíso, Chile and SWAM associated team); supervised by Mireille Bossy during his stay, Eduardo is supervised in Chile by Hector Olivero-Quinteros and Kerlyns Martinez Rodriguez.
- Postdoc in progress: Chiara Calascibetta, "Using Machine Learning tools for controlling a swarm of micro-swimmers" started in October 2024; financed by Inria; co-supervised by Laetitia Giraldi and Jérémie Bec.
- Postdoc in progress: Christian Reartes, "Developing Boundary element methods for the dynamics of immersed fibers" started in September 2025; financed by the ANR Nemo; co-supervised by Laetitia Giraldi and Jérémie Bec.
- M2 internship: John Alexander Osorio Henao (Université Côte d'Azur); supervised by Laetitia Giraldi and Christophe Henry.
- M2 internship: Bernhard Eisvogel (Sorbone Université) supervised by Mireille Bossy.

10.2.3 Juries

- PhD defense Referee: Laetitia Giraldi served as referee for the PhD thesis of Karl Maroun (University of Poitiers).
- PhD defense Chair: Mireille Bossy served as Jury chair for the PhD theses of Mathis Fitoussi (Université Paris-Saclay).
- PhD defense Examiner: Mireille Bossy served as an examiner for the PhD theses of Marius Duvillard (Institut polytechnique de Paris).
- PhD Individual Monitoring Committee (IMC): Christophe Henry was a member of the IMC of Aryamaan Jain (Inria, GRAPHDECO), supervised by Guillaume Cordonnier.
- PhD Individual Monitoring Committee: Christophe Henry was a member of the IMC of Defa Sun (Physics Institute of Nice), supervised by Christophe Brouzet and Jérémie Bec.

10.2.4 Educational and pedagogical outreach

Christophe Henry took part in the yearly national meeting of the *Association des Professeurs de Mathématiques de l'Enseignement Public de la maternelle à l'université* (APMEP) that was held in Toulon (October 18-21, 2025). He was invited to give a 90-minutes presentation on "Sandcastles: is there a recipy that does not fail?" and to animate a 90-minutes workshop on "Geometry and physics behind sphere packing".

10.3 Popularization

10.3.1 Specific official responsibilities in science outreach structures

- Christophe Henry is a member of the project committee of Terra Numerica (a federative project for the dissemination of digital science, initiated by CNRS, Inria and Université Côte d'Azur), helping punctually in the design of new large-audience workshops since September 2025.

10.3.2 Participation in live events

- Café In: The communication team within Inria Centre at Université Côte d'Azur is organizing general audience talks where researchers present some of their activities to all staffs from the Inria Center at Université Côte d'Azur.
  - Christophe Henry gave a 1h presentation on "*Pipes: why do they clog so often?*" on January 9th, 2025.
- Fête de la Science: Every year, a science festival is held across France in autumn where researchers present their activities to the public (especially for childrens and students).
  - Christophe Henry took part in the festival held in Valbonne (October 4, 2025), in Villeneuve-Loubet (October 5, 2025), in Biot (October 11, 2025) and in Nice (October 12, 2025).
- Terra Numerica (TN): TN is a federative project for the dissemination of digital science (initiated by CNRS, Inria and Université Côte d'Azur).
  - Christophe Henry took part in 7 of the TN live events held every first Saturday of each month, from 2pm to 6pm, animating various practical workshops related to physics and numerics.
- Sciences pour Tous 06 (SPT06): SPT06 is an association that organizes regular scientific conferences for the general public in the Alpes-Maritimes department.
  - Christophe Henry gave a 1h presentation on "*Sandcastles: is there a recipy that does not fail?*" on three occasions (in Saint-Martin du Var on January 25, 2025, in Falicon on September 3, 2025 and in Aspremont on September 10, 2025) as well as a 1h presentation on "*Pipes: why do they clog so often?*" on three occasions (in the detention center of Grasse on April 7, 2025, in Valdeblore on April 18, 2025 and in Biot on November 27, 2025).

11 Scientific production

11.1 Publications of the year

International journals

[1] M. Bossy and P. Maurer. 'On the ε-Euler-Maruyama scheme for time-inhomogeneous jump-driven SDEs'. In: *Stochastic Processes and their Applications* (5th Aug. 2025), p. 104747. DOI: 10.1016/j.spa.2025.104747. URL: https://inria.hal.science/hal-04404438 (cit. on p. 19).

[2] C. Campolina, E. Simonnet and S. Thalabard. 'Non-unique self-similar blowups in shell models: insights from dynamical systems and machine-learning'. In: *Journal of Physics A: Mathematical and Theoretical* 58.17 (23rd Apr. 2025), p. 175701. DOI: 10.1088/1751-8121/adc773. URL: https://hal.science/hal-05407713 (cit. on p. 21).

[3] L. Palazzolo, M. Binois, L. Berti and L. Giraldi. 'Parametric Shape Optimization of Flagellated Micro-Swimmers Using Bayesian Techniques'. In: *Physical Review Fluids* (14th Apr. 2025). DOI: 10.1103/PhysRevFluids.10.034101. URL: https://hal.science/hal-04699705 (cit. on p. 17).

[4] N. Valade, J. Bec and S. Thalabard. 'Surface quasigeostrophic turbulence: The refined study of an active scalar'. In: *Journal of Fluid Mechanics* 1021 (25th Oct. 2025), A17. DOI: 10.1017/jfm.2025.10698. URL: https://hal.science/hal-05408199 (cit. on p. 18).

Conferences without proceedings

[5] H. Meheut, F. Gerosa and J. Bec. 'A unique solution to overcome the barriers to planetesimal formation at low dust-to-gas ratio'. In: Semaine de l'astrophysique française. Toulouse, France, 2025. URL: https://hal.science/hal-05343429.

Scientific books

[6] J.-P. Minier, M. Ferrand and C. Henry. *Understanding Turbulent Systems : Progress in Particle Dynamics Modeling*. Lecture Notes in Physics LNP-1093. Springer Nature Switzerland, 2025. DOI: 10.1007/978-3-031-84466-9. URL: https://hal.science/hal-05320438 (cit. on p. 15).

Doctoral dissertations and habilitation theses

[7] P. Maurer. 'Analysis and approximation of some stochastic differential equations for the modeling of non diffusive phenomenons : application to turbulent transport'. Université Côte d'Azur, 14th Nov. 2025. URL: https://theses.hal.science/tel-05520081 (cit. on p. 29).

[8] N. Valade. 'Surface quasi-geostrophic turbulence'. Université Côte d'Azur, 29th Sept. 2025. URL: https://theses.hal.science/tel-05492610 (cit. on p. 29).

Reports & preprints

[9] M. Bossy, K. Martínez Rodríguez and P. Maurer. *Weak rough kernel comparison via PPDEs for integrated Volterra processes*. 13th Jan. 2025. URL: https://inria.hal.science/hal-04885861 (cit. on pp. 19, 20).

[10] C. Calascibetta, L. Giraldi and J. Bec. *Harnessing swarms for directed migration of interacting active particles via optimal global control*. 2nd Dec. 2025. URL: https://hal.science/hal-05408173 (cit. on p. 17).

[11] P. Maurer and J. Zurcher. *A Poisson-Alekseev-Gröbner formula through Malliavin calculus for Poisson random integrals*. 14th Oct. 2025. DOI: 10.48550/arXiv.2510.05300. URL: https://hal.science/hal-05313794 (cit. on p. 20).

[12] L. Palazzolo, M. Binois and L. Giraldi. *Non-Locally Controllable but Trackable Magnetic Head Flagellated Swimmer*. 2025. DOI: 10.48550/arXiv.2511.02535. URL: https://inria.hal.science/hal-05348147 (cit. on p. 17).

[13] L. Palazzolo, M. Binois and L. Giraldi. *Optimal Control of Microswimmers for Trajectory Tracking Using Bayesian Optimization*. 10th Feb. 2026. URL: https://hal.science/hal-05504613.

[14] C. Prud'Homme, V. Chabannes, L. Giraldi, A. Chouippe and C. V. Landeghem. *Two-way Coupling of Fluid-Structure Interaction for Elastic Magneto-Swimmers: A Finite Element ALE Approach*. 10th Nov. 2025. URL: https://inria.hal.science/hal-05482283.

[15] W. Ruffenach, E. Simonnet and N. Valade. *Spontaneous stochasticity and the Armstrong-Vicol passive scalar*. 22nd Apr. 2025. URL: https://hal.science/hal-05230304.

[16] W. Ruffenach, E. Simonnet and N. Valade. *Spontaneous stochasticity in the Armstrong-Vicol passive scalar*. 19th Sept. 2025. URL: https://hal.science/hal-05281255.

Other scientific publications

[17] L. Palazzolo, M. Binois, L. Berti and L. Giraldi. ‘Parametric shape optimization of flagellated microswimmers using Bayesian techniques’. In: SAMO 2025 - International Conference on Sensitivity Analysis of Model Output. Grenoble, France, 23rd Apr. 2025. URL: https://hal.science/hal-05010013 (cit. on p. 17).

11.2 Cited publications

[18] L. Campana, M. Bossy and J. Bec. ‘Stochastic model for the alignment and tumbling of rigid fibres in two-dimensional turbulent shear flow’. In: *Physical Review Fluids* 7.12 (2022), p. 124605. URL: https://hal.inria.fr/hal-03718232 (cit. on p. 19).

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[20] M. I. Ávila-Thieme, D. Corcoran, A. Pérez-Matus, E. A. Wieters, S. A. Navarrete, P. A. Marquet and F. S. Valdovinos. ‘Alteration of coastal productivity and artisanal fisheries interact to affect a marine food web’. In: *Scientific reports* 11.1 (2021), p. 1765 (cit. on p. 16).

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[24] L. Dubus, S. Muralidharan and A. Troccoli. ‘What Does the Energy Industry Require from Meteorology?’ In: *Weather & Climate Services for the Energy Industry*. Ed. by A. Troccoli. Cham: Springer International Publishing, 2018, pp. 41–63 (cit. on p. 14).

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