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SALT SEEDING FROM AIRCRAFT OVER LINGANAMAKKI CATCHMENT, SOUTH INDIA

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1. BACKGROUND

Acute power shortages because of weak monsoons in the summers of 1973, 1974, and 1975 led to several cloud seeding operations over hydroelectric catchments throughout India. One of these involved salt seeding of warm cumulus clouds from aircraft over the Linganamakki catchment in southwest India during the summer of 1975, at the request of the Karnataka State Government. Operational details have been given by the Karnataka State Electricity Board (KSEB, 1975). Rainfall measured in the target area and in adjacent control areas (Fig. 1) is used for the present evaluation.

The project was similar to that conducted in the preceding two years 1300 km to the northeast over the catchment of Rihand reservoir (24^{0} 12'N, 83^{0} 03' E, 310 m MSL) in the extreme southeast corner of Uttar Pradesh, south of Varanasi (Banaras). A limited number of raingauges in and around the catchment indicated increases on seeded days of 17 to 28 percent, which was not statistically significant (Kapoor et a., 1976). Despite the strong chance of similar inconclusive results from a non-randomized operational project, the Karnataka authorities requested an operational project, to alleviate a critical water shortage.

The 2000 sq. km Linganamakki catchment (14^{0} 12'N, 74^{0} 50'E, 704 m MSL) is the headwaters of the Sharavati River, which flows northwest and west through the Western Ghats to the Arabian Sea. Three comparison or "control" areas were defined immediately north, east and south of the target (Fig. 2), having respectively 14, 8 and 14 raingauges. Daily rainfalls averaged for 14 target area raingages during five summer monsoon seasons (June-September, 1970-1974) had correlation coefficients of 0.38, 0.27, and 0.37, with the north, east and south area averages respectively.

The Linganamakki region's rainfall comes mainly during the summer monsoon, with more than 60 percent of annual rainfall in July and August. Westerly airflow in the lower troposphere brings a large influx of moisture. Clouds generally are stratus and cumulus, with bases about 1,500 meters MSL. The western edge of the catchment, along the crest of the Western Ghats, is 600 to 700 meters MSL, the eastern and southern boundary somewhat higher (Fig. 2). Rainfall on the west (windward) slopes of the Ghats is heavy, but decreases sharply inland, to the northwest (Fig. 3). The number of days on which seeding was conducted in different portions of the target varied from 9 in the southeast to 43 and 44 over the central part (Fig. 1).

Aircraft temperature observations were made in the lower atmosphere up to 10,000 ft. ASL during the cloud seeding operations. The details of the aircraft thermometer were described elsewhere (Ramachandra Murty et al., 1976). The mean lapse rates of temperatures obtained on 47 days of the experiment are shown in Figure 5. The thermodynamical characteristics of the lower atmosphere were examined on the days of the experiment and the mean lapse rates of temperatures on days with rainfall (R) in three categories (i) R 80mm, (ii) R 20 80 mm, and (iii) R 20 mm and the mean lapse rates for the total period of the experiment (47 days) are shown in Figure 6. The lapse rates in the sub-cloud layer (below 3000') were nearly dry adiabatic on all the three categories of the days. Above this level, the lapse rates were steeper, the rate of fall being the largest for Category I. The lapse rate decreased at a slower rate in case of categories II and III.

2. OPERATION

On 48 days between 21 June and 31 August, 1975, a pulverized mixture of salt and soapstone, at a 10:1 ratio with particle model diameter of 10 μm, was released from a special device in a DC-3 aircraft, about 600 m above bases of warm stratocumulus and cumulus. About 1500 kg of salt mixture were dispersed on each seeded day.

Target area rainfall, as measured by the 14 target area gauges, was 7, 349, and 163 percent greater than expected by comparison with rainfall in the north, east and south control areas, but the increases are not significant statistically (Table 1). Rainfall at the single Linganamakki gauge was greater (by 10 to 1000 percent) than expected from individual comparisons with 30 control gauges, less (by 20 to 30 percent) than predicted by the pre-seeding ratios with 6 other gauges.

The increase of 73.25 feet in reservoir water level during the seeding operation was 25.7 percent greater than the largest increase reported in the preceding 10 years. However, no data were available on reservoir releases, so the significance of the increase in water level could not be established. The apparent precipitation increases must be viewed cautiously because of the limitations in evaluation of operational cloud seeding experiments.

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REFERENCES

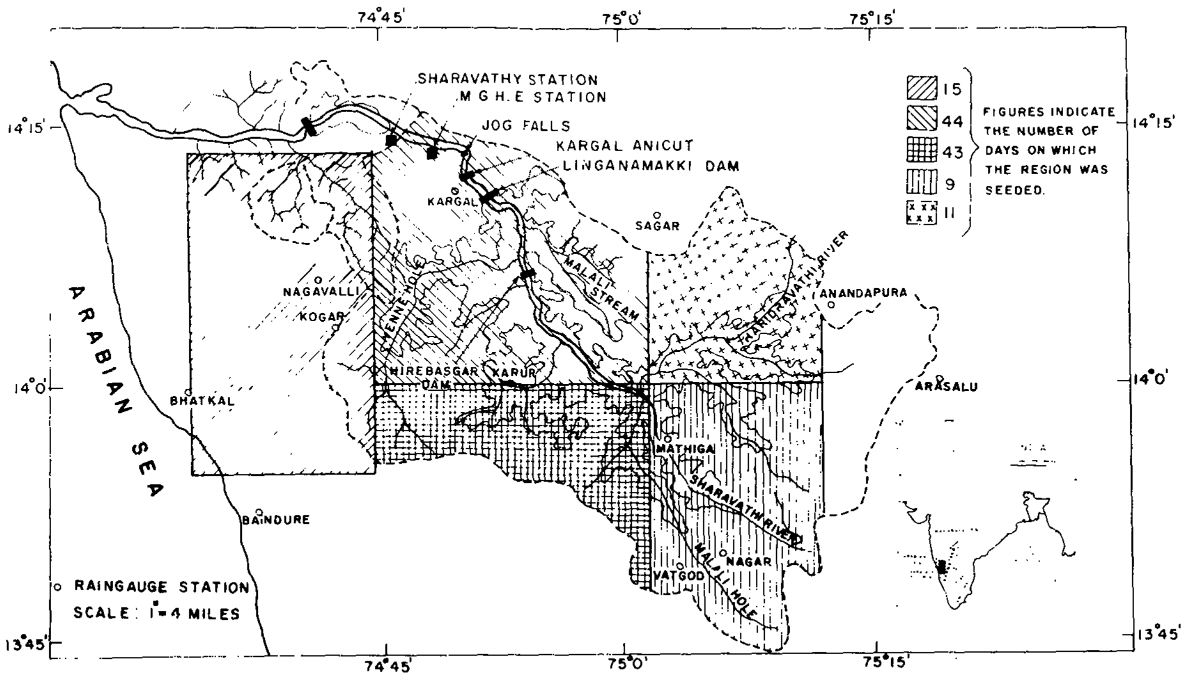
Kapoor, R.K., K. Krishna, R.N. Chatterjee, A.S.R. Murty, S.K. Sharma and Bh. V. Ramana Murty, 1976: An operational rain stimulation experiment using warm technique over Rihand Catchment in northeast India during summer monsoon of 1973 and 1974. Proceedings of the Second WMO Scientific Conference on Weather Modification, Boulder, CO., 2-6 Aug., 1976, 15-20.

Karnataka State Electricity Board, 1975: Report on cloud seeding operations over Linganamakki catchment - Sharavathy Valley Project, 21 June 1975 to 31 August 1975, Bangalore.

Ramachandra Murty, A.S., A.M. Selvam, R. Vijayakumar, S.K. Paul and Bh. V. Ramana Murty, 1976: Electrical and microphysical measurements in warm cumulus clouds before and after seeding. J. Appl. Meteor., 15, 1295-1301.

Table 1. Average rainfall (mm) in Target (T) and North, South, and East Control Areas (C_N , C_S , C_E) on Seeded Days over Linganamakki Catchment.

1975	T	C_N	C_S	C_E	T/C_N	T/C_S	T/C_E
JUN 21	159.5	80.7	144.0	23.4	1.98	1.11	6.82
22	221.4	105.0	183.1	49.7	2.11	1.21	4.45
23	198.7	97.6	161.7	46.7	2.03	1.23	4.25
28	66.4	28.8	53.5	19.3	2.30	1.24	3.44
29	59.8	17.0	58.8	10.5	3.52	1.02	5.69
JUL 02	30.6	14.2	23.0	5.6	2.15	1.33	5.46
03	50.5	30.9	37.0	4.1	1.63	1.36	12.32
04	52.8	27.2	27.0	4.7	1.94	1.95	11.23
06	26.3	8.8	34.2	5.8	2.99	0.77	4.53
10	128.1	78.4	99.4	41.1	1.63	1.29	3.12
12	122.2	30.7	102.2	9.4	3.98	1.19	13.00
13	55.8	12.4	67.1	4.3	4.50	0.83	12.98
14	41.9	11.8	34.8	9.4	3.55	1.20	4.46
15	14.8	5.1	22.0	0.3	2.90	0.67	49.33
16	24.0	6.8	20.6	0.0	3.53	1.16	-
17	34.0	9.3	33.0	1.8	3.65	1.03	18.89
20	12.1	15.5	21.1	8.0	0.78	0.57	1.51
21	3.3	0.7	13.2	9.9	4.71	0.25	0.33
22	6.4	1.3	26.5	8.4	4.92	0.24	0.76
23	2.6	1.7	2.6	7.2	1.53	1.00	0.36
24	6.2	7.6	5.4	19.6	0.81	1.15	0.32
29	51.8	16.5	39.1	9.8	3.14	1.32	5.29
30	27.4	11.3	31.5	10.8	2.42	0.87	2.54
31	19.9	10.1	15.5	12.4	1.97	1.28	1.60
AUG 03	92.4	37.7	70.8	23.1	2.45	1.30	4.00
04	77.1	38.1	71.6	17.5	2.02	1.08	4.40
05	74.5	37.2	75.7	6.4	2.00	0.98	11.64
06	76.6	24.5	56.7	8.6	3.13	1.35	8.91
07	44.5	12.2	30.1	4.4	3.65	1.48	10.11
08	48.3	13.8	43.7	6.3	3.50	1.10	7.67
09	48.4	21.6	53.9	12.2	2.24	0.90	3.97
12	102.0	21.1	99.0	27.2	4.83	1.03	3.75
13	93.4	20.2	95.7	20.8	4.62	0.97	4.49
14	119.4	49.1	115.6	33.9	2.43	1.03	3.52
18	29.1	13.6	36.5	4.5	2.14	0.80	6.47
19	22.5	3.8	27.1	6.4	5.92	0.83	3.51
20	34.9	5.0	28.0	4.2	6.98	1.25	8.30
21	16.0	3.6	16.7	7.1	4.44	0.96	2.25
22	17.7	4.5	15.5	5.9	3.93	1.14	3.00
23	15.5	7.1	15.2	3.3	2.18	1.02	4.70
24	11.3	6.6	4.5	2.6	1.76	2.58	4.46
25	6.8	2.8	10.1	2.8	2.43	0.67	2.43
26	13.4	1.4	26.0	2.0	9.57	0.51	6.70
27	13.7	1.5	20.6	12.5	9.13	0.66	1.10
28	26.5	4.7	59.3	5.1	5.64	0.45	5.20
29	36.4	6.1	41.0	3.3	5.97	0.89	11.03
30	11.9	4.6	24.6	3.3	2.59	0.48	3.60
31	12.5	3.1	14.4	0.7	4.03	0.87	17.86



EXPANDED MAP OF SHARAVATHI BASIN IN KARNATAKA STATE

FIG. 1: Map of Sharavati Basin. Number of days of seeding operations is also shown

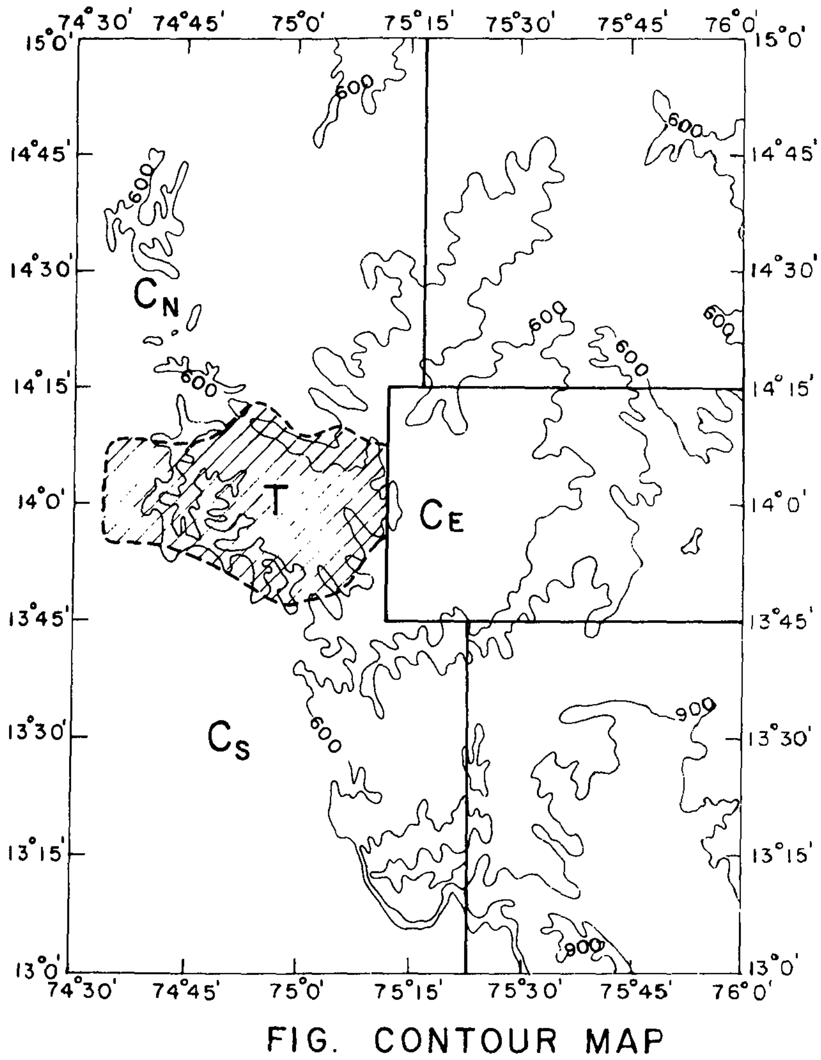


FIG. 2: Isolines of station height (metres ASL)

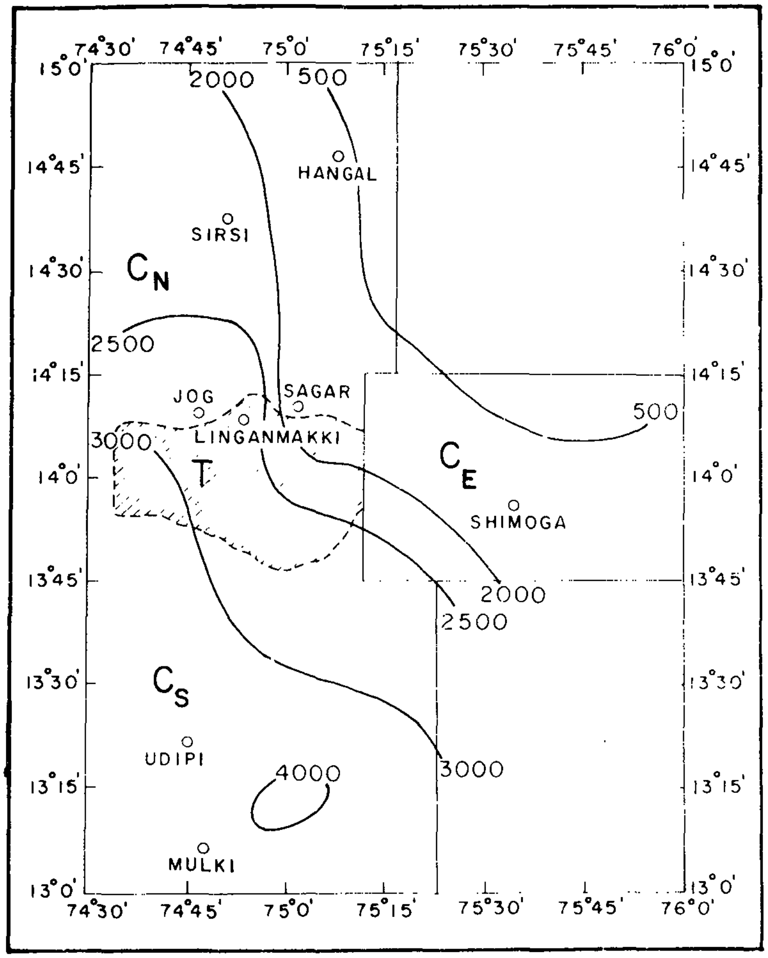


FIG. ISOHYETS OF SEASONAL MEAN RAINFALL (mm

FIG. 3: Isohyets of seasonal mean rainfall (mm)

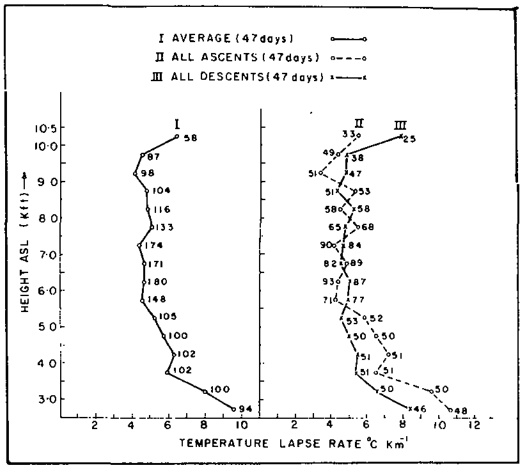


FIG. 4: Mean lapse rates of temperatures based on 47 days aircraft temperature observations.

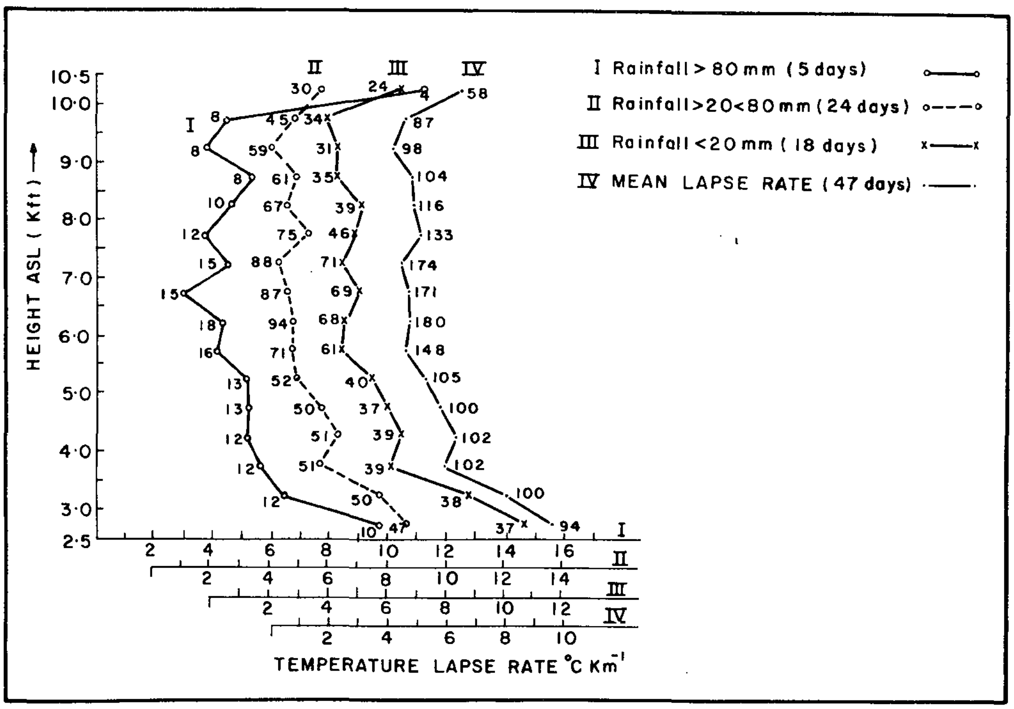


FIG. 5: Mean lapse rates on days with different rainfall amounts. Numbers on the curve indicate the number of observations available for the particular height.

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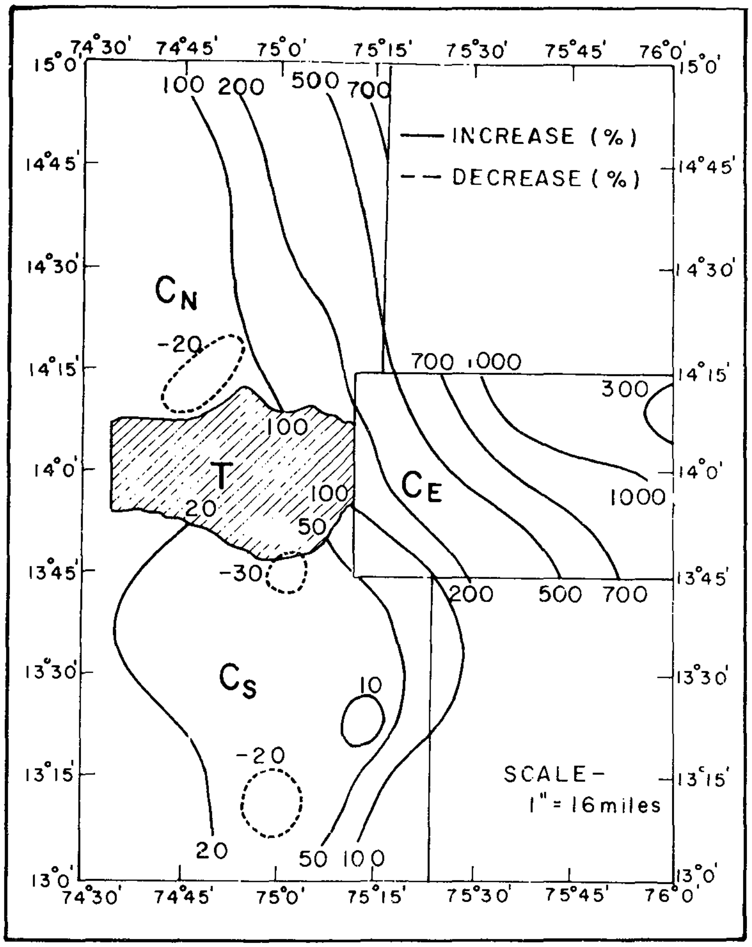

FIG. PERCENTAGE INCREASE/DECREASE IN RAINFALL DUE TO SEEDING.

FIG. 6: Spatial variation of percentage increase/ decrease in rainfall due to seeding.