RESULTS OF PRECIPITATION ENHANCEMENT PROJECT BY SURFACE-SEEDING DURING WINTER AT DELHI

R.N. Chatterjee, R.K. Kapoor, Gurmukh Singh
and
Bh. V. Ramana Murty

Indian Institute of Tropical Meteorology
Poona 5, India

ABSTRACT

A series of surface-seeding experiments by silver iodide smoke undertaken at Delhi during successive winter seasons since 1968 came to a close in 1975. Randomization in the seeding programme was observed from the third season. Evaluation was done on the basis of 24 hours rainfall data obtained from a close raingauge network within 25 km. It was also done on the basis of observations made with a 3.2 cm weather radar.

The result was expressed (i) pair-wise and (ii) season-wise. Pair-wise analysis indicated inconclusive result both by raingauge and radar. According to season-wise analysis, result was positive in five out of the seven seasons by raingauge. It was positive in three seasons by radar. The results are not statistically significant.

I INTRODUCTION

Results relating to a complete series of surface-seeding experiments using warm technique conducted at different stations in India during 1957-66 were published (Roy et al., 1961; Roy et al., 1964; Biswas et al., 1967; Ramana Murty and Biswas., 1968; Chatterjee et al., 1969). A new series of surface-seeding experiments, using cold technique, under the precipitation enhancement project was undertaken at Delhi (28^{0} 35'N, 77^{0} 12'E and 217 m A.M.S.L.) in 1968. This series, also concluded after 1974-75, winter season. The results of the first five seasons were published (Kapoor et a., 1974). In this paper, the results of the complete series, which is of 7 winter seasons, are presented.

2. EXPERIMENT

The design of the experiment, the equipment used and the methods of analysis were described in the earlier paper. The important aspects are outlined below.

The silver iodide generator used was of Australian type (Adderley and Twomey, 1958). The seeding solution used in the first four seasons was prepared by dissolving silver iodide in acetone with sodium iodide as solubilizer. The solution used in the subsequent seasons contained ammonium iodide as

solubilizer in place of sodium iodide and was prepared after St. Amand et al., (1971).

The amount of silver iodide vaporized in the generator, on a seeded day, was about 1.4 kg. The total amount of silver iodide vaporized per season varied between 6 and 17 kg.

The site of operation was the first floor terrace of the laboratory building situated on a ridge near the National Physical Laboratory, New Delhi.

The period of seeding in each year was the four winter months, December to March. The seed generator was operated on each seeded day for about four hours during the hot part of the day i.e. between 1100 and 1600 hrs. IST.

Active weather development leading to rain over the area is more commonly associated with cold fronts, often occluded, rather than the warm fronts. The freezing level during the winter season at the station is about 3 km.

The efficiency of nuclei production from the generator used in the experiment and the resulting concentration of the diffused material at various levels in the free air downwind have not been measured. In the absence of such measurements estimates have been made, following Sutton (1953), for a general meteorological situation assuming a certain plausible value of the output from the generator. If the yield of ice-forming nuclei produced by vaporizing one gram of silver iodide is taken as 10^{13} at $-15^{o}C$, the concentration of these nuclei at this temperature at a distance of 25 km downwind of the site of operation, under overcast conditions and for wind speed of 5 m sec^{-1}, would be $129.3 \times 10^{3}/m^{3}$. Assuming a deactivation factor of two orders of magnitude the effective concentration would be reduced to $1293/m^{3}$.

The target and control sectors, on each seedable day, were determined on the basis of mean wind for that day in the column from 0.3 to 2.1 km. The target area had been considered to extend from a short distance downwind up to 25 km. The area of each of the sectors is about 490 sq. km.

3. SEEDABLE DAYS, SEEDING DAYS AND THEIR DISTRIBUTION

(i) Seedable days

All days associated with low clouds of 3 octa or more have been considered as seedable days from which seeding days have been selected.

(ii) Seeding days

The selection of seeding days, from amongst seedable days, has been done on randomized basis from the third season. The procedure adopted in this regard was as follows. Successive seedable days were considered in pairs and selection of the seeding day was made from each such pair on a random basis and seeding was done on that day. The remaining day in that pair was not-seeded and left for control. In the first two seasons, however, all seedable days in the earlier part of each season were seeded while those in the later part were not-seeded.

(iii) Distribution of seedable days

The number of seedable days in each season, classified under the two categories seeded and not-seeded is presented in Table 1. The figures in brackets denote the number of seedable days when rain was recorded in one or both of the sectors, target and control, considered in the study. Out of the total number of 116 seedable days during seven seasons, seeding was done on 60 days while the reamining 56 days were left not-seeded. Rain was recorded in one or both sectors, only on 22 and 26 days amongst seeded and not-seeded days respectively.

4. SOURCE OF DATA FOR EVALUATION

The values of rainfall reported in the target and control sectors on the seedable days by a network of 24 raingauges (Figure 1), situated within 25 km around the seeding site, were used for evaluation.

Also, radar data collected for the period commencing from one hour after the start of the seeding operation and extending up to 2 hours after the cessation of seeding had been made use of for evaluation. The data collected relate to pictures on PPI taken at hourly intervals between 1000-1700 IST and depicting progressive developments in the areal echo coverage within 50 km. They also relate to the heights of the echoes which were measured partly, on the spot, from displays on RHI and partly from photographs taken on RHI/REI. The radar used was NMD-451A, operating on a 3.2 cm.

5. METHOD OF ANALYSIS

The rainfall data were analysed by comparing the 24-hours rainfall values in target (T) and control (C) sectors, relative to the two groups of seedable days - one seeded and the other not-seeded. The radar data were analyzed by comparing (i) radar areal echo coverage and also (ii) radar echo volume in the target and control sectors extending up to 50 km from the station, on seeded and not-seeded days. The radar echo volume is represented by the product value of areal echo coverage and mean echo height.

A value of the double ratio exceeding unity of T/C for the seeded and not-seeded days is taken as suggestive of a positive result. If it is less than unity, the result is negative. If it is unity or indeterminate, the result is inconclusive.

6. RESULTS

The data were evaluated in two ways: (i) pair-wise and (ii) season-wise

TABLE 1

DISTRIBUTION OF SEEDABLE DAYS

Season	Seeded	Not-seeded
1968-69	7 (2)	5 (3)
1969-70	13 (6)	10 (6)
1970-71	6 (3)	6 (2)
1971-72	11 (6)	11 (6)
1972-73	10 (3)	9 (3)
1973-74	4 (0)	5 (2)
1974-75	9 (2)	10 (4)
TOTAL	60 (22)	56 (26)

FIGURE 1

LOCATION OF RAINGAUGES AROUND DELHI

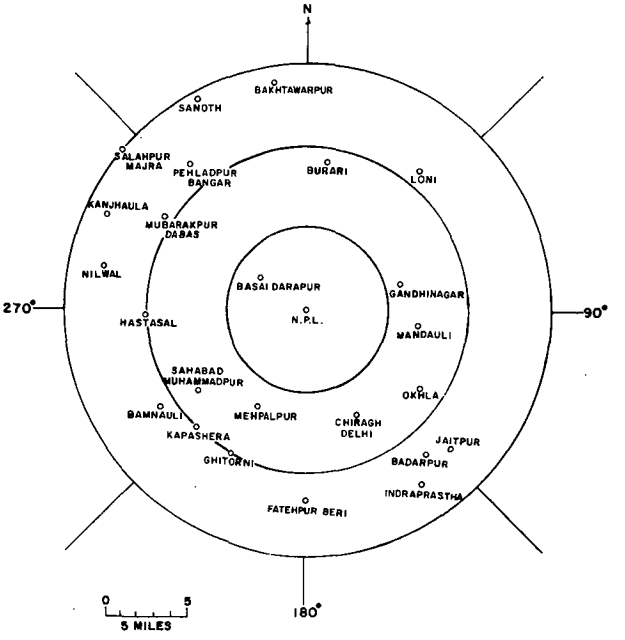

FIG. 1 LOCATION OF RAINGAUGES AROUND DELHI

(i) Pair-wise

The experiment was conducted on random basis in 5 successive seasons commencing from 1970-71. Rainfall data were available for 39 pairs of days and radar data for 38 pairs. The results are given in Table 2. Of the 39 pairs by raingauge, the value of the double ratio was indeterminate on as many as 33 pairs. Of the 38 pairs by radar, the corresponding number of indeterminates was 24.

The majority of the total number of pairs showed only inconclusive result. This feature is due to the frequent non-occurrence of rain (areal echo coverage) in the target/control sectors on one or both of the days in the pairs.

(ii) Season-wise

The data of all the 7 seasons were considered. The results are given in Table 3.

(a) Raingauge

The value of the double ratio was positive in 5 seasons, negative and inconclusive in one season each (Table 3a). The positive value varied upward of 33%. The overall value was positive and was 59%. Application of Mann-Whitney test indicated that the result is not statistically significant.

(b) Radar

(i) Areal echo coverage

The value of the double ratio was positive in four seasons and negative in the remaining three (Table 3B). The positive value varied upward of 11%. The negative value was as high as 91%. The overall value was positive and was 48%.

(ii) Echo volume

The value of double ratio was positive in three seasons and negative in the remaining four (Table 3C). The positive value varied upward of 37%. The negative value was as high as 94%. The overall value was positive and was 111%.

Application of Mann-Whitney test indicated that the results in both the cases are not statistically significant.

7. CONCLUSION

The results of the cold seeding experiment conducted at Delhi over a

TABLE 2

RESULTS, PAIR-WISE

	Raingauge	Radar	
		Areal coverage	Volume coverage
Total No. of pairs	39	38	32
No. of pairs showing positive result	3	7	2
No. of pairs showing negative result	3	7	6
No. of pairs showing inconclusive result	33	24	24

TABLE 3a

RESULTS, SEASON-WISE

Figures denote total rainfall in mm per station in target (T) and control (C) sectors

Season	Seeded			Not-seeded			Percentage change
	ΣT	ΣC	ΣT/ ΣC	ΣT	ΣC	ΣT/ΣC	
1968-69	4.6	2.8	1.64	10.8	12.7	0.85	+ 93
69-70	57.5	40.7	1.41	58.5	57.1	1.02	+ 38
70-71	0.9	0.8	1.13	9.4	7.3	1.29	- 13
71-72	24.1	3.2	7.53	9.8	15.3	0.64	+ 1076
72-73	9.0	16.3	0.55	3.0	9.1	0.33	+ 68
73-74	0.0	0.0	Ind	5.3	2.9	1.83	Inconclusive
74-75	12.2	7.0	1.74	11.8	9.0	1.31	+ 33
Total	108.3	70.8	1.53	108.6	113.4	0.96	+ 59

TABLE 3b

Figures denote total areal coverage in arbitrary units

Season	Seeded			Not-seeded			Percentage change
	ΣT	ΣC	$\Sigma T/\Sigma C$	T	C	$\Sigma T/\Sigma C$	
1968-69	1079	604	1.79	516	624	0.83	+ 116
69-70	576	516	1.12	4184	4835	0.87	+ 29
70-71	188	16	11.75	202	19	10.63	+ 11
71-72	520	659	0.79	298	141	2.11	- 63
72-73	221	212	1.04	384	273	1.41	- 26
73-74	102	114	0.89	310	33	9.39	- 91
74-75	1047	829	1.26	1132	2281	0.50	+ 152
Total	3733	2950	1.27	7026	8206	0.86	+ 48

TABLE 3c

Figures denote volume coverage in arbitrary units

Season	Seeded			Not-seeded			Percentage change
	ΣT	ΣC	$\frac{\Sigma T}{\Sigma C}$	ΣT	ΣC	$\frac{\Sigma T}{\Sigma C}$	
1968-69	6832	3588	1.90	3413	4930	0.69	+ 175
69-70	2735	3206	0.85	21603	34980	0.62	+ 37
70-71	552	50	11.04	1448	114	12.70	- 13
71-72	2218	2627	0.84	848	308	2.75	- 69
72-73	809	1236	0.65	2130	1375	1.55	- 58
73-74	576	510	1.13	1457	81	17.99	- 94
74-75	6450	2273	2.84	8162	13426	0.61	+ 366
Total	20172	13490	1.50	39061	55214	0.71	+ 111

period of 7 successive winter seasons were inconclusive. Surface seeding using cold technique in the plains of north India may not be promising. For further attempts of surface-seeding it may be desirable that the experiments are undertaken in the hill regions.

REFERENCES

Adderley, E.E., and S. Twomey, 1958. An experiment on artificial stimulation of precipitation in the snowy mountain regions of Australia. Tellus, 10 275-280.

Biswas, K. R., R. K. Kapoor, K. K. Kanuga, and Bh. V. Ramana Murty, 1967. Cloud seeding experiments using common salt. J. of Appl. Meteor., 6, 914-923.

Chatterjee, R. N., K. R. Biswas, and Bh. V. Ramana Murty, 1969. Result of cloud seeding experiment at Delhi as assessed by radar. Indian J. Meteor. Geophysics, 20, 11-16.

Kapoor, R. K., R. N. Chatterjee, K. K. Kanuga, S. K. Paul and Bh. V. Ramana Murty, 1974. Ground-based cloud seeding experiment at Delhi during winter. Proceedings of the WMO/IAMAP Scientific Conference on Weather Modification. Tashkent, 1-7, October 1973. WMO-No. 399, 149-158.

Ramana Murty, Bh., V., and K. R. Biswas, 1968. Weather modification in India. J. Meteor. Soc. Japan, 46, 160-165.

Roy, A. K., Bh. V. Ramana Murty, R. C. Srivastava, and L. T. Khemani, 1961, Cloud seeding trials at Delhi during monsoon months, July to September (1957-1959). Indian J. Meteor. Geophysics, 12, 401-412.

Roy, A. K., Bh. V. Ramana Murty, K. R. Biswas and L. T. Khemani, 1964. Cloud seeding experiments around Delhi using aircraft. J. Sci. Industrial Research, 23, 326-333.

St. Amand, P., W. G. Finnegan, L. Burkhardt, 1971. Understanding of the use of simple and complex ice nuclei generated from pyrotechnics and acetone burners. J. Weather Modification, Vol. 3, 31-48.

Sutton, O. G., 1953. Micrometeorology. New York, McGraw-Hill Book Co., Inc., 273-277.