RADAR EVALUATION OF THE EFFECT OF SALT SEEDING ON WARM MARITIME CUMULUS CLOUDS

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1. INTRODUCTION

The latent heat released due to massive salt seeding in the maritime atmosphere was experimentally studied (Woodcock and Spencer, 1967). From the experiments conducted during the summer monsoon of 1973, within 50 Km off the coast at Bombay (18^0 15' N, 72^0 49' E, 11 m a.s.l.), the effect of massive salt seeding on warm maritime cumulus clouds was investigated using radar observations (Krishna et al., 1976). The results showed increases in areal echo coverage, in vertical extent and also in echo intensity following the release of salt particles into the clouds. Since the data sample of the above study is very small, further experiments were undertaken in the same region during the summer monsoon of 1974. In addition to the radar observations, in-cloud electrical and microphysical observations were made during these experiments. The results of the study are presented below.

2. EXPERIMENTS

The details of the salt seeding experiment were described elsewhere (Krishna et al., 1974). A brief summary of the important points are given below.

The seeding material used was the pulverized mixture of salt and soapstone in the ratio of 10:1 with the particle mode diameter of 10 microns. Repeated aircraft penetrations were made through isolated cumulus clouds at a single level, a few hundred meters above the cloud base. The traverses made through each cloud varied from 7 to 10. Seeding material was released through a special gadget fitted to a Douglas DC-3 aircraft at the rate of 20 - 30 Kg per 3 Km in the entire flight path of the seeded traverses. Seeding material was released commencing from the second or subsequent traverse. Cloud physical and electrical measurements were made in two of the four seeded clouds. The details of the aircraft instruments used for the measurements were described elsewhere (Selvam et al., 1976; Ramachandra Murty et al., 1976).

An X-band 3 cm weather radar (Bharat Electronics Ltd., India) of the meteorological office at Santacruz Airport, Bombay was used to monitor the areal echo coverage, vertical extent and echo intensity of the clouds. An S-band surveillance radar (ASR-3, CA-3100) of the Air Traffic Control at the airport was used for piloting the aircraft seeding operations. The coast line and the radar location are shown in Figure 1.

3. RESULTS

The experiment was conducted between 22 to 28 September 1974. Four isolated cumulus clouds present within 120 Km off the coast at Bombay were selected for seeding. For each of the seeded clouds (targets) a neighbouring cloud simultaneously present was left unseeded and considered as control for the seeded cloud.

The details of the seeding and radar data of the target and control clouds are given in Table 1. The time variations of the areal and vertical extents and of the echo intensity of two pairs of target-control clouds (Cloud 1A and 1B; Cloud 4A and 4B) are shown in Figures 2 and 4 as sample data. A series of radar PPI photographs for one pair of target-control clouds (Cloud 1A and 1B), starting from the commencement of seeding are shown in Figure 3.

4. DISCUSSION

Of the four target clouds, two (Cloud 2A and Cloud 4A) did not produce radar echo initially, i.e., during the not-seeded traverses (Table 1). One of them (Cloud 2A) produced echo in 13 minutes after the commencement of seeding. The other (Cloud 4A) produced echo in 22 minutes (Figure 4). Thereafter, these two showed remarkable increases in their areal and vertical extents as well as in their intensity. Of the remaining two target clouds there was no change in the areal echo coverage in one (Cloud 1A) and there was a gradual decay in the other (Cloud 3A) following seeding. However, the height of echo top showed increase in both these cases also following seeding.

The details of the time variations noticed in the case of Cloud 1A may be seen from Figure 2. The areal echo coverage initially showed a steep decreasing trend, but 12 minutes after the commencement of seeding the value remained constant. It increased again and reached a maximum in 44 minutes after the commencement of seeding when the echo intensity was also strongest. The echo top which initially showed a decreasing trend, started increasing from the time of commencement of seeding and showed two maxima at 8 and 40 minutes after the commencement of the seeding.

The echoes from all the target clouds lasted longer than those from the control clouds (Column 9 of Table 1).

The echoes from the control clouds did not show the features exhibited by those from the target clouds and dissipated in shorter durations.

Electrical and microphysical observations were made in two target cloud cases (Cloud 1A and Coud 2A). The data are given in Table 2. Measurements were made along all the traverses but seeding commenced during the third traverse. Because all the sensors of the aircraft were forward of the location of release of the seeding material, measurements made during the first seeding traverse as well as those made during the non-seeded traverses were considered to represent natural conditions. Thus, the measurements made during the first three travereses through the two target clouds were taken to represent natural conditions.

The vertical electric field in both the cloud cases showed sign reversal from the initial negative to positive and intensified before the onset of rain. The in-cloud temperatures recorded an increase of 0.8°C following seeding. The median volume diameter of the cloud droplets showed increases up to 29 percent following seeding. The cloud liquid water content was measured by a JW-hot wire meter. It was also computed from the measured cloud droplet size distributions. The values of both the computed and the measured cloud liquid water content showed increases up to 44 percent and 86 percent respectively foll ing seeding.

5. CONCLUSIONS

A study of the radar observations, in-cloud electrical and microphysical observations made in maritime warm cumulus clouds seeded with hygrosocopic particles suggested the following:

i) Out of the four seeded cloud cases, two showed remarkable increases in areal extent. In the remaining two cases, the areal echo coverage remained nearly constant in one and decreased in the other. The echo intensity increased in three cases and decreased in one case. The height of the echo top increased in all the four cases. Such features were not noticed in the echoes from the control clouds.

ii) The in-cloud temperature showed an increase of 0.8°C following seeding.

iii) The median volume diameter of the cloud droplets and the cloud liquid water content showed increases in the subsequent travereses compared to the initial traverses made in the seeded clouds.

iv) The vertical electric field in the cloud, a few hundred meters above the cloud base, was initially negative and showed sign reversal before the onset of precipitation in seeded clouds. The sign reversal may be attributed to the transport of positive charges from the higher levels to the lower levels inside the cloud by the precipitation particles which are generally formed at the higher levels in the strong updraft regions. The electric field also showed intensification following seeding which could be due to the increased convective activity.

The above results help to contribute to the physical understanding of the effect of salt seeding on warm maritime cumulus clouds. However, it should be recognized that the study has the severe limitation of the lack of in-cloud observations in control clouds and the small size of the data sample.

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Table 1

Details of seeding and radar data of seeded (target) and not-seeded (control) clouds

	Cloud 1A (target)	Cloud 1B (control)	Cloud 2A (target)	Cloud 2B (control)	Cloud 3A (target)	Cloud 3B (control)	Cloud 4A (target)	Cloud 4B (control)
1. Azimuth (degrees)	262	268	227	249	229	247	249	319
2. Range (km)	37	38	43	29	113	126	77	83
3. Seeding period (hrs IST)	1443-1514	-	1530-1600	-	1546-1655	-	1514-1545	-
4. Quantity of salt used (kg)	900	-	900	-	1400	-	900	-
5. Total traverses made	7	-	7	-	9	-	10	-
6. Seeding traverses	3-7	-	3-7	-	2-9	-	3-8	-
7. Areal echo coverage (sq.km)								
Initial traverse	9.3	3.8	0.0	0.6	72.2	66.7	0.0	5.3
At commencement of seeding	5.4	0.5	0.0	0.0	63.5	57.4	0.0	2.8
At termination of seeding	4.0	0.0	5.9	0.0	0.0	0.0	6.7	0.0
Maximum following seeding	5.4	3.8	18.9	0.6	55.6	66.7	9.5	5.3
8. Height of echo top (km)								
Initial	1.8	1.8	0.0	1.1	NA	6.0	0.0	3.0
At commencement of seeding	2.0	NA	0.0	NA	5.4	NA	0.0	3.2
At termination of seeding	2.0	NA	1.5	NA	0.0	NA	NA	0.0
Maximum following seeding	2.5	1.8	2.2	1.1	5.8	6.0	3.2	3.2
9. Total echo duration (minutes)	88	13	80	10	62	32	34	11

Note : NA = Data Not Available.

Table 2

In-cloud electrical and microphysical data

	Traverse	Vertical Electric Field ($V\,m^{-1}$) Sign	Max. Positive	Min. Positive	Max. Negative	Min. Negative	Cloud droplet median volume diameter μm	Cloud liquid water content ($gm\,m^{-3}$) Computed	Measured Max.	Measured Min.	In-cloud temperature °C	Visual observation
Cloud IA	I	-			99.2	17.7	16.96	0.215	0.9	0.1	19.2	No rain
	II	-			99.2	14.2	16.34	0.208	1.0	0.1	19.6	No rain
	III	-			99.2	35.2	17.06	0.203	1.0	0.1	18.2	No rain
	IV	-			105,6	24.8	18.50	0.299	1.3	0.3	18.0	Rain
	V	+	135.0	45.0			18.24	0.267	1.0	0.1	18.2	Rain
	VI	+	225.0	67.5			19.83	0.256	0.8	0.1	18.8	Rain
	VII	+	225.0	180.0			19.90	0.293	0.7	0.1	20.0	No rain
Cloud 2A	I	-			99.2	16.0	N.A.	N.A.	0.9	0.2	18.2	No rain
	II	-			112.5	7.1	N.A.	N.A.	0.9	0.2	17.8	No rain
	III	-			225.0	45.0	20.46	0.475	1.4	0.4	18.0	No rain
	IV	-			22.5	0.0	N.A.	N.A.	0.8	0.4	17.8	No rain
	V	+	225.0	157.5			26.30	0.853	1.0	0.1	19.0	No rain
	VI	-			96.6	9.6	24.54	0.729	1.0	0.1	18.0	Rain
	VII	+	90.0	22.5			N.A.	N.A.	1.3	0.1	18.4	Rain

Note : N.A. : Data Not Available
Traverses I, II and III represent natural conditions (see text for explanation).

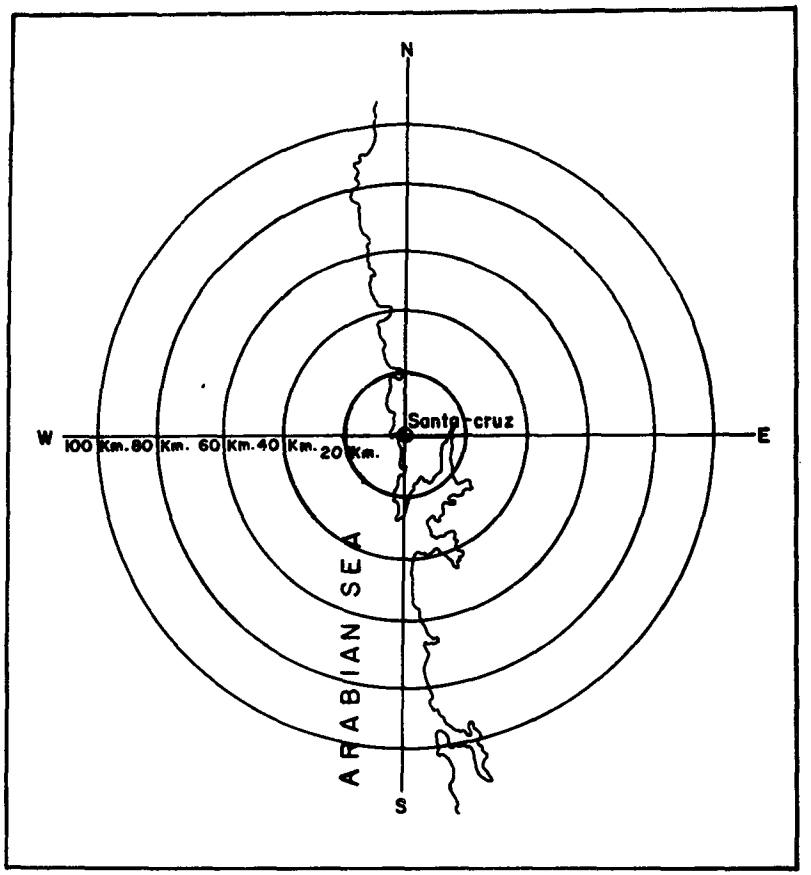

Figure 1. Location of the radar and the area of the experiment.

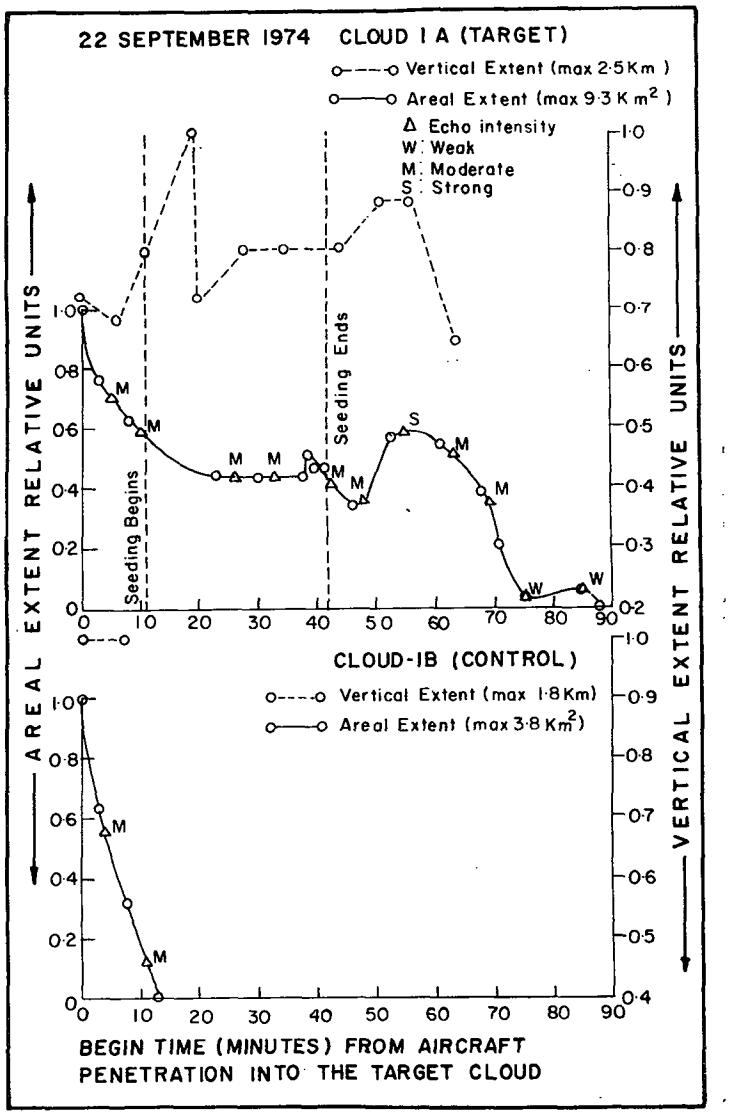

Figure 2. Time variations of the areal and vertical extents and the echo intensity for Cloud 1A and Cloud 1B.

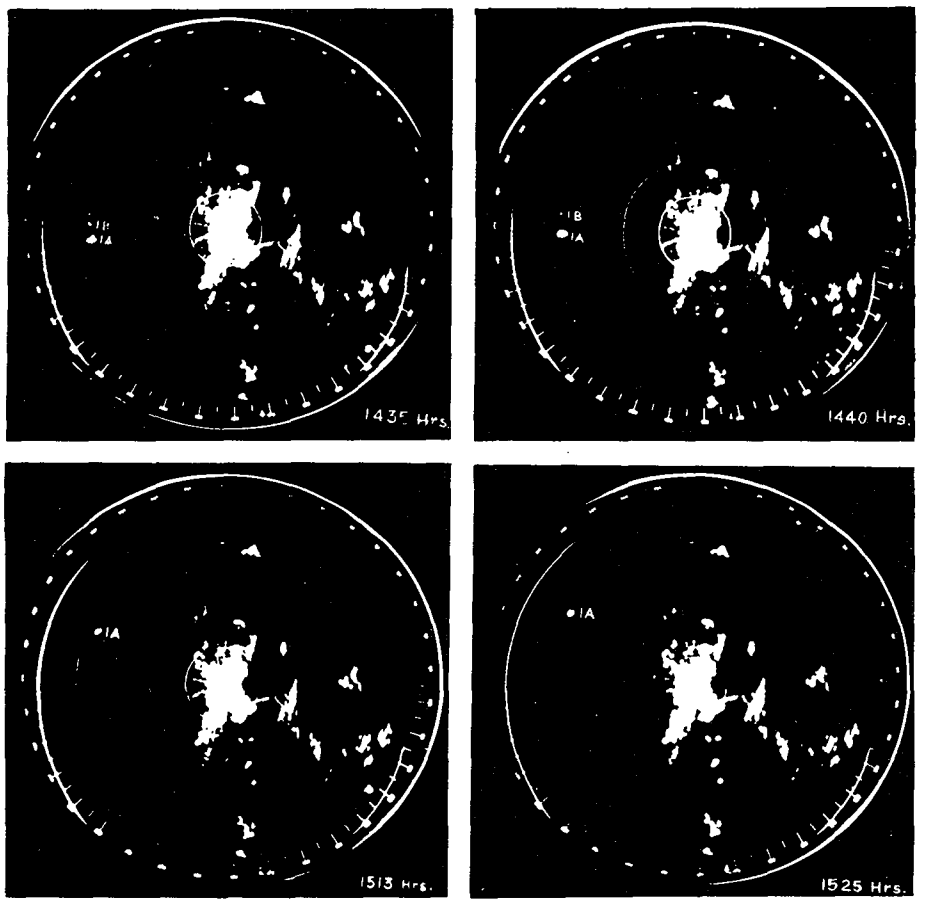

Figure 3. Radar PPI Photographs for Cloud 1A and Cloud 1B.

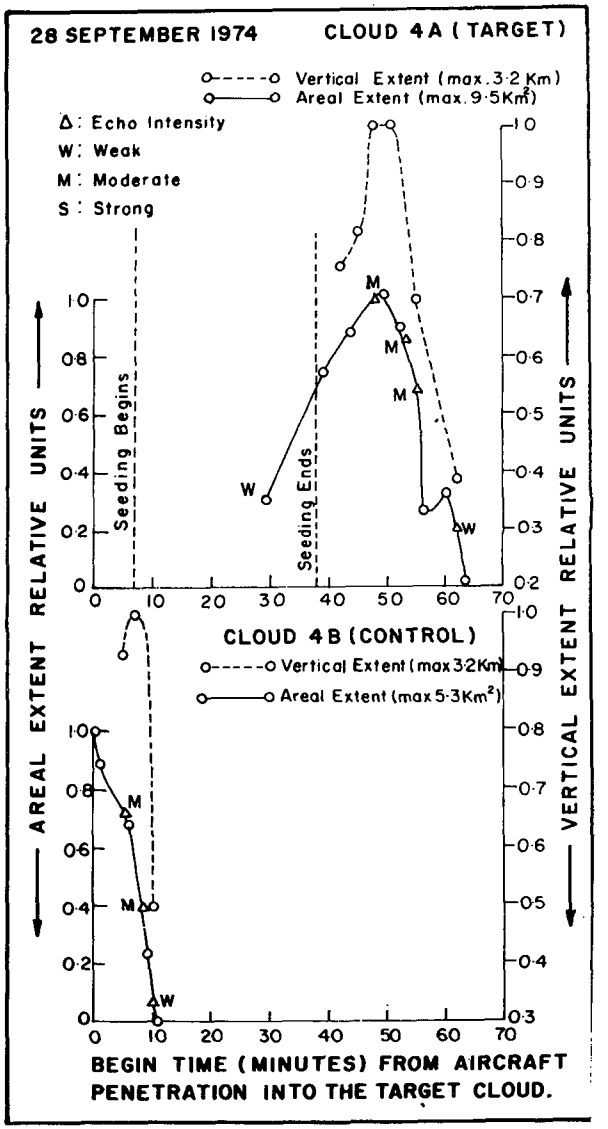

Figure 4. Same as Figure 2 for Cloud 4A and Cloud 4B.