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雑誌名	Science reports of the Tohoku University. Ser. 5, Geophysics
巻	4
号	2
ページ	83-87
発行年	1952-10
URL	http://hdl.handle.net/10097/44485

Observations of the Rate of Growth of Ice Crystals Artificially Produced in the Atmosphere

by

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(Received July 15, 1952)

1. Introduction

It has been demonstrated in the laboratory (1) and also in the atmosphere (2, 3) that the clouds of supercooled water droplets may be completely changed into crystals by seeding dry ice or silver iodide into the supercooled clouds. No experiments, however, have been done on the behaviour of ice crystals after they were produced, so that it is not known experimentally, whether ice crystals really grow into snowflakes so fast as were predicted theoretically by HOUGHTON (4) basing on the BERGERON-FINDEISEN theory.+ It will be of fundamental importance in cloud physics and accordingly in cloud seeding to estimate the rate of growth of ice crystals by the observations in the natural atmosphere. The present investigation was undertaken as the preliminary experiment on this problem. As the result of the experiment it was found that the dominant form of ice crystals produced in the atmosphere by seeding silver iodide was in agreement with those obtained by KAMPE and WEICKMANN (5) in the cold chamber at corresponding temperature. Further the rate of growth of ice crystals was found to be numerically of the same order with that of HOUGHTON's calculation, although the observations could be done only for the very early stages of ice-crystal growth.

2. Scheme of Observations

Observations were carried out on a slope of Mt. Zaô in northern Honshû. Mt. Zaô is known as a famous place of rime formation, where supercooled clouds may be expected to form most frequently. In addition, in order to observe the rate of ice-crystal growth in the atmosphere it is necessary to have as possible as a flat, extended place along the prevailing wind direction. The location shown in Fig. 1 was selected from these points of view. Here by the topographic effect of mountain range shown in Fig. 1, the prevailing wind direction in winter is WSW. A spray nozzle type smoke generator was settled on a hill on the windward side of the area (J in Fig. 1). Observations of cloud droplets and ice-crystals were made at three stations. The first station (A in Fig. 1) was situated about 100 m NNW of the generator where clouds were expected to be under no influence of the seeding. The second (B in Fig. 1) and the third station (C

+ After the present paper was written, we have known Mr. REYNOLDS' paper on "Ice crystal Growth" (Journ. Meteor. 9, 36-40, 1952), in which he reported that laboratory measurements on the rate of ice-crystal growth by sublimation are found to be in good agreement with HOUGHTON's calculations.

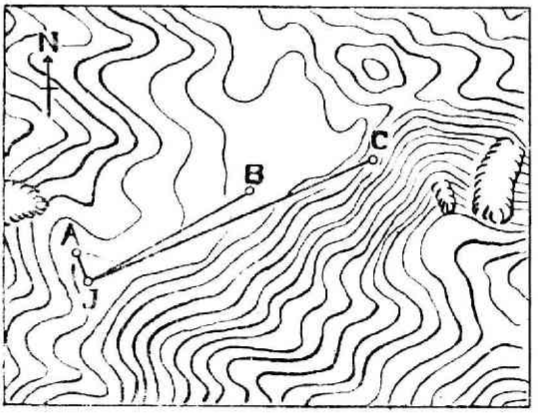

Fig. 1

in Fig. 1) were situated respectively about 570 m and 970 m leeside of the generator.

At each station the microphotographs of supercooled cloud droplets and ice crystals were taken. Droplets and crystals were captured on the oil film coated on the deck glass of the microscope. The slide glass was put into a small metal case with a small hole at the top. Drawing the air by the syringe which was connected to the case, droplets and crystals were easily captured on the oil film. Large ice crystals, however, were captured directly on the glass plate which was exposed in the air.

The temperature and the humidity of the air were observed by the Assmann psychrometer at about 1 m above the ground. The wind direction and speed were observed by the small portable anemometer with a vane installed, also at about 1 m above the ground. During the observation the air temperature was always below 0° C, thus the covering cloth of the wet bulb froze at every time of the observations. It should, therefore, be noted that the humidies which appear in the following chapters are those with resqect to ice. The spray nozzle of the generator was a standard commercial air atomizer, which was used to atomize an aceton solution of silver and sodium iodide with compressed hydrogen. The outer and the inner diameter of the nozzle were 2 and 3 mm respectively.

3. Results of Observations

Observations were carried out three times during 1 to 8 of March, 1952. The quantity of silver iodide used and the rate of discharge were shown in table 1.

Table 1

	Period of seeding	Quantity of Ag I used	Rate of discharge of Ag I
	h m h m	g	g/min
March 3	08 20 - 09 09	43.9	0.896
March 6	10 03 - 10 33	14.6	0.487
March 8	06 05 - 06 45	41.5	1.036

(1) Observation on March 3

On the morning of March 3 dense cloud accompanied with small snowflakes was invading in the area. Silver iodide particles were released from 8 h 20 m to 9 h 09 m.

The meteorological conditions during the observations were as follows. The temperature and the humidity were -5.9 ~ -6.1°C and 98 ~ 100 % respectively. WNW wind prevailed over each station, the mean velocities of which were 2, 4 and 4 m/sec at the first, the second and the third station respectively. The visibility fluctuated between 100 and 500 m. Examination of the microphotographs taken at the first station showed that almost all particles captured were supercooled cloud droplets and only few ice crystals were found on the photographs. At this station cloud conditions changed only slightly during the observation. At the second station from about 8 h 20 m the size of the snowflakes and the intensity of snowfall increased with time. Only a few ice crystals, however, were found on the microphotographs. From about 9 h the size and the number of the snowflakes increased at the third station and the amount of snowfall was estimated to be about 2 mm per 15 min. Considering the short distance of each station from the generator it will not be reasonable, however, to attribute the increase of snowfall to the effect of seeding.

(2) Observation on March 6

On the morning of March 6 the second observation was carried out from 9 h 30 m to 11 h 00 m. A thin cloud with neither ice crystals nor snowflakes formed at about 9 h and dissipated at about 11 h. Seeding was made for 30 minutes from 10 h 03 m to 10 h 33 m. The temperature was -5.9 ~ -7.1° C, and the relative humidity fluctuated between 46 and 73 %. These low humidities and their large fluctuations would be attributed to the condition of the cloud which was so thin that it sometimes dissipated. There was WNW or NW wind with mean speed of about 1 m/sec. The visibility fluctuated with the condition of the cloud from 300 m to 1000 m. At the beginning of the seeding no ice crystals were found in the cloud. 15 minutes after the onset of seeding very minute crystals were found floating on the first station, but the amount of them was rather very small.

On the second station small ice crystals were also found nearly at the same time as on the first station, the amount of which, however, increased with time until it reached maximum at about 10 h 30 m. They were seen to fall until 20 minutes after the end of discharge and disappeared with clearing up of the cloud.

On the third station ice crystals were observed 18 minutes after the onset of discharge and the amount of ice crystals increased with time. At about 10 h 40 m small number of snowflakes were also seen. The fall of crystals on the third station was so conspicuous that they completely covered the glass plate which was exposed in the air. Crystals disappeared at 11 h 15 m, when the cloud also dissipated.

To our great regret, however, only few crystals were sampled on the oil film. This was presumably, due to the smallness of the upper hole of the case through which the ice crystals were drawn and captured on the oil film.

(3) Observation on March 8

Most favourable conditions for the experiment dropped in on the morning of March 8. A cloud with no ice crystals formed early in the morning and dissipated at about 7 h 30 m. Seeding and observations were made from 6 h 05 m to 6 h 45 m and from 6 h to 8 h respectively. The temperature and the humidity during the observation were -9.2 ~ -10.0°C and 97 % respectively. There was a WNW wind blowing which was so mild that it occasionally became calm. The visibility fluctuated between 200 m and 600 m. On the first station ice crystals were found several minutes after the onset of seeding, the number of which was so scarce that they could not be taken by the microphotograph. It may be presumed that these crystals were formed near the generator and then transported there by the wind with unsettled direction.

About 15 minutes after the onset of seeding ice crystals were also observed on the second station. They increased the size and the number with time. Fig. 2 which was reproduced from one of the microphotographs taken at the second station shows the crystals which were captured on the glass plate exposed in the air between 6 h 00 m and 7 h 00 m. The crystals disappeared at about 7 h 40 m, when the cloud cleared up.

On the third station ice crystals were first found nearly at the same time as the second station. From 20 minutes after the onset of seeding they increased their size with time. Ice crystals captured on the glass plate exposed between 6 h 15 m and 6 h 25 m are shown in Fig. 3 and those between 6 h 45 m and 6 h 59 m are shown in Fig. 4. The intensity of the fall of the crystals was closely connected with the concentration of the cloud. Amount of the crystals fallen on the glass plate was so large that they were easily seen with the naked eye.

They disappeared at about 7 h when the cloud began to dissipate.

4. Discussion of the Results

From the above results it will be seen that only few crystals were observed on the windward side of the generator, whereas on the lee side the number of crystals increased with the distance from the generator. As on March 8 the meteorological conditions were most favourable and furthermore observations were most skilfully carried out, we will make some consideration on the results obtained on that day.

(1) The size of supercooled cloud droplets and the water content of the cloud

Using the microphotographs of the supercooled cloud droplets, one of which is shown in Fig. 5, the mean diameter of the droplets was estimated. It was 2.5 and 5.4 μ at the second and the third station respectively. To obtain the mean water content of the cloud TRABERT's formula (7) was employed, which was expressed by $W = cr/V$, where V is the visibility in m, r is the mean diameter of droplets in μ, W is the water content of the cloud in g/cm³, and c is the numerical factor which is equal to 2.6. Using the mean visibility and the mean diameter observed we can find that the mean water content was 0.02 and 0.03 g/cm³ at the second and thet hird station respectively (Table 2).

(2) The form, size and the rate of growth of ice crystals.

As seen from Fig. 2, 3 and 4 the most predominant form of the ice crystals was hexagonal plate. This is in good agreement with the result of the experiment by KAMPE, WEICKMANN and KELLY (5) who have studied the form of ice crystals associated with the temperature at which they were formed in the cold chamber.

Next the mean diameter and the thickness of the hexagonal plates were estimated from the microphotographs, the result of which is shown in table 2.

Table 2

	Second sta'ion	Third station	
Mean diameter of super-cooled cloud droplets	2.5	5.4	μ
Water content of cloud	0.02	0.03	g/m
Mean diameter of ice crystals	86.5	111.7	μ
Mean thickness of ice crystals	29.3	37.9	μ
Average mass of ice crystals	1.14	2.46	$\times 10^{-7}$g
Number of crystals fallen	52	476	/cm² min
Precipitation	0.0035	0,070mm/hour	

The mean volume of the crystals estimated from the mean diameter and the thickness was 1.42×10^{-7} and 3.07×10^{-7} cm³ at the second and the third station respectively. If we assume the density of the crystals as 0.8, which was obtained by V. J. SCHAEFER (6), the average mass of the plates at respective station will be given by 1.14×10^{-7} and 2.46×10^{-7}g. The mean rate of growth of crystals while they were transported from the second to the third station will be, then, easily estimated. As the mean speed of the wind was 0.5 m/sec and the distance between two stations was 400 m, it becomes 1.7×10^{-4} microgram per second. Now we shall compare the above result with HOUGHTON's calculation (4). According to his calculation the rates of growth of a hexagonal plate for various humidities of the air at -10°C are as follows.

Relative humidity	101	103	105	110%
Rate of growth	1.7	5.0	8.5	1.7 $\times 10^{-4}$ microgram per second

The above table shows that an ice crystal in the air at the humidity of 101 %, for instance, grows by sublimation at the rate of 1.7×10^{-4} microgram per sec and at 110 % (or at 100 % with respect to water) it grows at the rate of 17 microgram per sec. As stated afore, however, the mean humidity during the

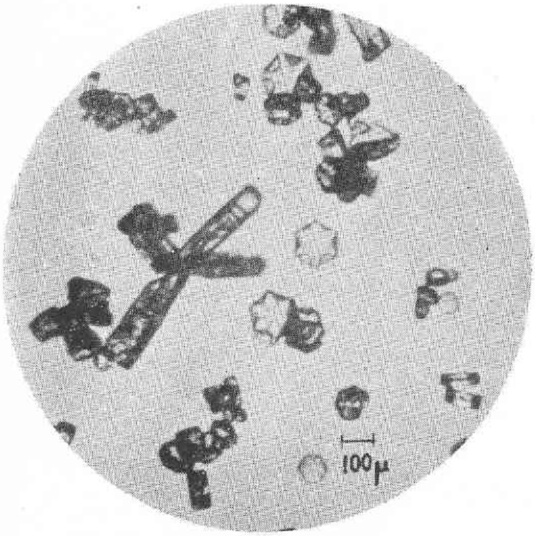

Fig. 2 Microphotograph of ice crystals at the second station.

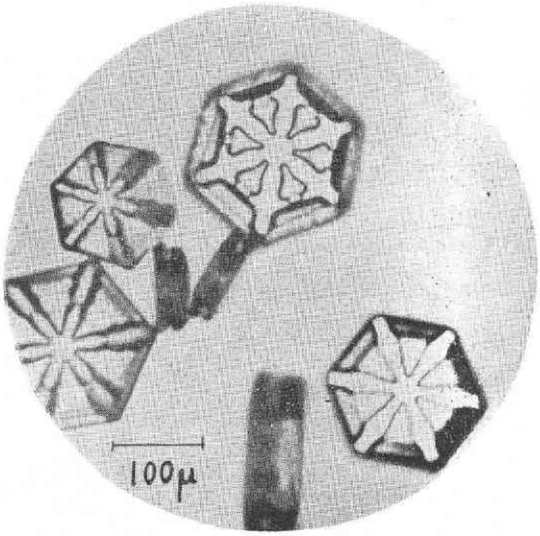

Fig. 4 Microphotograph of ice crystals at the third station.

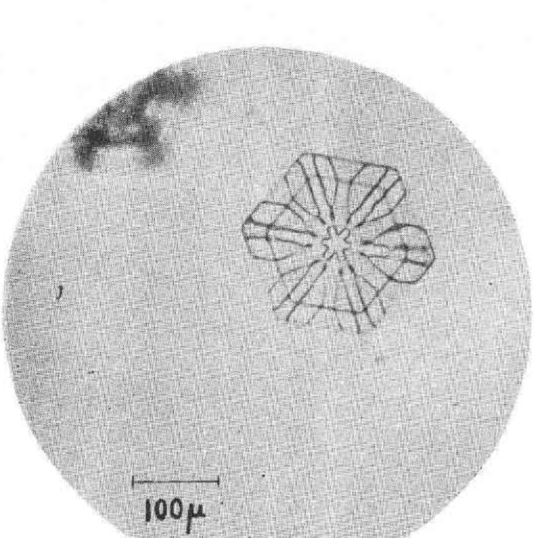

Fig. 3 Microphotograph of ice crystal at the third station.

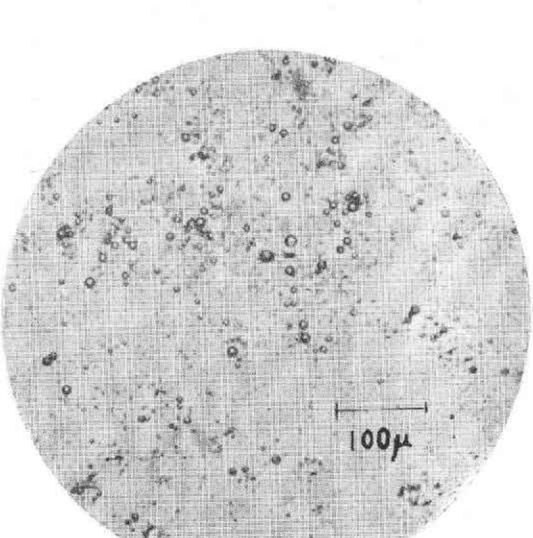

Fig. 5 Microphotograph of the supercooled cloud droplets.

observation was 97 %. In the upper atmosphere where the cloud was denser than near the ground, it may occur that the humidity was higher than at the low level. If the humidity in the upper atmosphere with which the ice crystals were transported were 101 %, which would not be an unreasonable assumption, the rate of growth estimated by us would agree with HOUGHTON's calculation.

Lastly, number of crystals fallen on the glass plate was estimated from the microphotographs. It was 52 and 476/cm² min for the second and the third station respectively, which shows that nine times as many crystals fell on the latter station.

From the results of the present observations it is concluded that the ice crystals are really produced by seeding the silver iodide in the area containing supercooled cloud droplets and that they grow by sublimation at the rate of numerically nearly same order as that of HOUGHTON's calculation. These results will offer a powerful support on the possibity of the artifical rain making.

5. Acknowledgements

The writers are pleased to acknowledge indebtness to Prof. H. TOMINAGA, Frof. S. KINUMAKI for the construction of the generator and the preparation of silver iodide. It is also expressed with thanks that the present investigation was carried out as the preliminary experiment of artificial rain making under the financial support of the Tôhoku Electric Power Company, Ltd., Sendai.

References

(1) SCHAEFER, V. J. : "The production of ice crystals in a cloud of supercooled water droplets", *Science*, **104** 457 (1946)

(2) SCHAEFER, V. J. : "The natural and artificial formation of snow in the atmosphere", *Trans. Amer. Geophys. Union* **29**, 492 (1948)

(3) VONNEGUT, B. : 'The nucleation of ice formation by silver iodide", *J. Appl. Phys.* **18**, 593 (1947)

(4) HOUGHTON, H. G. : "A preliminary quantitative analysis of precipitation mechanisms", *J. Met.* **7**, 363 (1950)

(5) KAMPE, H. J. aufm, H. K. WEICKMANN and J. J. KELLY : "The influence of temperature on the shape of ice crystals growing at water saturation", *J. Met.* **8**, 168 (1951)

(6) SCHAEFR, V. J. : Properties of particles of snow and the electrical effects they produce in storms", *Trans. Amer. Geophys. Union* **28**, 587 (1947)

(7) TRABERT, W. : *Meteor. Z*, **18**, 518 (1901)