Some Measurements of Snow Pellet Bulk-Densities[1]

ROSCOE R. BRAHAM, JR.

Cloud Physics Laboratory, The University of Chicago

(Manuscript received 18 March 1963)

ABSTRACT

In-cloud collections of snow and ice pellets in summer cumulus clouds have been made on Project Whitetop. These collections provided an opportunity for measuring the bulk densities of 129 snow pellets and ice pellets. Results show that their densities ranged from about 0.87 gm per cc to 0.91 gm per cc.

1. Introduction

Several decades of observations and measurements of hydrometeors have firmly established the fact that the predominant forms of solid precipitation in active portions of cumulus clouds are ice pellets and snow pellets.

During the early 1940's, observations on cumulus cloud hydrometeors were carried out by Kuettner (1950) from the top of the Zugspitze and by Weickmann (1949, 1953) who employed an open-cockpit airplane to carry him into large cumuli where he could observe and collect the precipitation particles. Both of these studies showed that the solid hydrometeors in the active parts of large cumuli had developed by collision and riming with cloud drops. These observations have been verified by subsequent studies. However, neither the studies of Kuettner and Weickmann, nor those of subsequent authors, provide a physical description of these particles adequate for detailed understanding of cumulus cloud precipitation.

An opportunity to extend these observations arose in connection with a field study of cloud seeding being conducted by the University of Chicago, Cloud Physics Laboratory, under the sponsorship of the National Science Foundation. Some of our findings as to the nature of these pellets have already been reported (Hoffer and Braham, 1962; Koenig, 1963). This paper is concerned with our observations of the time and place of occurrence of these solid hydrometeors in cumulus clouds and with the results of bulk-density measurements on some of these particles as they were found inside the clouds.

2. Observations of pellet occurrences

Throughout the summer months of 1960, 1961 and 1962 the author has been actively engaged in a study of convective weather clouds which formed in the vicinity of West Plains, Missouri. The clouds under investigation are typically cumuliform, ranging from cumulus mediocris to cumulonimbus. First priority, in the cloud study program, has been given the development of solid hydrometeors in cumulus congestus and cumulonimbus clouds. This emphasis reflects the fact that a part of Project Whitetop involves seeding of randomly selected groups of clouds with silver-iodide smokes. If silver-iodide affects the development of precipitation in these clouds, it surely must do so through the enhanced development of ice crystals and other solid hydrometeors.

The research plan includes flying through these clouds with an airplane instrumented for measuring various cloud and free-air parameters. Cloud traverses have been made at all altitudes up to 20,000 ft msl (the useful limit of our plane). Over 400 individual cloud traverses were made in the undercooled portions of 143 clouds; i.e., between the 0C level and the 20,000-ft level. (The average height of the 0C level was about 15,000 ft msl.)

Solid hydrometeors were detected on 125 of these traverses. (The lower size limit for dependable detection is 300–500 microns diameter.) These hydrometeors have been collected, examined and, in many cases, replicated. From these collections we have found that the solid hydrometeors may either be snow pellets or ice pellets.

The snow pellet is most commonly found. It is opaque, white and irregular in shape, tending toward an oblate spheroid. These pellets give the appearance of having grown through collision and riming of cloud droplets. They are undoubtedly the same as those identified as "graupels" by Weickmann (1953) and as "reifgraupeln" by List (1958). Most of the pellets used in the density measurements were of this type.

Ice pellets are similar in size and shape to snow pellets but are completely clear and transparent. These

[1] The research reported in this article was sponsored by the National Science Foundation under grant G22419.

also were described by Weickmann. They probably are the "frostgraupeln" of List.

Although our sample of ice pellets is rather small, it appears that their formation is limited to a region near the tops of the most active-updraft cores. At the altitudes attainable with our airplane, strong updraft regions are found to be completely free of solid precipitation particles of any kind—obviously because of the short time required for the air parcels to travel between the 0C level and our flight level. However, when we were lucky enough to sample a cloud just as a very strong updraft lost its vigor, or perhaps on the downshear side of a strong updraft, we likely would find clear ice pellets in great number.

In general, however, ice pellets are much less frequent than snow pellets in clouds of the types that we have been studying. This may only reflect the fact that conditions for growth by riming are so favorable that an opaque pellet quickly results, regardless of the nature of the initial particle.

Our observations have not shown appreciable numbers of ice crystals of high symmetry, indicative of growth by diffusion, in active portions of these clouds. Only in the quiescent regions, such as anvil tops, stratus shelves and the stratified residue remaining after the cessation of active convection, are regular ice crystals and snowflakes common. It is possible, of course, that the active clouds contained ice crystals too small for our detection. On the other hand, replicas taken with our continuous replicator show that even the small ice particles tend to be of irregular form.

3. Measurements of snow pellet densities

During 1962 a series of snow pellet collections was obtained for the purpose of determining their bulk-densities. Collections for this purpose were made at altitudes of 18,000 to 20,000 ft, at temperatures between −5C and −10C. Collection of snow pellets with the Project twin-Beech D18 is facilitated because this plane has no cabin insulation and is flown without cabin heat and with the cockpit windows open. It is equipped with a $3\frac{1}{2}$-inch sampling tube which permits outside air to flow directly into the cabin. A portion of the incoming air stream was diverted and used to cool the underside of a small table at the sampling station.

Table 1. Organic fluids used for measuring snow pellet densities.

Material	Density, gm per cc
Isooctane	0.710
n-Dodecane	0.754
Kerosene	0.822
Cumene	0.872
iso-amyl-Acetate	0.894
mixture of iso-amyl-Acetate and *o*-Fluorotoluene	0.914
2-methyl-Cyclohexanol	0.942

Table 2. Number of snow pellets and ice pellets that sank (S) or floated (F) in fluids of indicated densities.

Date 1962	Size of pellet	Density of fluid used for comparison											
		0.71		0.82		0.87		0.89		0.91		0.94	
		S	F	S	F	S	F	S	F	S	F	S	F
A. Snow pellets													
5 July	½ mm					1							
	1	4				1	1	2	1				4
	2							1	1				2
6 July	½ mm					6		4	1				6
	1			4		8	2	1	10				4
	2					4		1	5				2
9 July	½ mm					6	1	5	2				2
	1					1		2	1				9
	2								1				
Totals for snow pellets	Number:	4	0	4	0	27	4	16	22			0	29
	Per cent which sank:	100		100		87		42				0	
B. Ice pellets													
4 August	1 mm					2		3	1	1	4		
	2									1	6		3
	3							1		1			
Totals for ice pellets	Number:					2	0	4	1	3	10	0	3
	Per cent which sank:					100		75		23		0	

As the pellets emerged from the sampling tube they were caught on a clean cheese-cloth decelerator and deflected onto a sampling table covered with black velvet where they would remain indefinitely without melting.

After the pellets landed on the black cloth, some of them were picked up with the aid of balsam-wood tools made for this purpose and transferred to one of a series of small glass containers filled with organic fluids ranging in density from 0.71 to 0.94, Table 1. The containers of density fluids were provided with an independent heat sink which insured a fluid temperature of about −10C. The densities of these fluids at a temperature of −10C was determined gravimetrically in the laboratory.

As a pellet was placed in one of the density fluids it either sank or floated according to whether it was more or less dense than the fluid. Each pellet was placed in only a single fluid. From a series of such operations it is possible to determine the distribution of densities and the mean density of the pellet population.

Density measurements were made on a total of 129 pellets collected on four flights during July and August 1962. The data for snow pellets and ice pellets are reported separately in Table 2. When we started these measurements, we were surprised to find that the density range among the various pellets was very small indeed. Not a single pellet was found which would float on a fluid of density 0.82 gm per cc. The density curve for snow pellets appears to peak between 0.87 and 0.89 gm per cc. The relatively fewer ice pellets makes it impossible to be quite as certain as to their density; however, there appears to be no reason to believe that it is far from that of pure ice, viz., 0.91.

These values are somewhat higher than those reported by List (1958) for densities of reifgraupeln which he collected at the surface in the Swiss Alps. However, they are very close to values given by List for frostgraupeln. They stand in marked contrast to the values of less than 0.2 reported by Nakaya and Terada (1935). It would appear that the latter authors were describing clumps of ice crystals (perhaps snow-grains). These new values are somewhat larger than the value of 0.6 postulated by Weickmann for similar pellets which he collected and studied.

Acknowledgments. The assistance of the entire staff of Project Whitetop in the acquisition of these data is gladly acknowledged. I wish to express special appreciation to Mr. Paul Spyers-Duran of this laboratory for his help in the laboratory determination of the fluid densities.

REFERENCES

Hoffer, T. E., and R. R. Braham, Jr., 1962: A laboratory study of atmospheric ice particles. *J. atmos. Sci.*, **19**, 232–235.

Koenig, L. R., 1963: The glaciating behavior of small cumulonimbus clouds. *J. atmos. Sci.*, **20**, 29–47.

Kuettner, J., 1950: The electrical and meteorological conditions inside thunderclouds. *J. Meteor.*, **7**, 322–332.

List, R., 1958: Kennzeichen atmospharischen eispartikeln, 1 teil. *Z. Math. Phys.*, **10**, 180–192.

Nakaya, U., and T. Terada, Jr., 1935: Simultaneous observations of the mass, falling velocity, and form of individual snow crystals. *J. Fac. Sci.*, Hokkaido, ser. II, Phy., **1**, 169–171.

Weickmann, H., 1949: Die eisphase in der atmosphare. *Ber. Deut. Wetterd. US-Zone*, No. 6, 54 pp.

——, 1953: Precipitation in cumulonimbus. *Thunderstorm electricity*, Chicago, Univ. Chicago Press, 66–133.