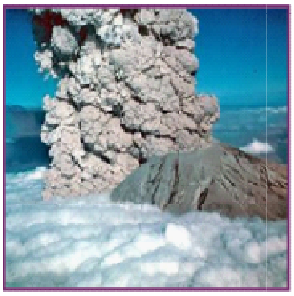
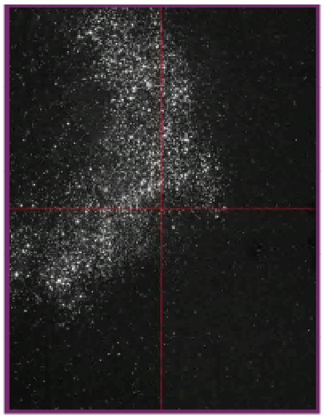
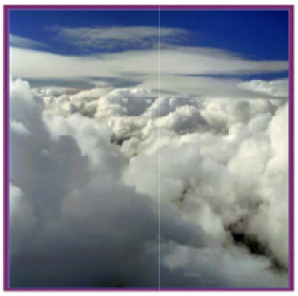
Inertial particules in turbulence

How do raindrops form in clouds? How are plankton or micro-plastics dynamics affected by sea conditions? What are the consequences for the trophic chain? How do pollutants and volcanic ash disperse in the atmosphere? Where can they fall and how fast? What are the optimum parameters for a sewage treatment plant, an engine or a chemical reactor? All these questions can be answered by studying inertial particles in turbulence. These particle-laden flows are ubiquitous but so complex to study because of the very large number of intertwinned control parameters and the lack of theoretical predictions.

We propose an experimental study, including time resolution, to improve the physical and empirical modelling of polydisperse dynamics in the presence of turbulence. This work is part of a joint project with ENS-Lyon, IFPEN Lyon, LMFL Lille and Buenos Aires University.







General framework

A specific form of multiphase flow results from the seeding of a flow by inertial particles, i.e. particles whose time scale is different from that of the fluid, either because of their relative density with respect to the fluid, or because of their size or shape. Such inertial particle-laden flows are ubiquitous, playing important roles in combustion chambers and chemical reactors, the transport of fuels, the dispersion of pollutants, bacteria and viruses, and the suspension of aerosols or micro-plastics....

The four main characteristics of these flows are clustering, which controls the formation of very dense or depleted particle regions in the concentration field; alteration of the settling velocity of the particles, by increasing or decreasing it; alteration of collisions and therefore of the coalescence or reactivity of the particles; and the feedback of the particles on the dynamics of the carrier phase. Despite the extreme diversity of applications and the fundamental interest of these flows, our modelling capabilities are severely limited and require strong simplifications such as very dense or point-like particles. Even with such constraints, the parameter space for spherical particles is of dimension 5: relative density ratio, mass loading, turbulence level (Reynolds number), inertia (Stokes number) and relative gravity intensity (Froude number). This complexity of the parameter space, which also presents a strong entanglement of the five parameters, explains why these four phenomena remain unresolved until now.

Our goals

Simulations and experiments in water and air facilities will study the impact of turbulence on individual particle settling. Simulations using Basilisk and point particle fully resolved DNS from Buenos Aires and Madrid teams will be conducted. The experiments in ENS-Lyon, LMFL-Lille and ENSTA-Paris will simultaneously monitor the particles dynamics and that of the surrounding fluid using challenging high resolution 3D Lagrangian Particle Tracking, with the unique capacities offered by new tracking algorithms such as Shake-the-Box. This is key to address subtle couplings at play (relative velocity and acceleration, preferential sampling). First measurements will focus on the statistics of particles velocity and acceleration when the particles' size and density as well as the turbulence are varied in order to systematically explore the parameter space (particle size, Stokes number, Rouse number, particle-to-fluid density ratio and Reynolds number). The combined diagnosis on particles and surrounding fluid will shed light on the relative importance of local slippage velocity effects (non-linear drag effects), local relative acceleration (added mass and history forces) and preferential sampling effects related to particles inertia (preferential sweeping or loitering) which are key to distinguish between regimes for which turbulence eventually enhances or hinders the settling. With increasing seeding density, we will explore the role of collective effects by addressing the possible connection between local concentration of particles and additional settling enhancement/hindering. Simulations will benchmark experimental results and explore the parameter space further than experiments allow.

Last publications on the topic:

Dejoan, A. and Monchaux, R. (2024). Settling of not so heavy particles in turbulent flows: insights from 2way coupled direct numerical simulations. In preparation.

Zürner, T., Toupoint, C., De Souza, D., Mezouane, D., & Monchaux, R. (2023). Settling of localized particle plumes in a quiescent water tank. Physical Review Fluids, 8(2), 024301.

De Souza 2021 - De Souza, D., Zürner, T., and Monchaux, R. (2021). Simple distinction of similar-looking inertial particles and fluid tracers on camera images. Experiments in Fluids, 62(5), 1-14.