CALISTO

Stochastic **A**pproaches for **C**omplex F**l**ows and Env**i**ronment

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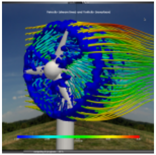
Stochastic approaches for complex flows and application to wind and hydropower energies



Inria Brasil Workshop on Digital Science and Energy

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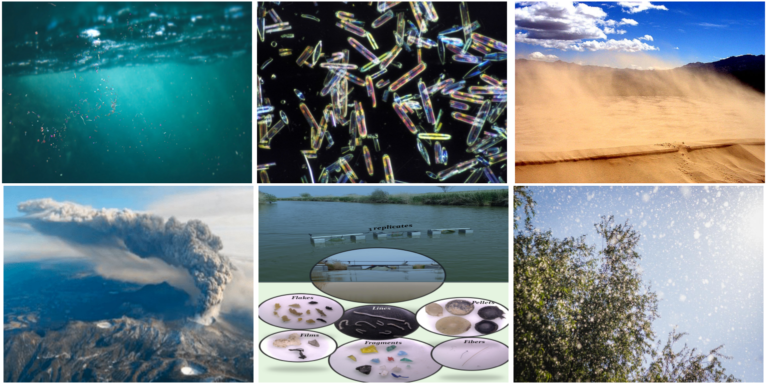
Particle laden flow

Particles in turbulence play a crucial role in various industrial, biological, and environmental applications.



In addition to turbulence modelling , there are various other effects and issues to consider:

- Passive vs Active particle
- Size, Shape, Inertia, Rheology
- Particle-particle interactions (collisions, agglomerations)
- Additional forces (electrostatics, Brownian motion)

Overall scientific objectives and main research axis

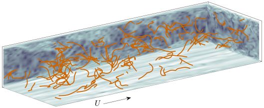
CALISTO develops cutting-edge researches, models and numerical methods, from the most fundamental aspects to the engineering applications of *complex flows in interaction with complex particles*.

Ⓐ Complex flows: from fundamental science to applied models

Micro-Macro modeling for polydisperse, complex-shaped, deformable particles.

Particle interactions and size evolution;

Transfers between the dispersed phase and its environment;



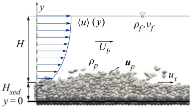
Snapshot of (DNS of) elongated fibers transported by a turbulent channel flow. The colored slices represent the magnitude of the fluid velocity vorticity.

Ⓑ Particles and flows near boundaries: Lagrangian approaches for large scale simulations

Stand-alone Lagrangian simulations in atmospheric/oceanic boundary layer;

Advanced stochastic models for discrete particle dispersion and resuspension;

Coherent descriptions for fluid and particle phases.



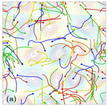
Snapshot of particle resuspension in complex beds (DNS) *(Jain et al., 2021)*

Ⓒ Active agents in a fluid flow

Micro swimmers in complex environment;

Models, controlability and optimisation.

Reinforcement learning for the navigation.



Swimmers immersed in a 2D non-steady flow that follow five admissible policies: snapshot of the fluid vorticity, with the instantaneous position of swimmers colored according to their policy *(El Khiyati et al., 2023)*.

Ⓓ Mathematical and numerical analysis of stochastic systems

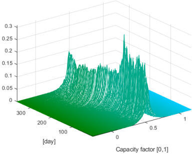
Mathematics for fundamental aspects of turbulence and turbulent transport;
Advanced stochastic models, accounting for some specific micro-physical phenomena (memory effects, anomalous diffusions, spatial/temporal correlations).

Ⓔ Variability and Uncertainty in flows and Environment

Variability in wind–hydro energy simulation at small scale;

Meta modelisation and uncertainty quantification;

Uncertainty models for machine-learned dataset in meteorological context.



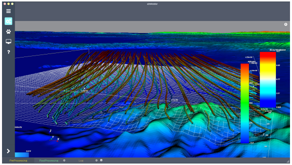
Calendar uncertainty PDF on a ML model for hydropower capacity factor at the France territory scale *(Sessa et al., 2021)* .

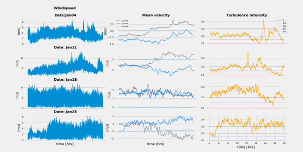
Wind forecasting models, wind-farm modelling

Several scales and methods

Persistence – Naive Predictor	$U(t+k) = U(t)$	very short term (seconds to 30 minutes)
Physical Approach	Global Forecasting, WRF, ...	for long term (one day to one week)
Statistical Approaches	ANN, TS-models	for short term (30 minutes to 6 hours)
Hybrid Structures	NWP + ANN, ...	medium and long term (6 hours to one week)

Calisto produces tools for physical approach at the windfarm scale (few kilometers) and times series analysis.

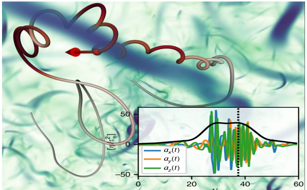




taking the perspective of a 'air parcel', and given the flow field $\mathscr{U}(t, x)$,

we consider parcel's state variables (x_f, U_f)

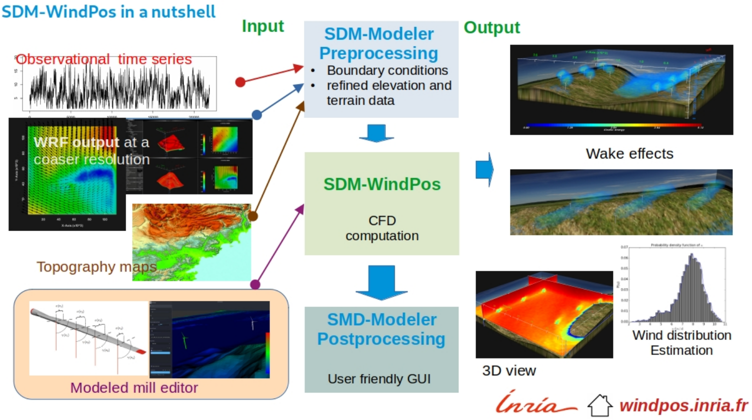
$$\frac{dx_f}{dt}(t) = U_f(t),$$
$$U_f(t) = \mathscr{U}(t, x_f(t)).$$

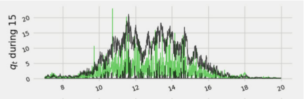


tracers trajectories in turbulence

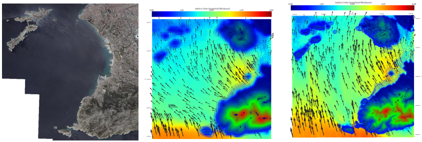
Modelling effort concentrated on $\mathscr{U}(t, x_f(t))$ interacting with boundaries, wind mill structures.

Examples of realizations





Prediction at 20 minutes of the 95% Confidence interval of turbulence intensity (obtained by sampling the within-year posterior distribution of parametrisation and the time dependent turbulent intensity statistic, $\Delta t = 30s$.



Digital domain of the Marseilles water body in WRF+SDM-WindPoS. Synchronized snapshot of wind magnitude during the day on 04-24-21 at the first height (10 m) of SDM-WindPoS; middle, the sub-domain is resolved at 150 m. right, the resolution is 50 m.

Our current collaborations with Brasil

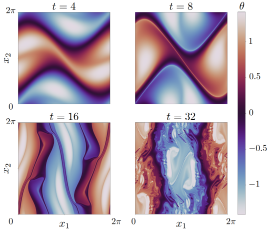
Calisto collaborate mainly with the Alexei Mailybaev's team at the Instituto de Matematica Pura e Aplicada (IMPA, Rio de Janeiro) on **spontaneous stochasticity in singular flows** (in the presence or absence of walls), and in both the Lagrangian and Eulerian senses.

Pikeroen, Q., Barral, A., Costa, G., Campolina, C., Mailybaev, A., and Dubrulle, B. (2023).
Tracking complex singularities of fluids on log-lattices.

Considera, A. L. P. and Thalabard, S. (2023).
Spontaneous stochasticity in the presence of intermittency.

Mailybaev, A. A. and Thalabard, S. (2022).
Hidden scale invariance in navier–stokes intermittency.
Philosophical Transactions of the Royal Society A, 380(2218):20210098.

Thalabard, S., Bec, J., and Mailybaev, A. A. (2020).
From the butterfly effect to spontaneous stochasticity in singular shear flows.
Communications Physics, 3(1):122.



Exchanges with Brasil have been consolidated by the recruitment of Ciro Campolina (former IMPA PhD) for a 2-year ANR postdoc in Calisto, and the 8-month visit of André Considera, (PhD candidate with A. Mailybaev).

Financial supports via:

- Franco-Brazilian mathematics network and IMPA for French visits to Brasil
- Doeblin federation (CNRS and UniCa) and IDEX UCAJEDI (visiting professorships, doctoral visit program, etc.) for Brazilian visits to France.

References

Considera, A. L. P. and Thalabard, S. (2023). Spontaneous stochasticity in the presence of intermittency.

El Khiyati, Z., Chesneaux, R., Giraldi, L., and Bec, J. (2023). Steering undulatory micro-swimmers in a fluid flow through reinforcement learning. *The European Physical Journal E*, 46(6):43.

Jain, R., Tschisgale, S., and Fröhlich, J. (2021). Impact of shape: Dns of sediment transport with non-spherical particles. *Journal of Fluid Mechanics*, 916:A38.

Mailybaev, A. A. and Thalabard, S. (2022). Hidden scale invariance in navier–stokes intermittency. *Philosophical Transactions of the Royal Society A*, 380(2218):20210098.

Sessa, V., Assoumou, E., Bossy, M., and Simões, S. G. (2021). Analyzing the applicability of random forest-based models for the forecast of run-of-river hydropower generation. *Clean Technologies*, 3(4):858–880.

Thalabard, S., Bec, J., and Mailybaev, A. A. (2020). From the butterfly effect to spontaneous stochasticity in singular shear flows. *Communications Physics*, 3(1):122.