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The dynamics of inertial particle ensembles in raindrop formation and sedimentation.

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The natural world is replete with examples of particle advection. In examples such as cloud microphysics, sedimentation and sewage transport, many millions of particles are suspended in a relatively small volume of fluid. In a numerical simulation, respecting all of the interactions between a turbulent fluid and individual particle trajectories is extremely computationally expensive; the current state of the system includes contributions from the historical trajectories of each particle.

To alleviate this problem, we move from a micro-scale mechanistic model of fluid-particle interaction towards a macro-scale statistical model of particle ensembles. We derive a linearisation of the Perron-Frobenius-Ruelle integro-differential operator that provides a finite-dimensional - and hence computationally tractable - projection of the probability density functions of particle concentration. It was demonstrated by Haller in 2008, that particle trajectories converge exponentially to an inertial manifold; we use this insight to ensure we preserve the inertial properties of the particle ensemble.

The practical use of our approach is demonstrated in a series of interesting cases: the first is an analogue to cloud microphysics - the turbulent breakdown of Taylor Green vortices; in the second, we model a turbulent jet which has application both in sewage pipe outflow and pesticide spray dynamics; and finally, we apply the model to investigate precipitation rates of sand particles in turbulence.

One important feature of our statistical model is that we can straightforwardly feed back particle concentrations to influence the fluid phase. Irregular distributions of relatively dense or buoyant ensembles of particles induce a baroclinic torque on the flow, which inevitably couples with the future evolution of the distribution of inertial particles. Under certain circumstances this feedback is unstable. We discuss how this could influence natural processes such as raindrop formation and sedimentation through classical analysis of turbulent flow statistics.