Prediction of sling events at high Reynolds numbers

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Collisional droplet growth plays an important role in rain formation in warm clouds.[1] Turbulence enhances droplet collisions, for example, through the sling effect,[2 3 4] which leads to large collision velocities. A quantitative description of sling events in fully developed turbulence valid for a range of Reynolds and Stokes numbers is needed, for example, to quantify the sling rate. Here, we present recent work,[5] in which we have developed a criterion for the occurrence of sling events in turbulence based on the velocity gradient history along particle paths. By combining theory and direct numerical simulations of Navier-Stokes turbulence, we argue that the creation of sling events is controlled by the smallest real eigenvalue of the fluid velocity gradient tensor, reducing the problem to effectively one dimension. For a sling event to occur, this eigenvalue has to be persistently below a threshold value determined by the particle response time τ. Based on the depth $\Delta\tau$ and duration $2D$ of such excursions below the threshold, we arrive at the criterion $\sqrt{\Delta}D > 1$, which connects excursions to sling events. We test the criterion using direct numerical simulation data, see figure below. Combined with large-deviation theory, this enables predictions of the sling rate as a function of Reynolds and Stokes numbers.

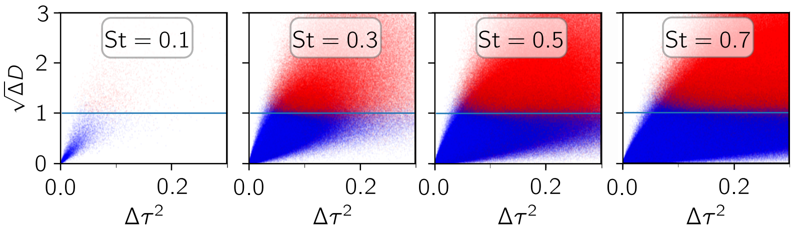

Figure 1: Scatter plot of non-dimensional depths and durations (parametrized through $\Delta\tau^2$ and $\sqrt{\Delta}D$) of fluid velocity gradient excursions for various Stokes numbers at $R_\lambda \approx 270$. When the excursion leads to a sling event in our one-dimensional model, the corresponding data point is plotted in red, otherwise in blue. The horizontal blue line corresponds to $\sqrt{\Delta}D = 1$, above which our criterion predicts the occurrence of a sling event.

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