GEOPHYSICAL RESEARCH LETTERS, VOL. 31, L13102, doi:10.1029/2004GL020167, 2004

Super-large raindrops

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Received 2 April 2004; revised 21 May 2004; accepted 15 June 2004; published 13 July 2004.

[1] Raindrops similar or greater in size to the largest ever observed, with maximum dimensions of at least 8.8 mm and possibly 1 cm, have been measured in rainshafts beneath cumulus congestus clouds spawned by a biomass fire in Brazil and in very clean conditions in the Marshall Islands. It is proposed that the super-large raindrops were produced by the rapid growth of drops colliding with each other within narrow regions of cloud where liquid water contents were unusually high. In Brazil, the initial growth of super-large raindrops might have been initiated by condensation onto giant smoke particles. *INDEX TERMS:* 1854 Hydrology: Precipitation (3354); 3314 Meteorology and Atmospheric Dynamics: Convective processes; 3354 Meteorology and Atmospheric Dynamics: Precipitation (1854). **Citation:** Hobbs, P. V., and A. L. Rangno (2004), Super-large raindrops, *Geophys. Res. Lett.*, *31*, L13102, doi:10.1029/2004GL020167.

1. Introduction

[2] Raindrops in free fall are often depicted as tear-shaped. In fact, drops in free fall that have diameters greater than about 2 mm are flattened on their undersides and gradually change in shape from essentially spherical to increasingly parachute- (or jellyfish-) like. If the initial diameter of the drop exceeds about 5 mm, the parachute becomes a large inverted bag with a toroidal ring of water around its lower rim. Theoretical and laboratory studies indicate that isolated, individual water drops in free fall may reach diameters of ~10 mm before spontaneously breaking up [*Pruppacher and Pitter*, 1971]. Generally, however, drops in clouds breakup prior to reaching such large sizes due to collisions with other drops [*Low and List*, 1982]. However, even when two drops collide, it is not inevitable that breakup will occur.

[3] For many years the largest raindrops observed had maximum dimensions of 4–5 mm [*Mason*, 1971]. However, *Beard et al.* [1986] reported raindrops with maximum dimensions up to 8 mm in a shallow convective rainband off the island of Hawaii. Here we report on airborne measurements of raindrops with maximum dimensions of at least 8.8 mm, and possibly as large as 10 mm.

2. Measurements

[4] In September 1995 the University of Washington, with its Convair C-131A research aircraft, was engaged in studies of smoke from biomass burning near the equator in northern Brazil [*Kaufman et al.*, 1998]. The burning, associated with the encroachment and clearing of the forests in the Amazon Basin, produces widespread and very hazy air in the lower atmosphere (Figure 1a). Also, under unstable atmospheric conditions, particularly hot fires spawn and augment convection and cumulus congestus clouds (Figure 1a). In passing at ~0.5 km below cloud base through a narrow (0.8 km wide) transparent rainshaft from one of these cumulus congestus clouds, a few unusually large drops were imaged by the Particle Measuring System's (PMS) OAP-2D-P precipitation probe, incorporating an array of thirty-two 100 μm square photosensitive diodes, aboard the aircraft (Figure 2a). The largest drop had a maximum recorded dimension of 8.8 mm; its reconstructed diameter, using the technique described by *Heymsfield and Parrish* [1978], was 8.2 mm. It was recorded in a sample volume of only 0.74 liters. Some ash particles with maximum dimensions of ~2 mm were also intercepted in and near the rainshaft. In the updraft regions of the cumulus congestus clouds, the average cloud droplet concentration was 900 cm^{-3}, with concentrations up to 1000 cm^{-3}. The largest droplets in concentrations of at least 3 cm^{-3} in the upper portions of the clouds was ~28 μm diameter. This is normally just below the size required for the growth of raindrops by the collision-coalescence mechanism [*Gerber et al.*, 1994]. The maximum cloud liquid water content was 3–4 g m^{-3}. The bases of the sampled clouds were at 1.6 km msl (18°C), and the tops of the highest clouds in the vicinity were at 5.0 km where the temperature was −2.5°C. Ice was neither detected by the research instruments aboard the aircraft nor observed visually when flying in, below, or around the tops of the clouds.

[5] We also measured super-large raindrops in July 1999 at the base of a cumulus congestus cloud, similar to those shown in Figure 1b, in the vicinity of Kwajalein Atoll, Marshall Islands, in the tropical Pacific Ocean. The atmosphere was unstable, and numerous towering cumulus clouds, cloud complexes and rain showers were present in the area. Radar imagery showed cloud tops near or slightly above the 0°C level. Cloud bases were at 0.3 km (24.5°C). In the upper regions of comparable clouds on this day, the largest droplets in concentrations of at least 3 cm^{-3} was >40 μm diameter, which is well above the droplet size required for the formation of raindrops by the collision-coalescence mechanism. As the aircraft approached the bases of a row of building cumulus clouds it was directed into a 30 s pass through a virtually transparent, rain shower just below cloud base. A burst of exceptionally large drops was detected by the PMS 2D-P probe just as the concentration of raindrops was in sharp decline. Coincidentally, the largest drop that was detected was identical to the largest drop detected in Brazil, namely, 8.8 mm in maximum dimension of the recorded image, with a reconstructed diameter of 8.2 mm (Figure 2b). It was registered in a sample volume of only 0.31 liters with two other drops with diameters greater than 5 mm. Another estimate of the

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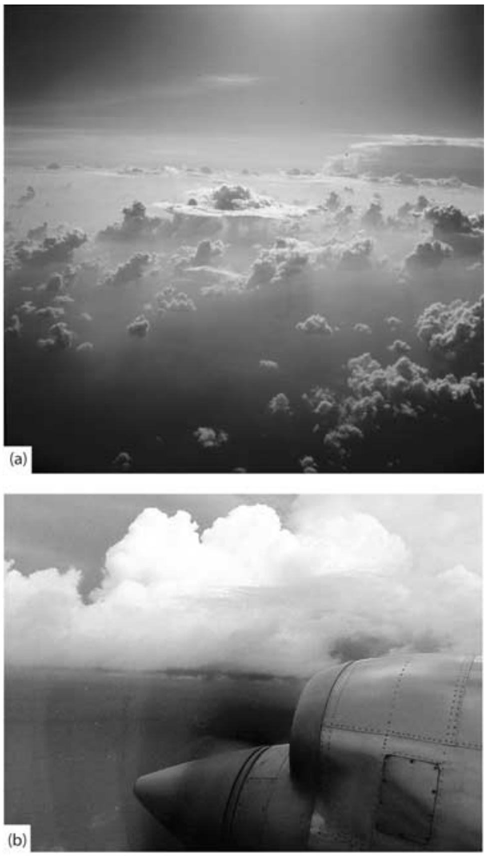

Figure 1. (a) Photograph of cumulus congestus clouds spawned by biomass fires in the Amazon. (Photo: A. Rangno.) (b) Photograph of cumulus congestus clouds over the Marshall Islands. (Photo: P. V. Hobbs.) See color version of this figure in the HTML.

maximum dimensions of the largest drops can be obtained by sketching their likely outlines (shown by the dashed line in Figures 2a and 2b) using the dimension at the top of the 2D-P array as the maximum diameter. This yields maximum dimensions of ~10 mm for the largest drops in both Brazil and the Marshall Islands.

3. Discussion

[6] Smoke from biomass burning contains high concentrations of the particles upon which cloud droplets form, that is, cloud condensation nuclei–CCN [*Hobbs and Radke*, 1969; *Eagan et al.*, 1974]. Thus, in clouds affected by biomass smoke the available liquid water is shared among many droplets, so the average size of the droplets is small. This explains the high concentrations of small droplets in the clouds studied in Brazil. Such clouds, which are referred to as having "continental" characteristics, are generally not efficient rain producers because insufficient concentrations of precipitable drops form in these clouds [*Gunn and Phillips*, 1957; *Twomey*, 1960]. Except in and near the rainshaft where the super-large drops were measured, raindrops were not detected in the cumulus congestus clouds studied on this day in Brazil. However, if some giant (i.e., tens of micrometers in diameter) CCN are introduced into such a cloud, they may grow rapidly to raindrops by colliding and coalescing with the large concentration of small droplets [*Johnson*, 1982; *Illingworth*, 1988]. This has been observed in clouds downwind of paper mills, which emit large numbers of CCN including some giant particles [*Eagan et al.*, 1974; *Hindman et al.*, 1977a, 1977b, 1977c]. This is the rationale for the belief that rainfall from warm clouds might be increased by artificially seeding the clouds with giant CCN [*Bruintjes*, 1999]. In the case of the clouds in Brazil described here, the super-large raindrops might have been due to the "seeding" of the cloud by giant smoke or ash particles that served as efficient CCN [*Reid and Hobbs*, 1998; *Reid et al.*, 1998, 1999; *Andreae et al.*, 2004].

[7] In many hours of sampling the marine boundary layer in the Marshall Islands, under various conditions of winds and whitecaps, particles larger than 20 μm in diameter were not detected beneath cloud base [*Kaneyasu et al.*, 2001]. Therefore, in this case, it is unlikely that the super-large raindrop was initiated by condensation onto an ultra-giant cloud condensation nucleus. The super-large raindrop measured in the Marshall Islands may have been produced by rapid growth via the collision-coalescence process within narrow regions of the cloud where the liquid water content

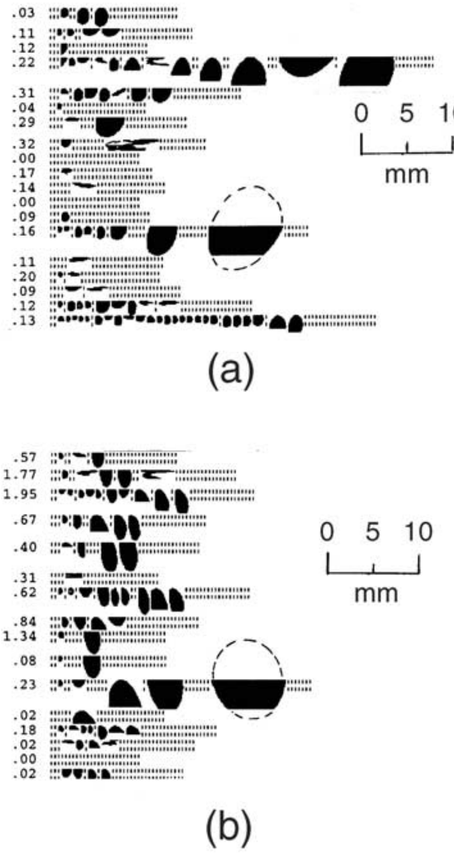

Figure 2. Images of plan views of large and super-large raindrops in cumulus congestus clouds recorded a) near Maraba, Brazil, a few hundred meters below the base of a cloud produced by a biomass fire, and b) below cloud base near the Kwajalein Atoll, Marshall Islands. Only portions of the largest drops are depicted because of instrument limitations. However, the maximum diameter of the drops can be derived by reconstruction.

was unusually high [*Twomey*, 1976; *Hobbs and Rangno*, 1985; *Rauber et al.*, 1991; *Szumowski et al.*, 1997]. This same mechanism may well have operated in Brazil, since to produce super-large raindrops rapid growth by collision-coalescence is necessary and enhanced liquid water content aids such growth. It is likely that relatively vertical filaments of high liquid water were present in the deeper cumulus congestus clouds in Brazil.

[8] It is remarkable that in two quite different environments, albeit both tropical but one extremely polluted and the other very clean, we measured raindrops that must have undergone numerous collisions without breaking up, and must have been on the verge of bag breakup or breakup due to collisions at the time we encountered them. Since these super-large raindrops were observed in sample volumes of less than 1 liter, we surmise that they were not uncommon, but fall in very short-lived vertical filaments tens of meters across that are rarely intercepted. Finally, we note that a few super-large drops may bias overall rain rates derived from radar due to the dependence of radar backscatter on the 6th power of drop radius.

[9] **Acknowledgment.** Research supported by NSF grant ATM-0314453 and NASA grant NNG04GD64G.

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