DYNAMIC EFFECT OF SALT SEEDING IN WARM CUMULUS CLOUDS

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ABSTRACT

Visual observations on clouds and measurements of cloud liquid water content and temperatute were made during a warm cumulus cloud seeding experiment which is in progress at Poona. Such observations and measurements relating to 32 seeding traverses in six cloud complexes of different thickness are presented and discussed.

Clouds of vertical thickness of 5,000 ft or more showed 1) rise in temperature of 1 to 2^{O}C, 2) rise in liquid water content up to 2 grams per cubic meter and 3) growth by a few thousand feet in the vertical, before onset of rain, following seeding.

The above features appear to be due to dynamic effect of salt seeding. These are explained, qualitatively, based on the chain reaction process involving condensation and updraft generation.

INTRODUCTION

The dynamic effect of silver iodide seeding is known from the various accounts of the field experiments conducted (Sax, 1969; Schleusener et al., 1970; Dennis and Schock, 1971; Simpson et al., 1971; 1972; Woodley and Simpson, 1972) and from the numerical models developed (Saunders, 1957; Simpson et al., 1965; Weinstein and MacCready, 1969; Simpson and Wiggert, 1971; Orville and Hubbard, 1973; Fukuta, 1973). The characteristics of the effect reported are a rise, by a fraction of a degree to a few degrees Celsius, in the temperature of the cloud; and an increase, by some thousands of feet, in its vertical thickness. These features are a consequence of the added buoyancy to the cloud from the heat of fusion as supercooled water is converted to ice. The massive seeding which is required to produce the said dynamic effect is called 'Dynamic Seeding'. A cloud subjected to dynamic seeding is shown to yield considerably more rain than if it were unseeded or seeded in the conventional manner.

Many experiments of salt seeding in warm cumulus clouds were reported (Biswas and Ramana Murty, 1968; Biswas and Dennis, 1971; Sutherland and Booker, 1973; Cunningham and Glass, 1972). But, the dynamic effect, if any, of salt seeding has not been established. But the possibility of such effect is seen reflected in the results reported of the salt seeding experiments in marine air (Woodcock and Spencer, 1967).

A randomized cloud seeding experiment with cross over design has been in progress in the low rainfall region east of Poona (18^o 32'N, 73^o 51'E, 559 m MSL) in the Deccan Plateau (Krishna et al., 1974). Under the program of this experiment, isolated cumulus clouds of different thickness were repeatedly seeded, in the monsoon season (June to September) 1973, on a number of seedable days with common salt until each cloud so seeded exhibited either development of precipitation or dissipation. Measurements and observations made in clouds, which subsequently developed precipitation, pointed out a rise in their temperature by 1 to 2^oC, and an increase in their vertical thickness by a few thousand feet, following seeding, suggesting that dynamic effect could be induced also in warm cumulus clouds by salt seeding. Also, an increase in cloud liquid water content by a fraction to a few grams per cubic meter was noticed, following seeding, in such cases, supporting the above contention. The cloud also showed growth in lateral direction following seeding. These measurements and observations are presented and discussed below.

MEASUREMENTS AND OBSERVATIONS

Temperature observations were made with the vortex thermometer on board the DC-3 seeder aircraft. Measurement of cloud liquid water content (LWC) was made with Johnson Williams hot wire meter model LWH (range 0 to 3 gm/m^3). Observations on vertical thickness of the cloud, before and after seeding, were made by flying, where possible, at the top of the cloud, or by estimation.

EXPERIMENT

The experiment entailed dispersal of seeding material, along with a predetermined level flight path, in the entire target area at a height of a few tens to a few hundred meters above the cloud base, whenever the target area was densely covered with clouds. But, when isolated cumulus clouds or cumulus cloud complexes were present in the target area, the experiment entailed seeding them repeatedly by following a flight path which involved repeated traverses through them at constant altitude. The seeding material used was a pulverized mixture of salt and soapstone taken in the ratio of 10:1 with particle mode diameter of about 10 microns. The rate of seeding varied between 10 and 30 kg per 3 km flight path. The cruising speed of the aircraft is about 180 kmph. The details of the experiment as well as the procedure followed for selection of seedable days were described (Krishna et al., 1974).

The experiment relating to repeated seedings provided material for the present paper. The maximum number of traverses made through a cloud complex, in the cases dealt with here, was six.

Observations of temperature, liquid water content (LWC) and cloud thickness were made as mentioned in 2.

RESULTS

Visual observations were made of the developments which took place in clouds following seeding. The features noticed ranged from dissipation to heavy rain depending upon the initial vertical thickness of the cloud at the time of seeding. Clouds of vertical thickness up to 1,500 ft (category I) dissipated. Those of vertical thickness between 1,500 and 5,000 ft (category II) produced visible rain, while those whose initial vertical thickness exceeded 5,000 ft (category III) produced heavy rain.

The results obtained of the measurements of LWC, temperature and cloud dimensions, in two specific cases under each of the three categories I, II and III are given, together with details of seeding, in tables 1 to 3 and figures 1 to 6. It may be noted that the relative measurements rather than the absolute values are more important in the present study. The liquid water content increased following seeding, in the cases of categories II and III. The extent of increase noticed in the case of category III was marked. The temperature increased over sections along the flight path following seeding in all the categories. The vertical and lateral thickness increased following seeding, in categories II and III. A few specific cases considered are discribed below.

Category I:

Two cloud complexes, one of initial vertical thickness of 1,500 ft (cloud A) and the other of 1,000 ft (cloud B), were seeded on 19th July 1973. Both of them dissipated, after developing gaps, within 10 minutes of completion of seeding. Also, their lateral thickness, as indicated by the time periods of traverses within, decreased as seeding progressed (column 2 of table 1b). The LWC maximum decreased from 0.40 gm/m^3 in traverse I to 0.05 gm/m^3 in traverse V in the case of cloud A. It decreased from 0.25 to 0.05 gm/m^3 from traverse I to IV in the case of cloud B. The initial maximum temperature inside the cloud (this is the maximum temperature which was noted inside the cloud in the very first traverse made through it) was much the same as the temperature of the air outside the cloud in both the cases, which was 20^{o}C for cloud A and 18^{o}C for cloud B (see table 1a). It rose, in each case, by 1^{o}C in subsequent traverses.

Category II:

A cloud complex of initial vertical thickness of 5,000 ft was seeded on 12th August 1973. It gained by 2,000 ft in the vertical, following seeding. Also, its lateral thickness increased as seeding progressed. The LWC maximum increased from 0.50 gm/m^3 in traverse I to 2.80 gm/m^3 in traverse IV. The initial maximum temperature (16^{o}C) inside the cloud was lower than the temperature of the air outside the cloud by 2^{o}C (see table 2a). It rose by 1^{o}C in traverses III and IV. Visible rain occurred over a flight path of 6 to 10 km in traverses IV and V. The temperature fell by 4^{o}C in traverse IV and by 1^{o}C in traverse V, from the maxima in the corresponding traverses, following rain. The raingauge on the surface in the region below, which measures 24 hours rainfall, recorded 5.6 mm.

A cloud complex of initial thickness of 4,000 ft was seeded on 13th August 1973. It gained by 2,000 ft in the vertical, following seeding. Also, its lateral thickness increased as seeding progressed. The LWC maximum in traverse I increased from 0.80 gm/m^3 to 1.80 gm/m^3 in traverse V. The initial maximum temperature (14°C) inside the cloud was lower than the temperature of the air outside the cloud by 1°C (see table 2a). It rose by 1°C in traverses III, IV and V. Visible rain occurred in traverses III and V over a flight path of 6 to 10 km when the values of LWC noted were high. The raingauge in the region recorded 2.2 mm.

Category III:

A cloud complex of initial thickness of 7,000 ft was seeded on 3rd August 1973. It gained by 4,000 ft in the vertical following seeding. Also, its lateral thickness increased as seeding progressed. The LWC maximum increased from 1.0 gm/m^3 in traverse I to more than 3.0 gm/m^3 from traverse IV (the range of J-W LWC meter used is limited to 3.0 gm/m^3). The initial maximum temperature (12°C) inside the cloud was lower than the temperature of the air outside the cloud by 2°C (see table 3a). It rose by 2°C in traverses II, III, V and VI. Rain was noticed from traverse II. Heavy to very heavy rain was noticed over a flight path of 10 km in traverses IV to VI. The temperature showed a marked decrease in traverses II, IV and VI, from the maximum in the corresponding traverses, following rain. The raingauge in the region below recorded 91.3 mm.

A cloud complex of initial thickness of 10,000 ft was seeded on 4th August 1973. It gained by about 4,000 ft in the vertical following seeding. Also, its lateral thickness increased as seeding progressed. The value of LWC maximum increased from 0.6 gm/m^3 in traverse I to more than 3.0 gm/m^3 from traverse IV. The initial maximum temperature (14°C) inside the cloud was lower than the temperature of the air outside the cloud by 2°C (see table 3a). It rose by 2°C in traverse II and by 1°C in traverses III, IV and V. Rain was noticed over flight paths of 6, 8 and 12 km respectively in traverses III, IV and V. The temperature fell by 1°C in traverses III, IV and V, following rain, from the corresponding maxima. The raingauge in the region below recorded 28.6 mm.

DISCUSSION

The cloud complexes, except those which dissipated following seeding, were initially colder than the environment by 1 to 2°C. Irrespective of whether there was dissipation or rain following seeding, the temperature inside the cloud complexes increased by 1 to 2°C as seeding progressed. The temperature inside the raining portions was generally lower than that in the non-raining portions up to 4°C. Except in the cases of dissipation, the LWC showed build-ups, sometimes exceeding 200 per cent of the initial value, as seeding progressed. The regions of higher LWC showed also higher temperatures in some traverses. Regions of high liquid water content have been reported to be associated with high temperatures from measurements made in USSR (Vulfson et al., 1973). The cloud complexes, after seeding, showed growth in the vertical up to 60 per cent and in the lateral upward of 20 per cent, following seeding. These findings point out that the cloud complexes became warmer, larger and collected more condensate mass, following seeding. Similar features were said to have been noticed from the experiments conducted in USA when warm convective clouds were seeded with hygroscopic particles in updrafts at or below mid-cloud level (Clark et al., 1972).

No observations were made in the present study on similar cloud complexes which were not seeded for the design of the experiment was such that it precluded any isolated cloud complexes in the target area to be left unseeded during the period of seeding. Consequently there were no data available, which may serve as control, for the purpose of comparison. The present observations on the seeded clouds do not, therefore, confirm that the features noticed in those clouds, were due to seeding alone. However, the measurements relating to the first traverse in each case are considered to represent, to a large extent, the natural conditions of the cloud in question because, in the seeder aircraft, the locations of the temperature and LWC sensors were upwind of that of the seed-releasing gadget, besides being at higher elevation.

The salt particles introduced into the cloud in the present experiments are presumed to make up for the deficiency, if any, of the large size droplets which are required for the efficient operation, inside the cloud, of coalescence mechanism to release rain. If that was the only role played by the salt particles, it is not clear why, in addition to rain, increases of temperature, LWC, and cloud volume should follow seeding. These particles might have actually played a complex role involving also a dynamic effect. The following remarks are offered in this connection.

The rise in cloud temperature noticed, which is a degree or two, appears to be consistent, for the value of LWC also showed a build-up up to 2 grams per cubic meter, and it is clear from first principles that increase of condensate mass by 1 gm in one cubic meter of air would raise the temperature of that air by about 2.5^{o}C. But, the problem then is to identiby the process by which such large increases in condensate mass as were observed following seeding, were brought in. It is not realistic to expect that the effect following condensation on the salt particles will explain this feature unless the effect is considered to be highly localized. If the dry salt particles of size 10 microns would form droplets of more than double their size while being carried up through the first few hundred meters of the cloud, and if the condensates so formed on the entire material seeded, which is 1,500 kg, are uniformly distributed within the body of the cloud, which may be 10^{11} m^3, its liquid water content may not rise by more than 10^{-4} gm/m^3. But, if such effect of seeding is considered to be localized in a strip of a few tens of meters wide and deep along the path length seeded, increases in liquid water content to the extent observed become possible. But the two alternatives considered are the two extremes and, in between them a number of alternatives, which are possible, exist. Consequently localized increases in liquid water content, of varying magnitude, become possible which should give rise, in their turn, to localized increases in temperature. Such increases in temperature may help induce updrafts or accelerate the prevailing updrafts (an increase of 1^{o}C in cloud temperature increases updraft speed by a few meters per second, Cunningham and Glass, 1965; Matsumoto et al., 1967; Simpson and Wiggert, 1971), enabling further build-up of cloud liquid water content, for, updraft and liquid water content are closely connected. Consequently, there will be further localized increases in temperature and the cycle repeats until either no more moisture supply from below is possible or the rain-caused downdrafts become dominant. Thus, the condensate mass, though small, brought about by salt-particle seeding could act as a trigger to set off a dynamic chain reaction facilitating rapid cloud growth as was observed following seeding. It may be mentioned that observations in cumulus clouds have indicated high LWC in the updraft regions and low or zero LWC in the downdraft regions (Takeuchi, 1972). Also, accumulation of LWC in the updraft region has been indicated in the numerical calculations reported (Schlesinger, 1973).

The dissipation noticed following seeding in the case of shallow clouds, in the present experiments could, perhaps, be understood in terms of the replacement of the ascending currents by the descending ones (Lebedev and Aleksandrov, 1965). When hygroscopic particles are introduced into a shallow cloud, the water removed by the hygroscopic particles evaporates beneath the cloud, cooling the subcloud layer, causing descending currents.

CONCLUSIONS

Following seeding by salt particles the cloud, in certain regions, showed a rise in temperature from 1 to 2°C as well as rise in LWC up to 2 grams per cubic meter, before onset of rain. The cloud also grew by a few thousand feet, in the vertical, following seeding. These characteristic features, which appear to be the dynamic effect of salt seeding, were noted in all the situations when the initial vertical thickness of the cloud exceeded 5,000 ft at the time of seeding. A kind of chain reaction involving the process of condensation and updraft generation has been invoked to explain qualitatively the features observed.

The observations reported in the present study would be of value for development of more realistic models simulating warm rain process in cumulus clouds (Silverman and Glass, 1973).

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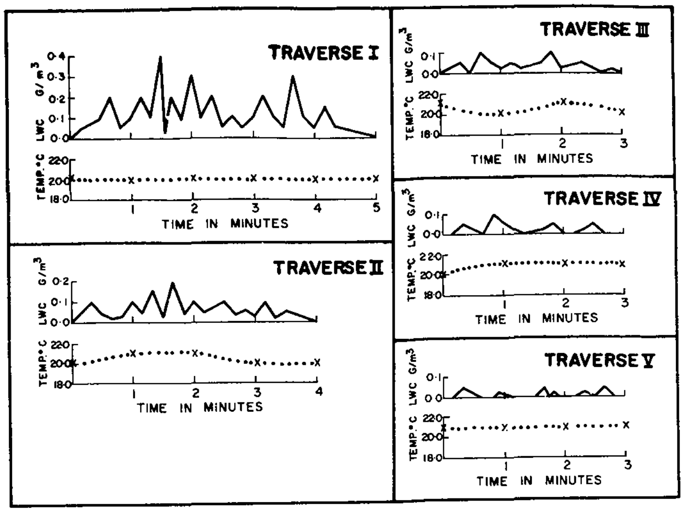

Figure 1 : Recordings of LWC and temperature in cloud complex A on 19.7.1973 (Traverses I to V).

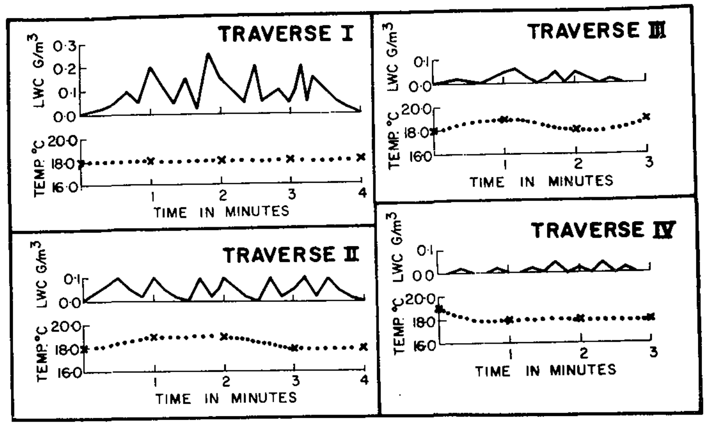

Figure 2 : Recording of LWC and temperature in cloud complex B on 19.7.1973 (Traverses I to IV).

Table 1 a

Summary of observations on clouds of category I

		Cloud A (July 19, 1973)	Cloud B (July 19, 1973)
1.	Vertical thickness before seeding	1500 ft	1000 ft
2.	Vertical thickness after seeding	dissipated	dissipated
3.	Cloud base height	4000 ft	5000 ft
4.	Length of cloud complex	15 km	12 km
5.	Amount of seeding material released	450 kg	300 kg
6.	Rate of seeding	20 kg per 3 km flight path	20 kg per 3 km flight path
7.	Level of seeding	4500 ft	5500 ft
8.	Air temperature before entering the cloud	20°C	18°C
9.	Initial maximum temperature inside cloud	20°C	18°C
10.	Maximum temperature inside cloud following seeding	21°C	19°C
11.	Maximum decrease in LWC following	0.35 g/m^3	0.20gm/m^3
12.	Number of traverses made during seeding	Five	Four

Table 1 b

Summary of observations - traverse-wise (category I)

Traverse	Duration of traverse, minutes	Liquid water content, gm/m^3		Temperature inside cloud, °C	
		Minimum	Maximum	Minimum	Maximum
Cloud A (July 19, 1973)					
I	5	0.02	0.40	20	20
II	4	0.02	0.20	20	21
III	4	0.0	0.10	20	21
IV	3	0.0	0.10	20	21
V	3	0.0	0.05	21	21
Cloud B (July 19, 1973)					
I	4	0.02	0.25	18	18
II	4	0.0	0.10	18	19
III	3	0.0	0.06	18	19
IV	3	0.0	0.05	18	19

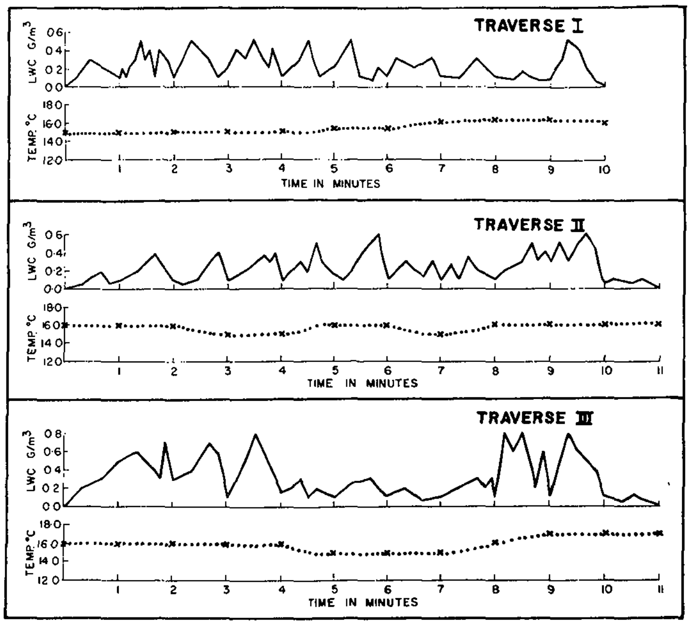

Figure 3a : Recordings of LWC and temperature in cloud complex on 12.8.73 (Traverses I to III).

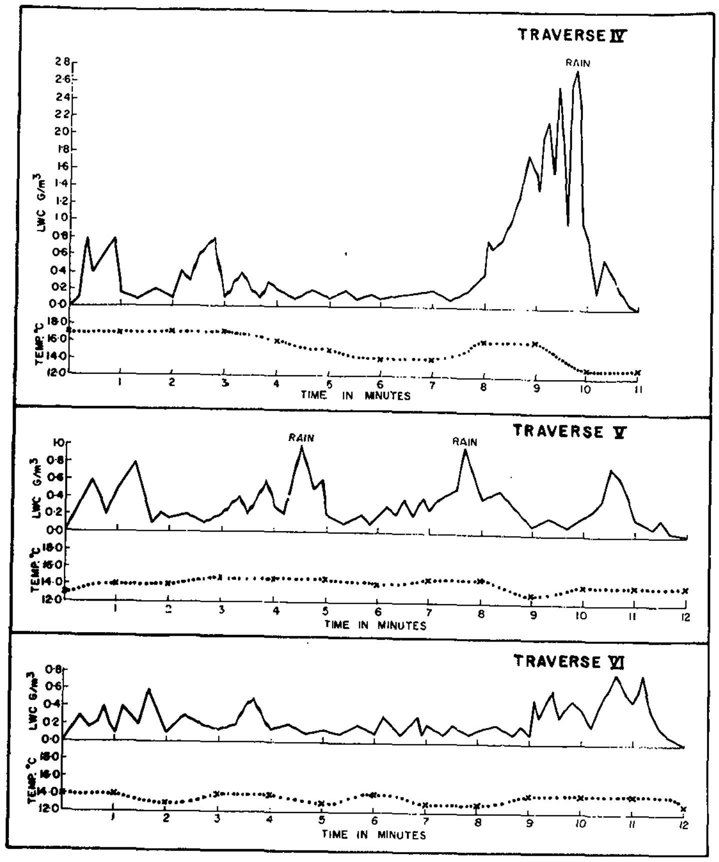

Figure 3b : Recordings of LWC and temperature in cloud complex on 12.8.1973 (Traverses IV to VI).

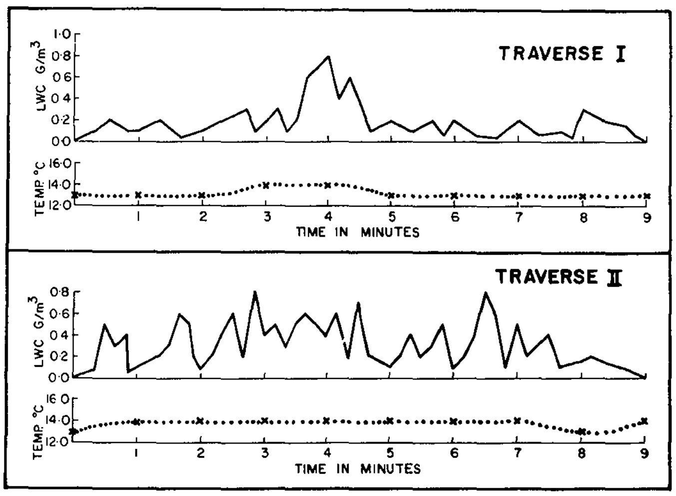

Figure 4a : Recordings of LWC and temperature in cloud complex on 13.8.1973 (Traverses I and II).

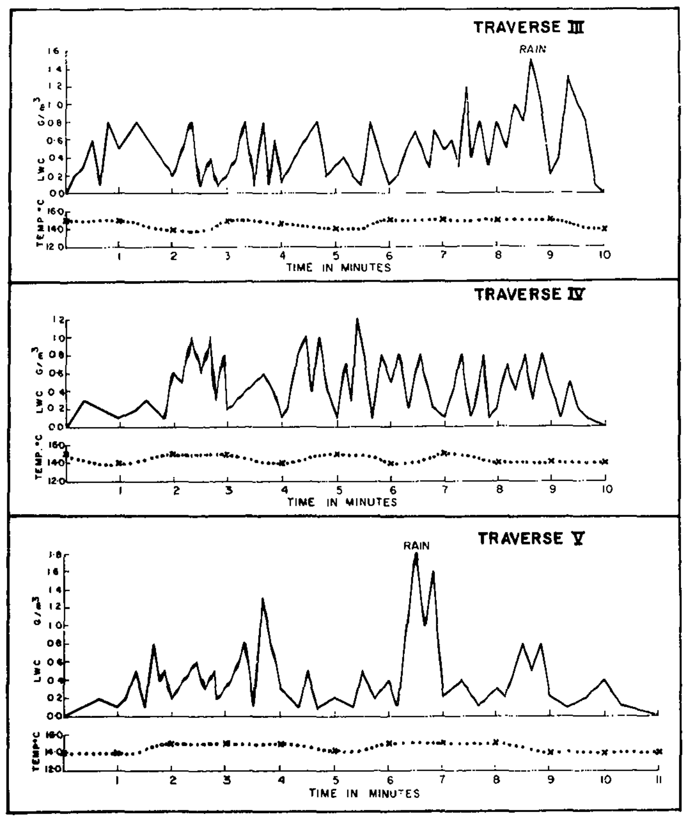

Figure 4b : Recordings of LWC and temperature in cloud complex on 13.8.1973 (Traverses III to V).

Table 2 a

Summary of observations in clouds of category II

		August 12, 1973	August 13, 1973
1.	Vertical thickness before seeding	5000 ft	4000 ft
2.	Vertical thickness after seeding	7000 ft	6000 ft
3.	Cloud base height	5000 ft	6000 ft
4.	Length of cloud complex	30 km	20 km
5.	Amount of seeding material released	1500 kg	1500 kg
6.	Rate of seeding	20 kg per 3 km flight path	30 kg per 3 km flight path
7.	Level of seeding	6000 ft	7000 ft
8.	Air temperature before entering the cloud	17°C	14°C
9.	Initial maximum temperature inside cloud	15°C	13°C
10.	Maximum temperature inside cloud following seeding	17°C	15°C
11.	Maximum increase in LWC following seeding	2.3 gm/m^3	1.0 gm/m^3
12.	Number of traverses made during seeding.	Six	Five

Table 2 b

Summary of observations-traverse-wise (category II)

Traverse	Duration of traverse, minutes	Liquid water content, gm/m^3		Temperature inside cloud, °C	
		Minimum	Maximum	Minimum	Maximum
August 12, 1973					
I	10	0.05	0.50	15	16
II	11	0.05	0.60	15	16
III	11	0.05	0.80	15	17
IV	11	0.05	2.80	13	17
V	12	0.05	1.00	13	14
VI	12	0.10	0.80	13	14
August 13, 1973					
I	9	0.05	0.80	13	14
II	9	0.05	0.80	13	14
III	10	0.10	1.50	14	15
IV	10	0.10	1.20	14	15
V	11	0.05	1.80	14	15

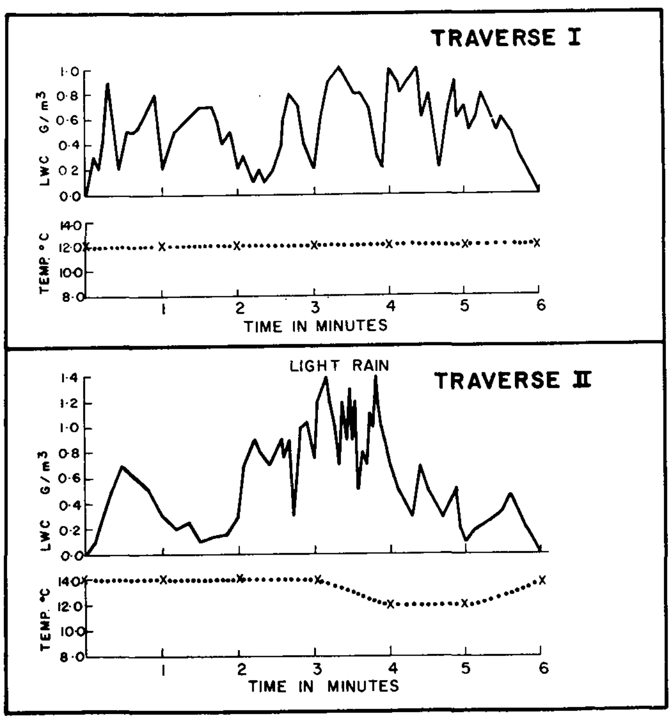

Figure 5a : Recordings of LWC and temperature in cloud complex on 3.8.1973 (Traverses I and II).

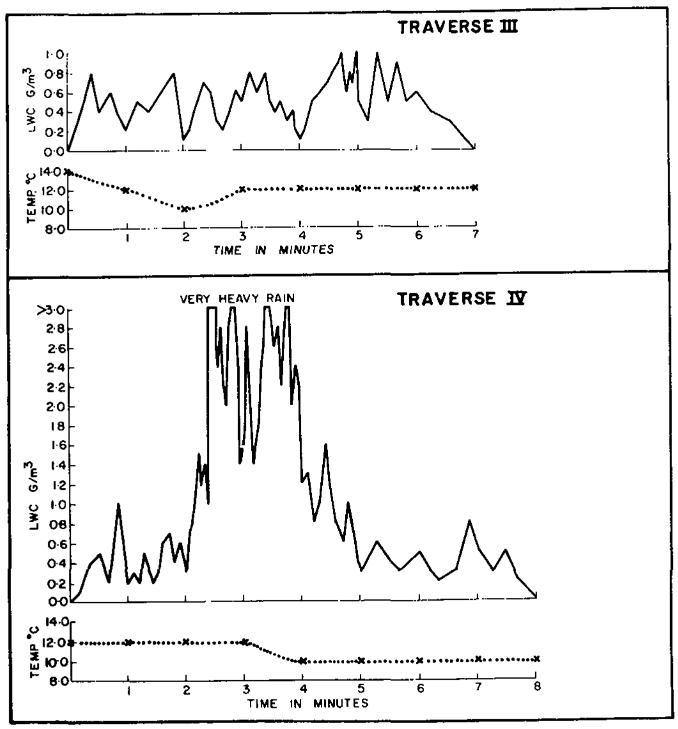

Figure 5b : Recordings of LWC and temperature in cloud complex on 3.8.1973. (Traverses III and IV).

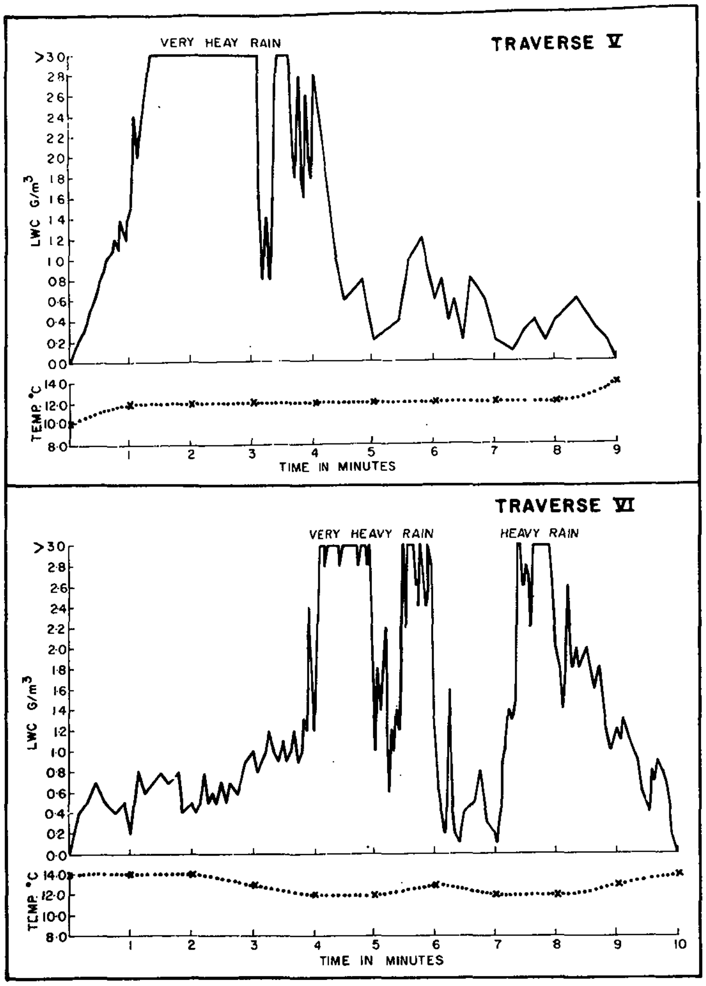

Figure 5c : Recordings of LWC and temperature in cloud complex on 3.8.1973 (Traverses V and VI).

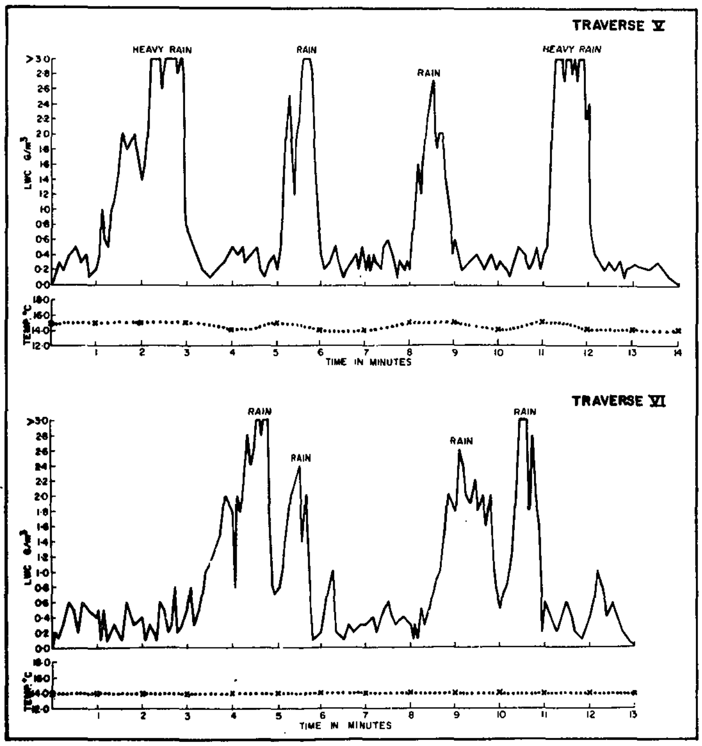

Figure 6c : Recordings of LWC and temperature in cloud complex on 4.8.1973 (Traverses V and VI).

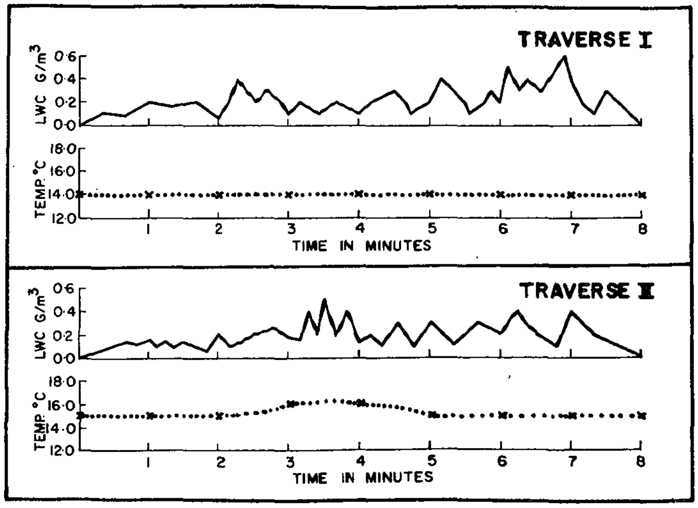

Figure 6a : Recordings of LWC and temperature in cloud complex on 4.8.1973 (Traverses I and II).

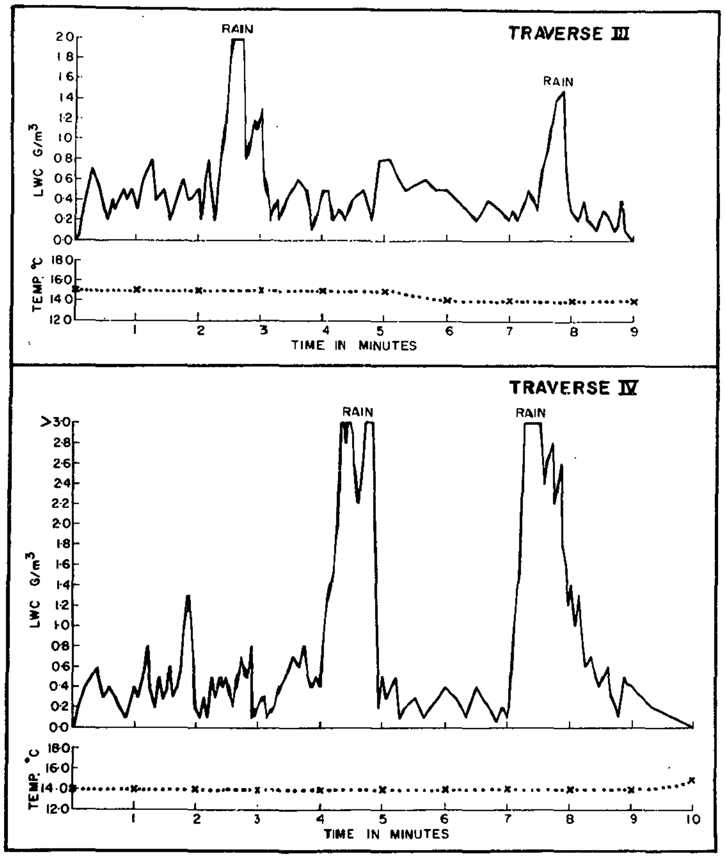

Figure 6b : Recordings of LWC and temperature in cloud complex on 4 4.8.1973 (Traverses III and IV).

Table 3a

Summary of observations on clouds of category III

	August 3,1973	August 4, 1973
1. Vertical thickness before seeding	7000 ft	10000 ft
2. Vertical thickness after seeding	11000 ft	14000 ft
3. Cloud base height	7000 ft	6000 ft
4. Length of cloud complex	15 km	25 km
5. Amount of seeding material released	1500 kg	1500 kg
6. Rate of seeding	30 kg per 3 km flight path	20 kg per 3 km flight path
7. Level of seeding	8,000 ft	7,000 ft
8. Air temperature before entering the cloud.	14°C	16°C
9. Initial maximum temperature inside cloud	12°C	14°C
10. Maximum temperature inside cloud following seeding.	14°C	16°C
11. Maximum increase in LWC following seeding.	> 2.0 gm/m^3	> 2.0 gm/m^3
12. Number of traverses made during seeding.	six	six

Table 3 b

Summary of observations-traverse-wise (category III)

Traverse	Duration of traverse, minutes	Liquid water content gm/m^3		Temperature inside cloud, °C	
		Minimum	Maximum	Minimum	Maximum
		August 3, 1973			
I	6	0.05	1.00	12	12
II	6	0.05	1.40	12	14
III	7	0.05	1.00	10	14
IV	8	0.10	> 3.00	10	12
V	9	0.10	> 3.00	10	14
VI	10	0.10	> 3.00	12	14
		August 4, 1973			
I	8	0.05	0.60	14	14
II	8	0.05	0.50	15	16
III	9	0.05	2.00	14	15
IV	10	0.05	> 3.00	14	15
V	14	0.10	> 3.00	14	15
VI	13	0.05	> 3.00	14	14