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A mock Cloud Seeding Experiment at Delhi

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ABSTRACT. The results of what may be called "A mock seeding experiment" at Delhi for a period of 12 years are presented. On the basis of comparisons of target and control sector rainfalls during the period of the mock trial with those during actual seeding experiments at Delhi during five monsoon seasons, 1957 to 1961, certain interesting conclusions are reached about the significance of the seeding results obtained so far.

1. Introduction

A programme of rain making experiments, based on attempted cloud seeding from ground, has been in progress at Delhi since 1957. Full details about the experiments and the results obtained during the first three years have been reported by Roy *et al.* (1961). Keeping in view the very considerable natural variations in rainfall distribution and consequent uncertainties in evaluation of the results of the seeding trials, the authors felt that it was necessary to continue the experiments for a number of years more, before a dependable and statistically significant conclusion could be reached. Since then the results of trials for two more years (1960 and 1961) have become available.

In giving the results to-date of the Delhi seeding trials, this note seeks to suggest a plan for testing the significance of the results obtained so far, on the basis of comparisons of rainfall data relative to a certain past period of an imaginary or what may be called "Mock seeding experiment" (Mason 1955) at the same site.

2. A brief account of Delhi rain making experiment

Reviewing briefly the design and the method of evaluation of the Delhi experiments, it is seen that the seeding trials are made during the monsoon season, July to September, based on the method of dispersing in the air hygroscopic nuclei of appropriate sizes produced by ground generators. Days suitable for seeding are fixed on the basis of advice obtained from the India Meteorological Department in regard to upper winds and probable development of clouds and weather over and around Delhi. Days on which development of clouds suitable for seeding is forecast and also wind at 1·5 km level is from either SE or NW are classified as "seedable". Of these, seeding actually is done on certain days only and the rest are left "unseeded" to provide the essential control data, as decided by a pre-selected series of random numbers. The target sector for days of SE'ly wind is the 90° quadrant of radius 25 km to the northwest of the seeding site, while the control sector is the similar quadrant to the southeast. For days on which wind is from northwest, the target and control sectors get interchanged.

In evaluating the trials, the criterion used has been as follows. The ratio T/C of rain per station in the target sector to that in the control sector is found for seeded and unseeded days, separately for each month. If the ratio T/C for the seeded

TABLE 1

Results of seeding experiment at Delhi

	Number of		
	Positive	Negative	Indeterminate
1957	4	0	2
1958	4	1	1
1959	4	1	1
1960	3	0	3
1961	5	1	0

days is higher than that for unseeded days, the result of the experiment is treated as positive, *i.e.*, seeding is considered to have caused some increase in the target area rainfall and, similarly, a lower ratio value is taken as indicative of a negative result. If the two ratios happen to be equal, or if one or both of these take on the indeterminate form 0/0, the result is considered inconclusive.

To get an idea of the net effect of seeding over a certain specified period, the cumulative ratios $\Sigma T/\Sigma C$ for the seeded and unseeded days are compared at successive monthly stages of the trials. A continued tendency of the cumulative ratio values for the seeded period remaining higher than those relative to non-seeded period is taken as a further indication of the consistency of the results of seeding operations.

Seeding experiment results for the period 1957—1959 have already been given in the paper referred to. The results to date for the entire period of 5 years, 1957 to 1961, are shown in Table 1 and in Figs. 1(a) and 1(b) of this note.

3. Description and results of the mock seeding experiment

The principle followed in the designing of the "mock" seeding experiment has been essentially the same as in the case of actual seeding trials conducted at Delhi. However, considering that the number of raingauge stations within 25 km around Delhi to provide for essential historical data of rainfall were quite inadequate—a close network of raingauges within 25 km around the station was set up only recently in connection with the seeding trials at Delhi—it was necessary to extend the mock experiment area to a radius of about 100 km. Daily rainfall data during monsoon months, July to September, for stations in this area for the 12-year period, 1943—1955 (excluding 1947), and corresponding upper wind data for Delhi were tabulated.

TABLE 2

Results of mock seeding experiment

	Number of		
	Positive	Negative	Indeterminate
1943	4	0	2
1944	1	4	1
1945	2	4	0
1946	1	4	1
1948	4	2	0
1949	4	2	0
1950	2	3	1
1951	4	1	1
1952	1	3	2
1953	2	3	1
1954	3	2	1
1955	4	1	1

There being no question of a forecast of probable cloud development over the area, in the case of the mock experiment, all days with wind at 1·5 km from SE or NW were taken as seedable days. These were then classified under two groups, "seedable seeded" and "seedable not-seeded" on the basis of pre-selected series of random numbers. The associated rainfall data for the two groups of days, with winds from SE and NW, were then analysed in the same way as data relative to actual seeding experiments. The results of the mock seeding experiment are presented

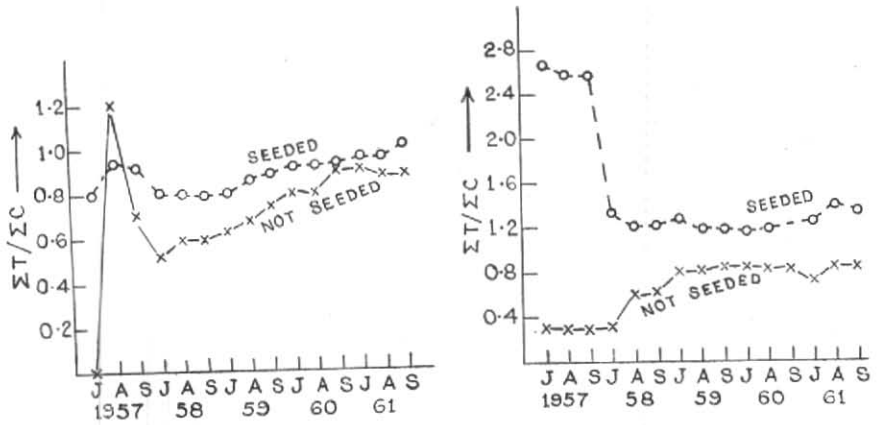

Fig. 1(a) Fig. 1(b)

Fig. 1. Ratio of cumulative values of rainfall in target and control sectors at various stages of trials—(a) Southeasterly wind and (b) Northwesterly wind

in Table 2 and Figs. 2(a) and 2(b). These correspond to Table 1 and Figs. 1(a) and 1(b) of the actual experiments.

The partial sums of the number of positives, negatives and indeterminates at various stages of operation of the actual as well as mock experiments are shown in Table 3.

4. Discussion

Ignoring the indeterminates, we see from Tables 1 and 2 that the number of positives and negatives are respectively 20 and 3, and 32 and 29, out of a total of 23 and 61 'unit' trials giving definite results in the case of the actual and mock experiments. It is seen that the number of positives and of negatives are more or less evenly balanced in the case of mock experiment, this being true also at different stages of the trial shown in Table 3. The "a priori" probability of the result being positive or negative being equal, this is what one would also expect on general considerations.

Now, considering the results of the actual seeding trials as presented in Table 1, one sees that the probability of obtaining, by pure chance, more than 16 positives at the conclusion of 23 valid trials, is less than 3 per cent. Also, the probability of obtaining the observed result is exceedingly small, the chances of obtaining 20 or more positives being vanishingly small (about 2^{-12}). Further, the observed degree of unbalance between positives and negatives at each stage of the actual seeding trials is much more than what may be expected to have occurred naturally.

Considerations as above would give a very strong support to the conclusion that seeding has helped an augmentation of rainfall in the target sector. However, no quantitative estimate of the increase in rainfall is possible on the basis of the above data.

With a view to attempting a rough quantitative estimate of the results of seeding, we may now compare the general trends of the cumulative ratio values ($\Sigma T/\Sigma C$) of target to control sector rainfall during seeded and not-seeded periods, as plotted in Figs. 1 and 2. In the case of actual seeding trials corresponding to days of SE'ly winds, it is seen that the $\Sigma T/\Sigma C$ values for the seeded periods lie, in general, above those for not-seeded periods, although the difference between the two has decreased with the progress of the trials. The observed difference would lead one to the tentative conclusion that seeding has helped some

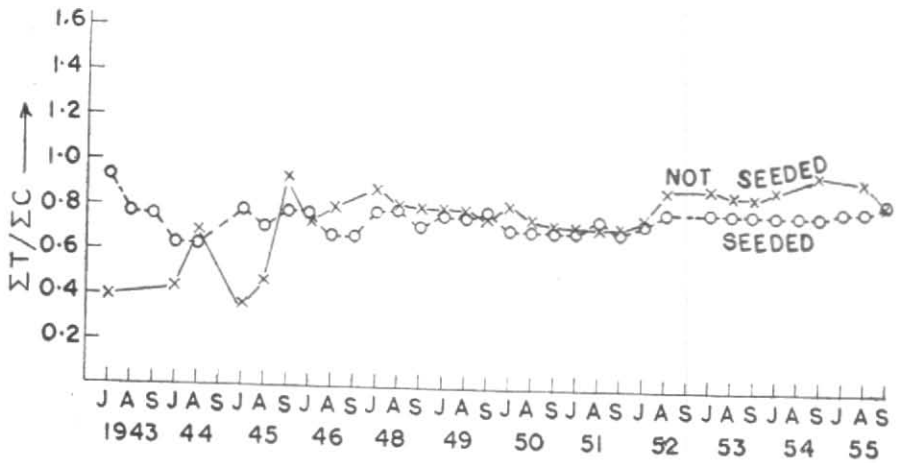

Fig. 2(a)

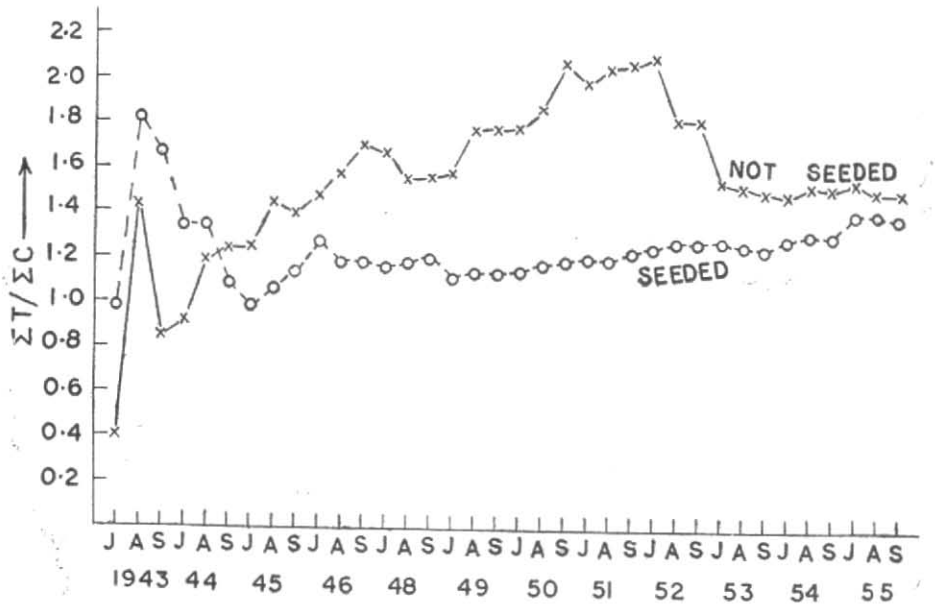

Fig. 2(b)

Fig. 2. Ratio of cumulative values of rainfall in target and control sectors at various stages of mock trials—2(a) Southeasterly wind and 2(b) Northwesterly wind

TABLE 3

Cumulative results of actual and mock seeding at various stages of the experiments

At end of	Actual			Mock		
	Postive	Negative	Indeterminate	Positive	Negative	Indeterminate
2 years	8	1	3	5	4	3
3 years	12	2	4	7	8	3
5 years	20	3	7	12	14	4
8 years	—	—	—	22	20	6
12 years	—	—	—	32	29	11

increase in the target sector rainfall and also that the order of increase is at least 5 per cent, as indicated by the difference between the two values of $\Sigma T/\Sigma C$ at the point of their closest approach. To judge further the validity of such a conclusion, we may now examine the corresponding data relating to the mock experiment, and note the order of differences in the values of $\Sigma T/\Sigma C$ between the two sets of days which may be presumed to have occurred due purely to natural variabilities in the incidence of rain. In this connection, a reference to Fig. 2(a) shows that, the $\Sigma T/\Sigma C$ ratio values relative to seeded periods are both above and below those for not-seeded periods, but during 1952—55 the unseeded values are higher than those corresponding to seeded periods by as much as 20 per cent.

Examining mock experiment data relative to days of NW'ly winds, we see that the differences between values of $\Sigma T/\Sigma C$ for the two sets of days 'seeded' and 'non-seeded' are even larger than in the case of SE'ly wind, the values for unseeded days being consistently higher except during the first two years, and that the two values tend to approach only at the end of 11 years. In contrast to this, we see, in the case of actual seeding trials under regime of NW'ly wind, that $\Sigma T/\Sigma C$ values for seeded periods lie well above those for periods not-seeded. While, at first sight, the feature brought out may seem most encouraging, the following considerations would show the need for extreme caution before accepting the results at their face value. In this connection, we have to note that, in relation to a mock trial like the one considered in this note, the persistence of a difference, whether in a positive or negative sense, between the two sets of values would have to be treated as purely fortuitous, being indicative of the same fact, namely, that, despite randomisation, the two groups of days 'seeded' and 'not-seeded' may not be sufficiently well balanced from the point of view of weather situations, so as to allow exact quantitative determinations being made of the possible augmentation of rainfall as a result of the seeding operations.

5. Conclusion

Evaluation of cloud seeding trials at Delhi, on the basis of comparisons of the number of positives and negatives as discussed in the note, when viewed against similar counts relative to the mock experiment, gives an overwhelming support to the view that the seeding trials have produced the desired results. As regards attempted quantitative estimate of the effects of seeding on the basis

of comparisons of the cumulative ratio values for seeded and not-seeded periods, it is, however, seen that no definite conclusion is possible unless the trials have been continued for a few more years.

6. Acknowledgement

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