Clustering of inertial cloud droplets in isotropic turbulence

Peter J. Ireland\textsuperscript{1}, John Clyne\textsuperscript{2}, Perry Domingo\textsuperscript{2}, Tim Scheitlin\textsuperscript{2}, and Lance R. Collins\textsuperscript{1}

\textsuperscript{1}Cornell University, Ithaca, NY, USA
\textsuperscript{2}U. S. National Center for Atmospheric Research, Boulder, CO, USA

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Abstract

This article accompanies the submission of a fluid dynamics video (entry 102248) of inertial cloud droplet clustering in isotropic turbulence for the Gallery of Fluid Motion of the 66th Annual Meeting of the American Physical Society, Division of Fluid Dynamics.

1 Numerical simulation

We performed a direct numerical simulation of statistically stationary homogeneous isotropic turbulence on over 8 billion grid points, using 16,384 processors on the NCAR Yellowstone supercomputer [1]. The Taylor microscale Reynolds number for the flow is about 600, the highest Reynolds number ever simulated for inertial-particle-laden isotropic turbulence. The domain is a cube of length 3500\(\eta\), and the flow evolves for a period of about 100\(\tau_\eta\). (\(\eta\) and \(\tau_\eta\) are the Kolmogorov length and time scales of the turbulence, respectively.) A subregion of the cube measuring approximately 2000\(\eta\times2000\eta\times150\eta\) is shown.

The flow was seeded with about 3 billion inertial (i.e., denser than the carrier fluid) cloud droplets. We show a subset of these droplets in the video for two sizes: \(St = 1\) (corresponding to intermediate-sized droplets \(\sim 100 \mu\text{m}\) in diameter), and \(St = 30\) (corresponding to rain-sized drops \(\sim 0.5 \text{ mm}\) in diameter). The Stokes number \(St\) is a non-dimensional measure of particle inertia. The particle concentration field (isocontours) is visualized in blue,
and regions of high fluid vorticity (direct volume rendering) are visualized in yellow. We notice that the intermediate-sized droplets ($St = 1$) are centrifuged out of regions of high vorticity, as originally suggested in [2]. As a result, they form small, dense clusters. The typical length of these clusters is $10\eta$ [3], or about $1/200^{th}$ of the width of the subregion shown. Large, rain-sized drops ($St = 30$) are less responsive to the underlying vorticity field and instead form much larger, less dense clusters. The typical length of these clusters is about $200\eta$, or about $1/10^{th}$ of the width of the subregion shown.

We quantify the degree of particle clustering through the radial distribution function (RDF). The RDF is the ratio of particle pairs at a given separation to that of a uniform distribution. We notice that $St = 1$ particles are tightly clustered, with clustering over 20 times that of a uniform distribution at the smallest separations. The RDF rapidly drops off at larger separations, suggesting that the particle clusters have small length scales. $St = 30$ particles, on the other hand, are loosely clustered (clustering is about twice that of a uniform distribution at the smallest separations), but this clustering persists to larger scales, as is evident in the visualizations.

2 Physical significance

Standard microphysical cloud models are unable to predict the rapid onset of precipitation in warm cumulus clouds [4]. The accelerated rate of precipitation has been linked to turbulence-induced collisions within clouds [5], which are enhanced by clustering due to the inertia of the droplets [6]. Our visualizations provide clear verification of this clustering at the highest Reynolds number simulated to date. A detailed examination of the physical processes is in preparation [7].

3 Acknowledgements

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