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Collision efficiencies empirically determined from laboratory investigations of collisional growth of small raindrops in a laminar flow field

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Abstract

In laboratory experiments at the vertical wind tunnel of the University of Mainz the collisional growth of drops with radii between 70 and 170 μm in radius were observed while the collector drop freely floated in a cloud of droplets with radii ranging from 1 to 7 μm. Previously existing tables with collision efficiency values were interpolated and completed in such a way that drop growth rates calculated with these collision efficiencies match with observed growth rates. These new tables provide collision efficiency values for a wide range of drop sizes and radius ratios p including those ranges where efficiency values missed so far. This is of high importance for small p-ratios where the collision efficiency changes significantly. The empirically derived collision efficiencies can be used in cloud models. Growth rates observed during the laboratory experiments on drop collisions and those obtained by using model simulations of continuous growth using theoretically determined values of the collision efficiencies are in very good agreement.

Keywords: Laboratory experiments; Wind tunnel; Collision efficiency; Water drops

1. Introduction

The collision efficiency of drops is the main factor controlling the drop collection rate and warm rain formation in liquid water clouds. It is defined as the ratio of the number of drops actually colliding with a larger falling drop (the collector drop) to the total number of drops lying within the geometrical volume of interaction and depends strongly on the sizes of the collision partners. The efficiency values lie, in general, between values close to zero (no collisions) and one; values higher than one may occur owing to wake capture of droplets in the rear eddies of the larger collision partner.

So far, experimental verification of theoretically calculated collision efficiencies is rather sparse. Drop collisions were studied experimentally by, e.g., Kinzer and Cobb (1958), Woods and Mason (1964), Beard and Pruppacher (1971), Jonas and Goldsmith (1972), Vohl et al. (1999). The lack of reliable data exists particularly for collisions between cloud droplets themselves and between small raindrops and cloud droplets. To the best of our knowledge, referenced tables of collision

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efficiencies do not contain data concerning collisions of 1 to 3 μm radius cloud droplets with raindrops (see, e.g., Hall, 1980; Beard and Ochs, 1984) corresponding with so-called p-ratios (the ratios of radii of colliding drops) as low as around 0.05. According to Pruppacher and Klett (1997) the collision efficiency increases very strongly with p for p-values less than 0.1 that means small variations of the p-ratio lead to significant changes in the collision efficiency. Therefore, the investigation of these size ranges is highly important. The knowledge of the efficiencies of these collisions is important for appropriate description of 1) comparable contribution of diffusion and collision growth of drops to drop spectrum evolution, and 2) evaluation of the rate of scavenging of micrometer-size droplets and aerosol particles from clouds by collisional processes.

In order to obtain data for the missing range of p-values, laboratory experiments were conducted on the continuous growth of small raindrops while the drops freely float within a cloud of droplets. These experiments were carried out in laminar flow using the vertical wind tunnel at the University of Mainz under controlled environmental conditions. From these experimental results collision efficiencies were determined empirically to fill the gaps mentioned above. In the end it was proven if the empirically determined collision efficiencies and the experimentally obtained drop growth rates verify collision efficiencies and growth rates numerically calculated by Pinsky et al. (2001).

2. Laboratory experiments

The experiments were carried out in the vertical wind tunnel at the University of Mainz which allows floating drops of micrometer to millimeter size range in a vertical air stream. For its entire range of air speeds the tunnel shows a turbulence level of less than 0.5% (Vohl et al., 1999). For details of the wind tunnel see Pruppacher (1988). During the present experiments a single collector drop was injected into the tunnel set at a speed matching the terminal velocity of the drop so that the drop was captured within the observation section of the tunnel in a free floating condition. The radius of this collector drop was between 70 and 170 μm. Upstream of the floating drop a cloud of droplets was produced by a battery of sprayers so that the larger collector drop grew by collision with the droplets. The droplet size spectrum was determined using a light scattering size spectrometer (Classical Scattering Aerosol Spectrometer Probe Electronics (CSASPE) from Particle Measuring Systems, Inc., Boulder, Colorado, USA). The droplet radii were between 1 and 7 μm.

The total liquid water content of the droplet cloud was determined from the actual temperature and the dew point of the tunnel air. To measure the dew point the tunnel air was sucked isokinetically into a heated inlet tube so that the droplets evaporated. The liquid water content of the droplet cloud was kept as stable as possible by switching the sprayers successively on as the tunnel air speed increased. Examples of typical size distributions of the small droplets and of the liquid water content of the cloud of small drops during the experiments can be found in Vohl et al. (1999) and in Vohl (2000).

The growth rate of the collector drop was determined from the change in terminal velocity while it was kept continuously suspended in the observation section during its growth. The air velocities in the wind tunnel were converted into equivalent drop radii using the relation given by Beard (1976). For details see Vohl et al. (1999) and Vohl (2000). Regarding the p-ratio of the drop sizes it was between 0.006 and 0.1, i.e. in a range where the collision efficiency changes significantly with the p-ratio.

3. Empirical determination of the collision efficiencies

During a wind tunnel collisional growth experiment a single levitated collector drop is allowed to grow in a cloud of small droplets streaming past the collector

Table 1
Collision efficiencies empirically determined from experimental results for collector drop radii between 100 and 600 μm and p-ratios ≤ 0.5

p	r_1 (μm)						
	600	501	398	316	200	158	100
0.005	0.6	0.24	0.1	0.01	0.001	0.0003	0.0001
0.01	0.85	0.66	0.51	0.23	0.04	0.001	0.001
0.025	0.98	0.91	0.88	0.82	0.61	0.42	0.04
0.05	1	0.97	0.95	0.94	0.87	0.78	0.48
0.075	1	1	0.97	0.96	0.93	0.89	0.72
0.1	1	1	1	0.98	0.95	0.93	0.81
0.125	1	1	1	1	0.96	0.95	0.87
0.15	1	1	1	1	0.97	0.96	0.91
0.175	1	1	1	1	0.98	0.96	0.93
0.2	1	1	1	1	0.99	0.97	0.94
0.225	1	1	1	1	1	0.98	0.95
0.25	1	1	1	1	1	1	0.96
0.275	1	1	1	1	1	1	0.965
0.3	1	1	1	1	1	1	0.97
0.325	1	1	1	1	1	1	0.98
0.35	1	1	1	1	1	1	0.99
0.375	1	1	1	1	1	1	1
0.4	1	1	1	1	1	1	1
0.425	1	1	1	1	1	1	1
0.45	1	1	1	1	1	1	1
0.475	1	1	1	1	1	1	1
0.5	1	1	1	1	1	1	1