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Summary of Observations Indicating Dynamic Effect of Salt Seeding in Warm Cumulus Clouds

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ABSTRACT

Measurements of cloud liquid water content and temperature were made along with visual observations in 32 traverses carried out in six warm cumulus clouds subjected to salt seeding. The results showed (i) a rise, of 1–2°C, in temperature, (ii) an increase, sometimes exceeding 200%, in liquid water content, and (iii) vertical growth, up to 60%, in seeded clouds which developed rain. The features noticed could be due to the possible dynamic effect of salt seeding in warm clouds.

1. Introduction

A dynamic effect due to massive artificial glaciation has been successfully demonstrated in many seeding experiments on cold cumulus clouds (Simpson and Dennis, 1972). The possibility of such an effect being produced in warm cumulus clouds through seeding with hygroscopic materials has not been adequately explored, though there have been indications that seeding warm clouds with hygroscopic materials causes increases in (i) in-cloud updrafts and downdrafts, (ii) cloud water content, and (iii) cloud growth (Hall *et al.*, 1971; Clark *et al.*, 1972). Any information available about a possible dynamic effect of seeding warm clouds is therefore of value. The present authors have had some opportunity to explore this aspect from the extensive measurements made of cloud water content and cloud temperature in isolated cumulus clouds and/or cloud complexes which had been repeatedly seeded with common salt in the region east of Poona (18°32′N, 73°51′E, 559 m MSL) under a program of randomized cloud seeding experiment with crossover design. These measurements are summarized below.

2. Measurements and observations

Details of the randomized seeding experiment referred to above were described elsewhere (Krishna *et al.*, 1974). The important points relevant to the present context are mentioned here. The seeding material used was a pulverized mixture of common salt and soapstone taken in the ratio of 10:1 with particle mode diameter of about 10 μm. Repeated seeding was adhered to when isolated clouds or cloud complexes were available. Seeding was done by flying at a height of a few tens to a few hundred meters above the cloud base, and by making repeated traverses through the cloud at constant altitude. Seeding material was used through the entire flight path of all the traverses made in the cloud. The rate of seeding varied between 20 and 30 kg per 3 km flight path. The crusing speed of the seeder aircraft, which is a DC-3, is about 180 km h^{-1}.

Temperature observations were made with a vortex thermometer on board the seeder aircraft. Measurements of cloud liquid water content (LWC) were made with a J-W hot wire meter model LWH (range 0 to 3 g m^{-3}). Observations of vertical thickness of the cloud,

TABLE 1. Summary of observations on clouds under different categories.

Observed parameter	Category I 19 July 1973 Cloud A	Category I 19 July 1973 Cloud B	Category II 12 August 1973	Category II 13 August 1973	Category III 3 August 1973	Category III 4 August 1973
Vertical thickness before seeding (ft)	1500	1000	5000	4000	7000	10000
Vertical thickness after seeding (ft)	dissipated	dissipated	7000	6000	11000	14000
Cloud base height (ft)	4000	5000	5000	6000	7000	6000
Length of the cloud complex (km)	15	12	30	20	15	25
Amount of seeding material released (kg)	450	300	1500	1500	1500	1500
Rate of seeding per 3 km flight path (kg)	20	20	20	30	30	20
Level of seeding (ft)	4500	5500	6000	7000	8000	7000
Air temperature before entering the cloud (°C)	20	18	17	14	14	16
Initial maximum temperature inside cloud (°C)	20	18	15	13	12	14
Maximum temperature inside cloud following seeding (°C)	21	19	17	15	14	16
Difference in LWC between the maximum value in the first traverse and the maximum value in subsequent traverses (g m^{-3})	0.35	0.20	2.30	1.00	>2	>2.4
Number of traverses made during seeding	5	4	6	5	6	6
Rainfall received at the surface below the cloud (mm)	nil	nil	5.6	2.2	91.3	28.6

before and after seeding, were made by flying, where possible, at the top of the cloud, or by estimation.

As the above measurements were not originally planned with the definite end goal of studying the dynamic effect, no measurements were made in similar clouds in the target area left unseeded for the purpose of control. 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 temperature and LWC sensors were upwind of the seeding release mechanism, and at a higher elevation.

3. Developments following seeding

Visual observations were also made of the developments in the clouds following seeding. The features noticed, as already mentioned (Krishna *et al.*, 1974), ranged from dissipation to heavy rain depending upon the initial vertical thickness of the cloud at the time of seeding. Clouds of thickness up to 1500 ft (category I) generally dissipated. Those of thickness between 1500 and 5000 ft (category II) often produced visible rain, while those which exceeded 5000 ft (category III) invariably produced heavy rain.

4. Results and discussion

The data relating to LWC, temperature and cloud dimensions, for two specific cases under each of the three categories I, II and III are given, together with seeding details, in Tables 1 and 2 and Figs. 1 to 6.

The cloud complexes, except those which dissipated following seeding, were initially colder than the environment by 1–2°C. Irrespective of whether there was dissipation or rain following seeding, the temperature over sections along the flight path increased by 1–2°C as seeding progressed. The temperature inside the raining portions was generally lower (by up to 4°C) than

TABLE 2. Summary of observations during cloud traverses.

Traverse	Duration of traverse, (min)	Liquid water content (g m^{-3}) Minimum	Liquid water content (g m^{-3}) Maximum	Temperature inside cloud (°C) Minimum	Temperature inside cloud (°C) Maximum
Cloud A (19 July 1973) Category I					
1	5	0.02	0.40	20	20
2	4	0.02	0.20	20	21
3	4	0.0	0.10	20	21
4	3	0.0	0.10	20	21
5	3	0.0	0.05	21	21
Cloud B (19 July 1973) Category I					
1	4	0.02	0.25	18	18
2	4	0.0	0.10	18	19
3	3	0.0	0.06	18	19
4	3	0.0	0.05	18	19
(12 August 1973) Category II					
1	10	0.05	0.50	15	16
2	11	0.05	0.60	15	16
3	11	0.05	0.80	15	17
4	11	0.05	2.80	13	17
5	12	0.05	1.00	13	14
6	12	0.10	0.80	13	14
(13 August 1973) Category II					
1	9	0.05	0.80	13	14
2	9	0.05	0.80	13	14
3	10	0.10	1.50	14	15
4	10	0.10	1.20	14	15
5	11	0.05	1.80	14	15
(3 August 1973) Category III					
1	6	0.05	1.00	12	12
2	6	0.05	1.40	12	14
3	7	0.05	1.00	10	14
4	8	0.10	>3.00	10	12
5	9	0.10	>3.00	10	14
6	10	0.10	>3.00	12	14
(4 August 1973) Category III					
1	8	0.05	0.60	14	14
2	8	0.05	0.50	15	16
3	9	0.05	2.00	14	15
4	10	0.05	>3.00	14	15
5	14	0.10	>3.00	14	15
6	13	0.05	>3.00	14	14

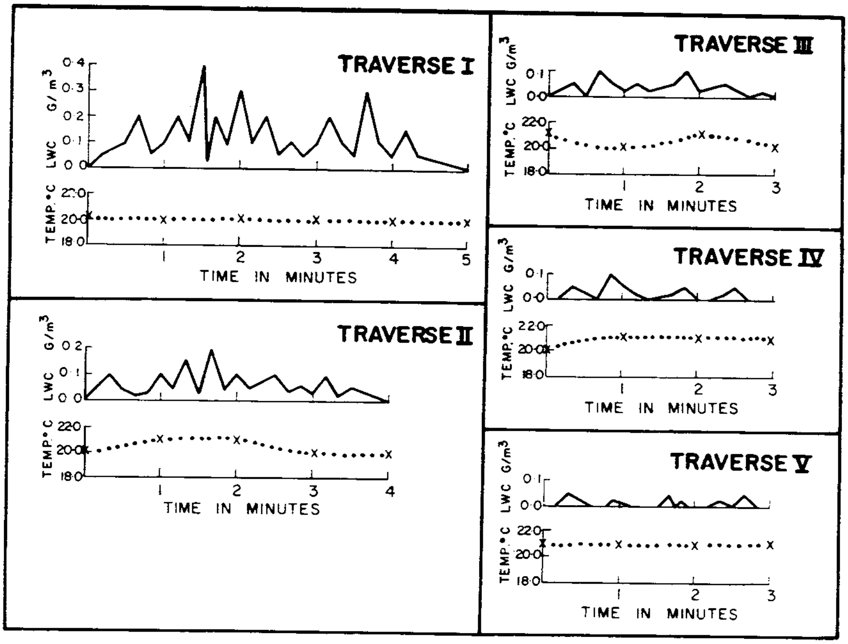

FIG. 1. Recordings of LWC and temperature in cloud complex A on 19 July 1973 (traverses 1 to 5).

that in the non-raining portions. The regions of higher LWC showed higher temperatures in some traverses. This feature is in agreement with reported measurements (Vulfson *et al.*, 1973; Takeuchi, 1972). Except in the cases of dissipation, the vertical thickness of the cloud complex increased up to 60% of its initial value as seeding progressed. Also, its lateral thickness as indicated by the duration of traverse, increased upward of 20%. Further, the LWC showed buildups, sometimes exceeding 200% of the initial value.

The features noticed above following seeding cannot be explained on the basis of physical calculations taking into consideration droplet growth by condensation on the salt particles artificially introduced into the cloud. Also, it is difficult to explain the dissipation of shallow clouds (Category I) in spite of the increase in the cloud temperature following seeding. The features noted appear to suggest what may be the possible dynamic effect of salt seeding in warm cumulus clouds. These are to be confirmed, on a statistical basis, by additional similar measurements and observations, taking into consideration control clouds.

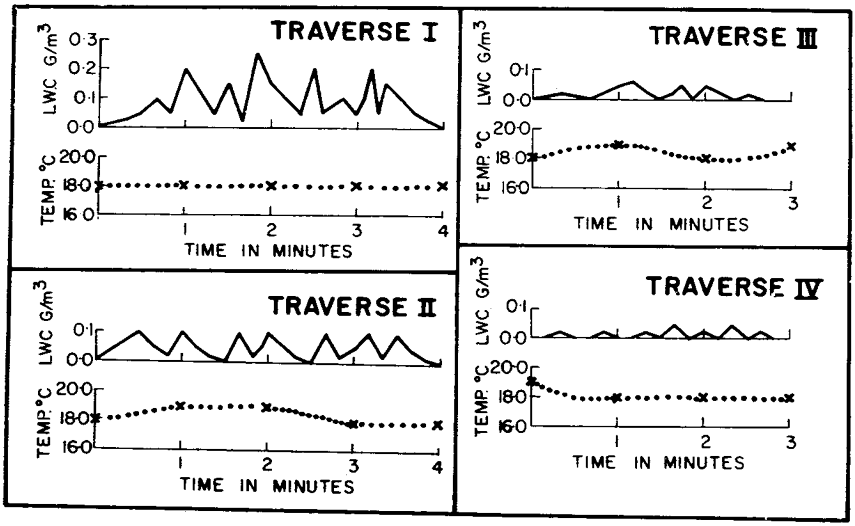

FIG. 2. Recordings of LWC and temperature in cloud complex B on 19 July 1973 (traverses 1 to 4).

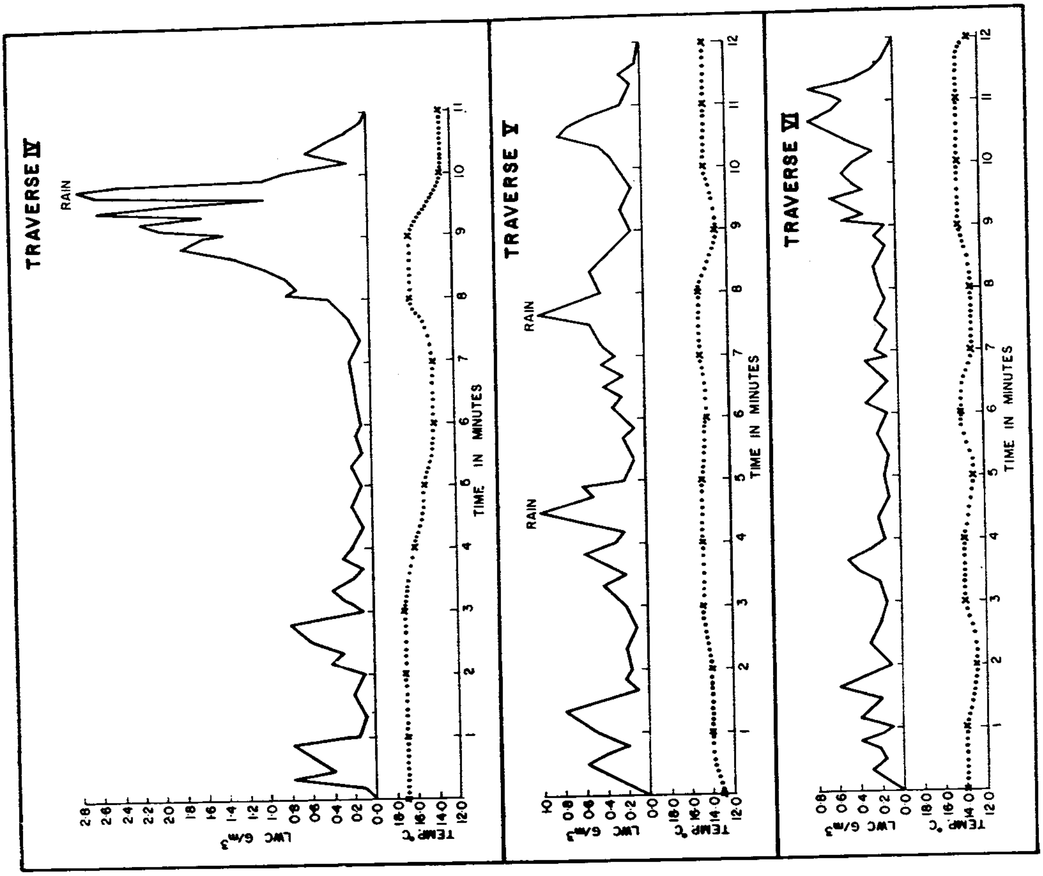

FIG. 3b. As in Fig. 3a except for traverses 4 to 6.

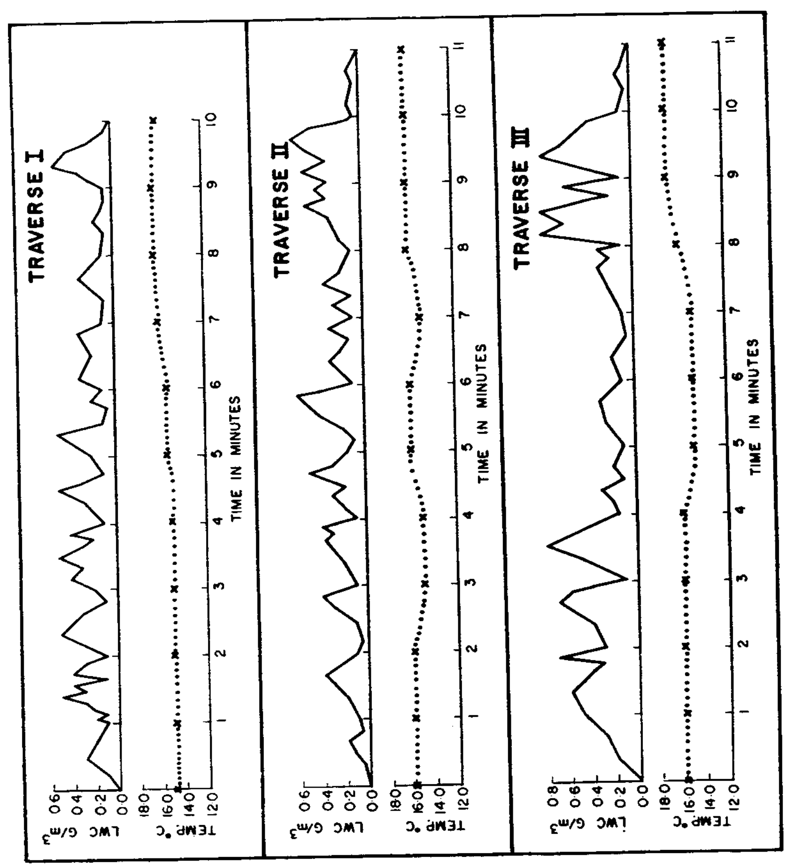

FIG. 3a. Recordings of LWC and temperature in cloud complex on 12 August 1973 (traverses 1 to 3).

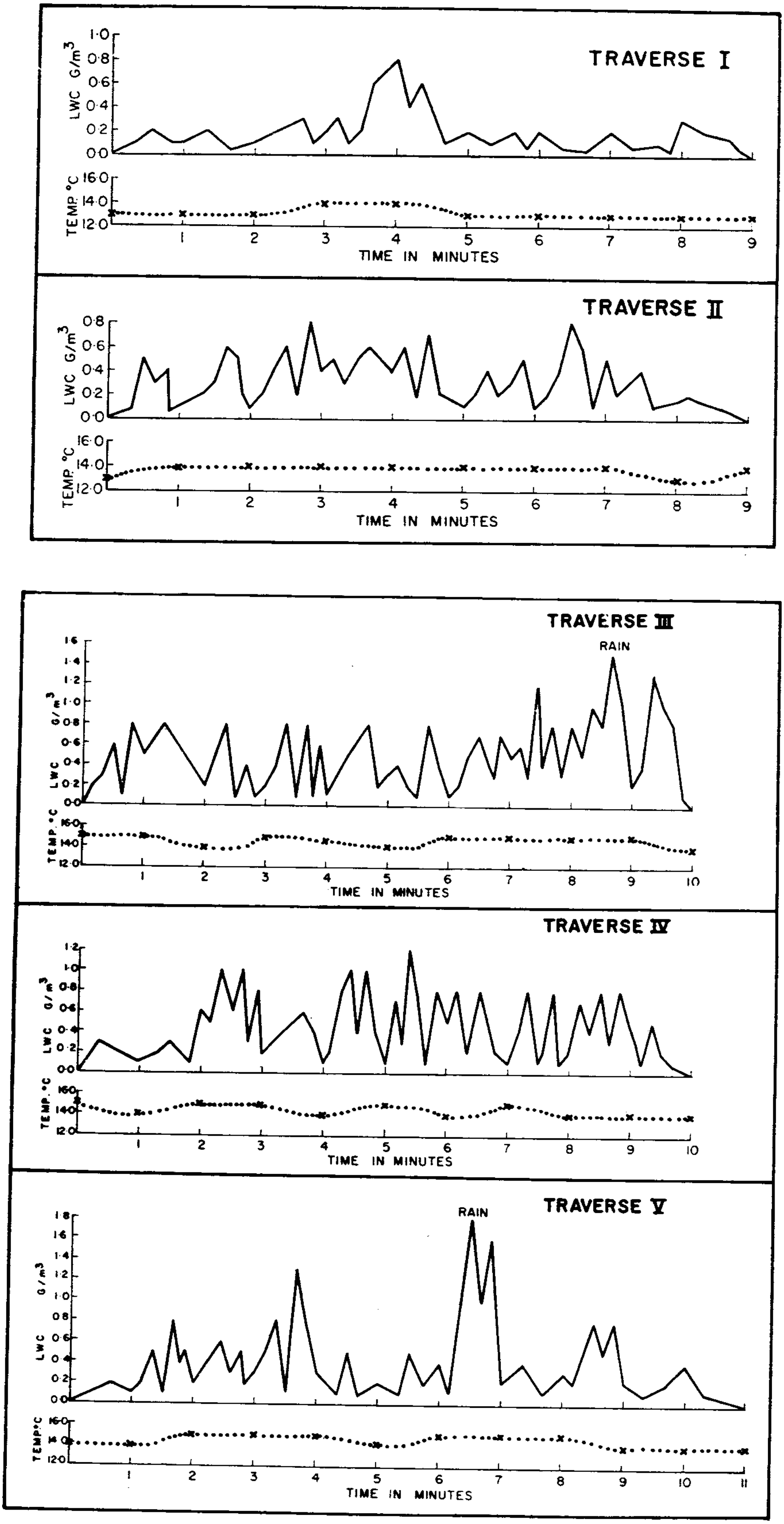

FIG. 4. Recordings of LWC and temperature in cloud complex on 13 August 1973.

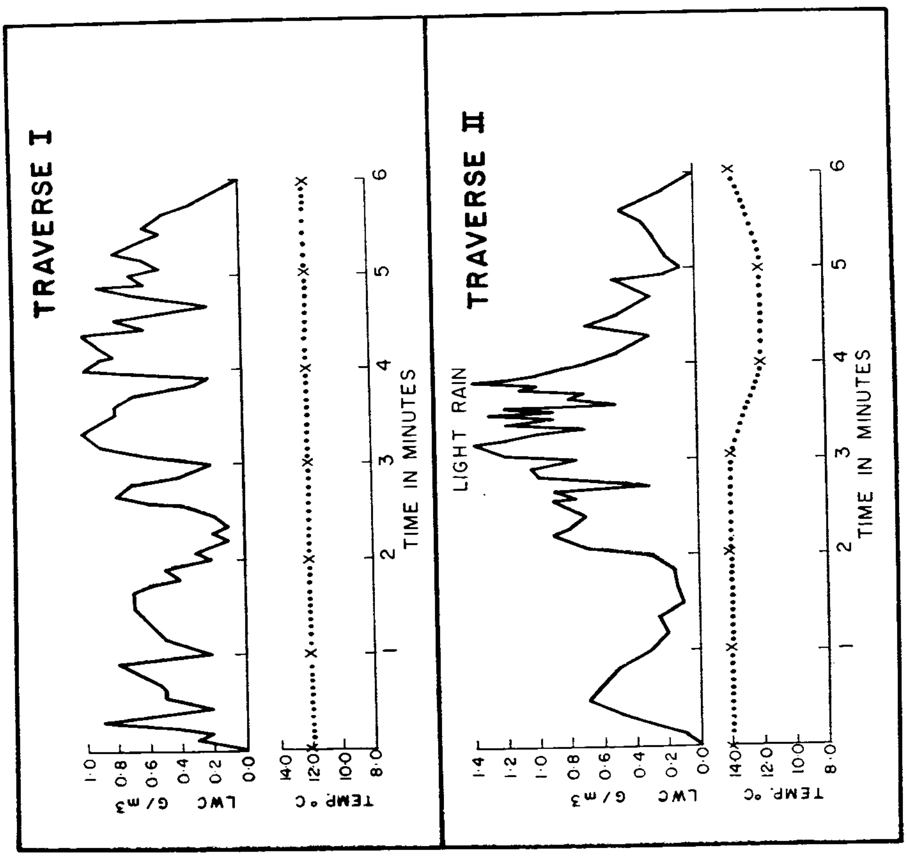

FIG. 5a. Recordings of LWC and temperature in cloud complex on 3 August 1973 (traverses 1 and 2).

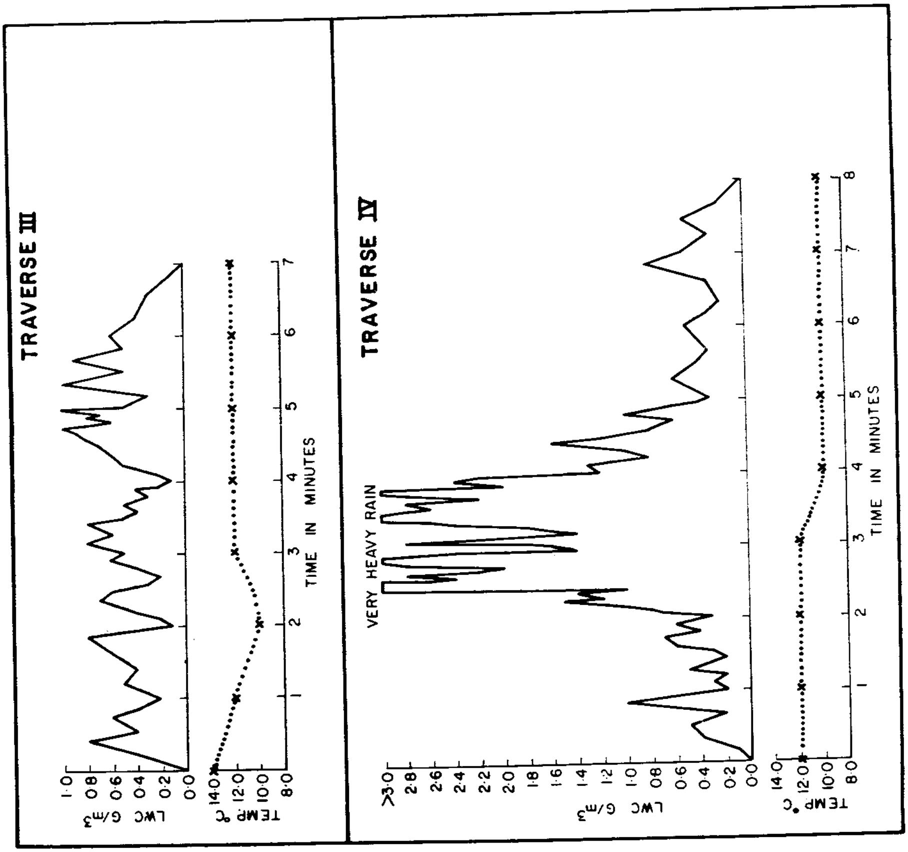

FIG. 5b. As in Fig. 5a except for traverses 3 and 4.

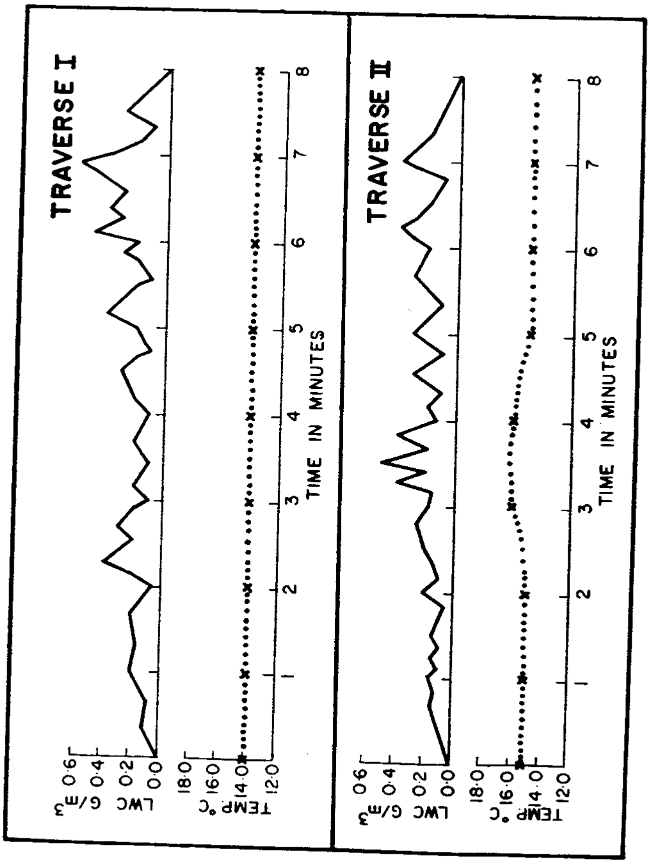

FIG. 6a. Recordings of LWC and temperature in cloud complex on 4 August 1973 (traverses 1 and 2).

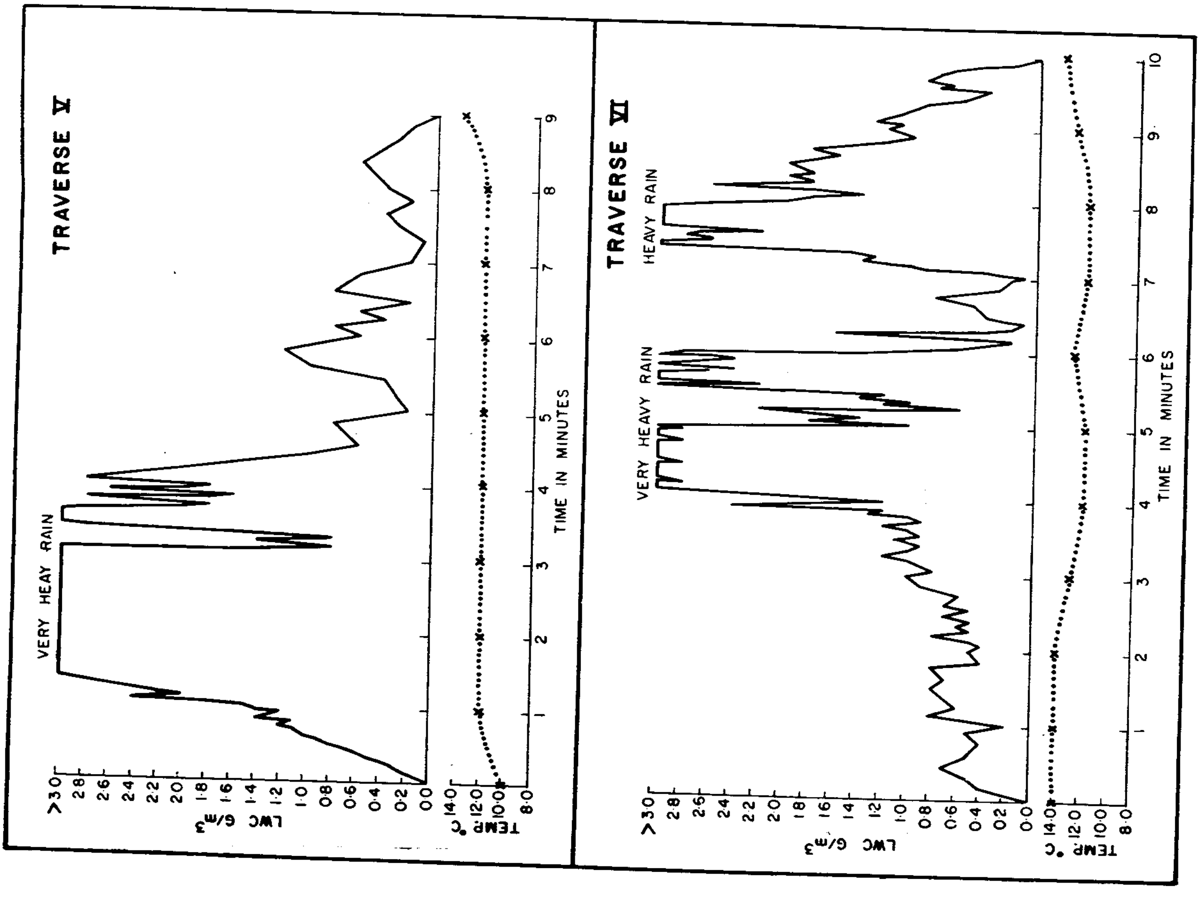

FIG. 5c. As in Fig. 5a except for traverses 5 and 6.

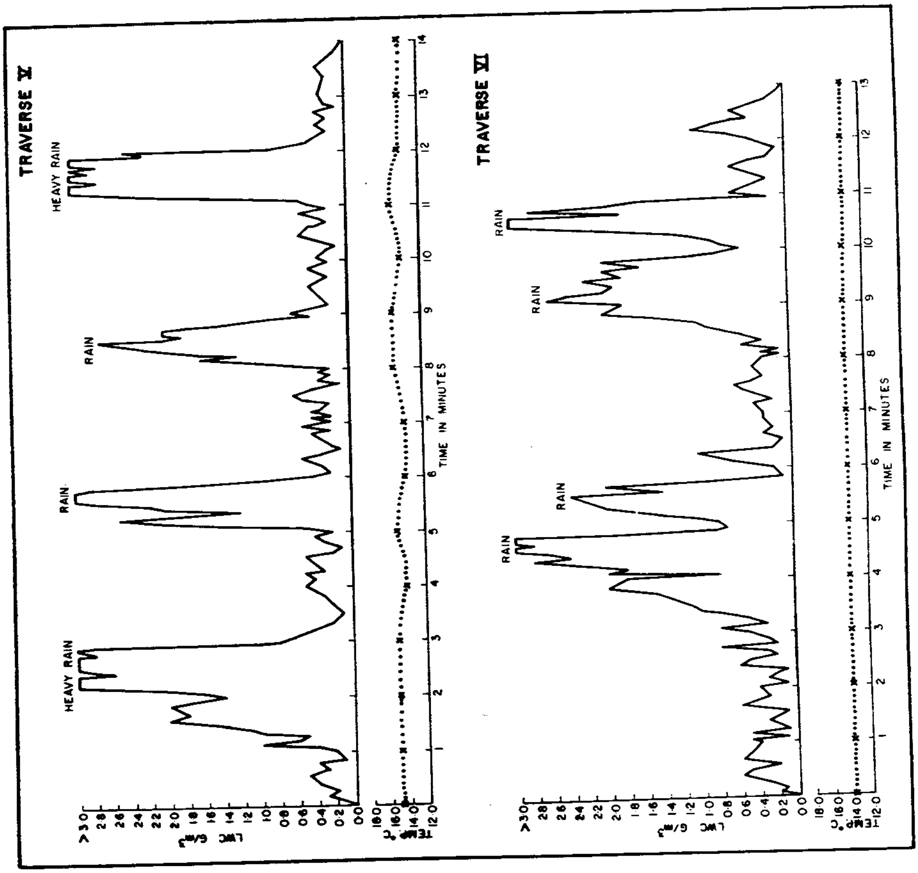

FIG. 6c. As in Fig. 6a except for traverses 5 and 6.

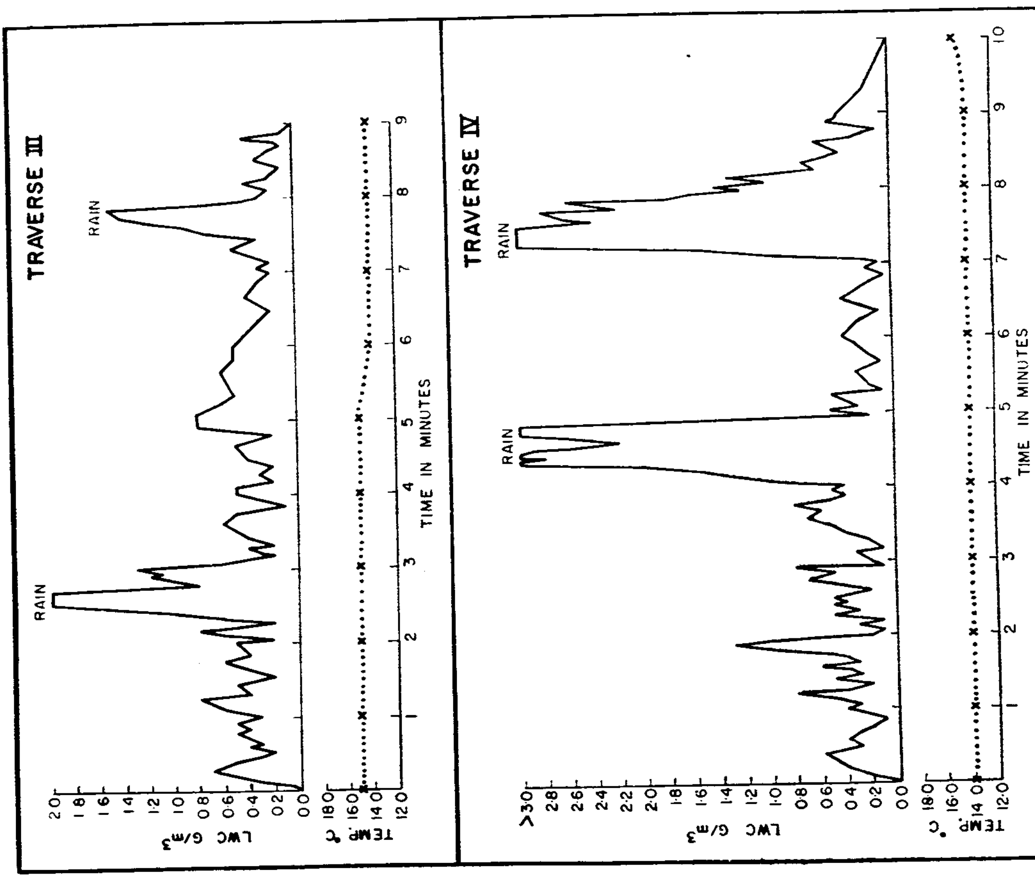

FIG. 6b. As in Fig. 6a except for traverses 3 and 4.

REFERENCES

Clark, R. S., P. St. Amand, and T. L. Wright, 1972: Modification of warm convective clouds by hygroscopic and hydrophillic materials. *Preprints Conf. Weather Modification*, Santa Barbara, Calif., Amer. Meteor. Soc., 179–181.

Hall, D. C., R. S. Clark, T. L. Wright, H. E. Cromin and R. W. Evert, 1971: A study of maritime cumulus modification. Phase II-Project Gulf Q. NWC Tech. Rept. TP 5145, Naval Weapons Center, Calif. 70 pp.

Krishna, K., R. K. Kapoor, A. S. Ramachandra Murty, A. M. Selvam, K. K. Kanuga, L. T. Khemani, B. K. Mukherjee, S. K. Paul, R. Vijayakumar and Bh. V. Ramana Murty, 1974: A randomized cloud seeding experiment in the Deccan Plateau, India—Preliminary results. *J. Wea. Modification*, **6**, 266–277.

Simpson, J., and A. S. Dennis, 1972: Cumulus clouds and their modification. NOAA Tech. Memo. ERL-OD-14, Boulder, Colo., 148 pp.

Takeuchi, D. M., 1972: Consideration of microphysical variations upon the potential cumulus modification. *Preprints Conf. Weather Modification*, Santa Barbara, Calif., Amer. Meteor. Soc., 166–170.

Vulfson, N. I., A. G. Laktionov and V. I. Skatsky, 1973: Cumuli structure of various stages of development. *J. Appl. Meteor.*, **12**, 664–670.