BRINGING CLOUDS INTO OUR LAB! THE INFLUENCE OF TURBULENCE ON EARLY STAGE RAIN DROPLETS

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Abstract We are investigating a droplet-laden flow in an air-filled turbulence chamber, forced by speaker-driven air jets. The speakers are running in a random manner; yet they allow us to control and define the statistics of the turbulence. We study the motion of droplets with tunable size in a turbulent flow, mimicking the early stages of raindrop formation. 3D Particle Tracking Velocimetry (PTV) is chosen as the experimental method to track the droplets and collect data for statistical analysis. Thereby it is possible to study the spatial distribution of the droplets in turbulence using the so-called Radial Distribution Function (RDF), a statistical measure to quantify the clustering of particles. Additionally, this technique allows us to measure velocity statistics of the droplets and the influence of the turbulence on droplet trajectories, both individually and collectively. In this contribution, we will present velocity statistics of the droplets and quantify their clustering using the RDF for different turbulence conditions.

INTRODUCTION AND EXPERIMENTAL SETUP

Turbulence is ubiquitous in atmospheric clouds [8]. The Reynolds numbers are enormous and consequently the range of active spatial and temporal scales is wide. For instance, the ratio of energy-containing to dissipative length scales typically is of an order of magnitude of 10^5 for convective clouds, where the large-eddy Reynolds numbers are in the order of 10^6 to 10^7 [2, 8]. Another characteristic feature of the high-Reynolds-number flows is the intermittent behavior of the energy dissipation rate, gradient changes at small scales and Lagrangian acceleration of fluid parcels and droplets. Furthermore, insight into the micro-scale collective behavior of the water droplets (and other aerosols as well) may help to understand the early stage of rain formation.
In order to address these unknown issues we have designed and built a setup for our experimental investigations, which is shown in fig. 1.

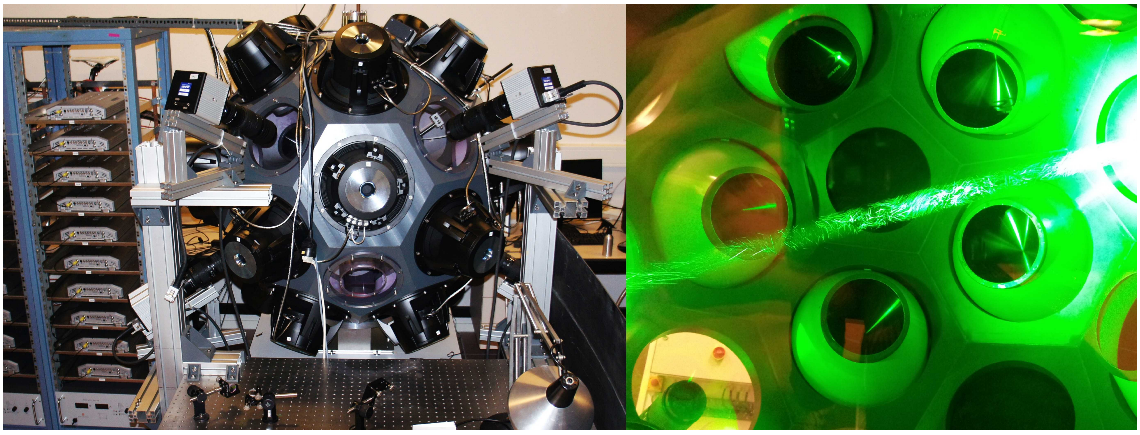

Figure 1. Photograph of the experimental setup equipped with 3D-PTV (on the left) and the photograph of the interior of the chamber while performing particle tracking measurements (on the right). The laser beam has a diameter of approximately 30 mm.

DROPLET CLUSTERING

Earlier numerical and experimental observations have revealed that the regions with high strain, which are generally outside of the vortices, are more likely to host dense particle regions: a phenomenon known as clustering [1, 5, 9]. The centrifugal force of a turbulent eddy acts on similar-sized (inertially compatible) particles in a similar way: they will be centrifuged out of the eddy and gather in the strain-dominated regions in between, thereby increasing the density of like-sized particles in these regions. This clustering leads to enhanced probability of collision (and coalescence) for droplets [8]. Sundaram et al. [10, 11] have introduced the radial distribution function (RDF) as a statistical measure of clustering, which is calculated from the spatial separations of particle pairs. McQuarrie defined the RDF as a measure of the probability of finding another particle at an arbitrary distance from the chosen particle [4, 5].

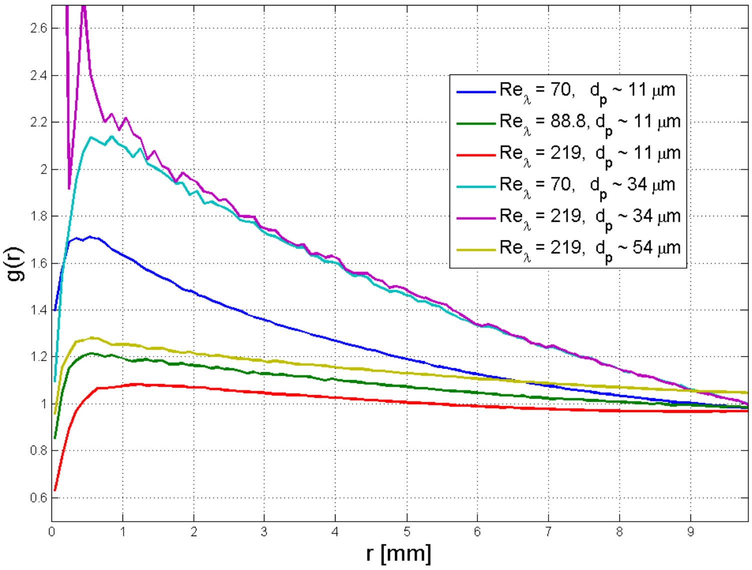

Figure 2. The RDF of particles in different turbulence conditions.

RESULTS

In order to compute the RDF, the distances between pairs of particles (M particles in total) are binned. The RDF is the particle concentration per bin compared with the mean concentration:

$$g(r_i) = \frac{N_i/\Delta V_i}{N/V}. \tag{1}$$

Here the subscript 'i' is used for distinguishing the discrete bin index. N_i is the number of particle pairs found with a separation in between r_i and $r_i + \Delta r$ (Δr is the bin width). ΔV_i is the volume of the spherical shell with inner radius r_i and outer radius $r_i + \Delta r$. The total number of particle pairs can be calculated as $N = M(M-1)/2$; V is the total measurement volume.

Figure 2 shows the calculated RDF for different turbulence levels and droplet mean diameters. Here we see the highest values of $g(r)$ for droplets with a mean diameter of 34 μm. We use the spinning-disc droplet generation technique [3], which produces droplets with a narrow size spectrum but not monodisperse. It is well known that clustering is sensitive to the size spectrum of droplets [6, 7]. The 34 μm-collection of droplets actually has the narrowest spectrum of the cases included in fig. 2, thereby clustering is most efficient. We will further interpret the RDF data using theoretical modeling of clustering [6, 7] and the size spectra measured using Interferometric Particle Imaging (IPI).

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