GROUND-BASED SALT SEEDING IN TAMIL NADU STATE, SOUTH INDIA, 1973-1977

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1. INTRODUCTION

A long series of ground-based salt seeding experiments in north India during the southwest monsoon seasons (June-September) of 1957-66 showed significant increases of about 20 percent in rainfall on seeded days (Ramana Murty and Biswas, 1968). In September of 1974, salt seeding from aircraft on isolated maritime warm cumulus clouds within 50 km off the coast at Bombay (18° 15'N, 72° 49'D, 11 m ASL) was followed by increases in radar echo area coverage in the vertical and in echo intensity (Chatterjee et al., 1978). To seek similar results in a different area, a randomized salt-seeding experiment, using a single ground-based generator, was conducted in 1973 and 1975-77 just west of Madras, on the Bengal coast 1,000 km southeast of Bombay. There in the state of Tamil Nadu, South India, the main rainy season is during the northeast monsoon (Oct-Dec), whereas in most parts of India, about 75 percent of the annual rainfall is received during the southwest monsoon (Ananthakrishnan, 1977).

Precipitable water in the Tamil Nadu region is maximum in July and August, but rainfall is greatest in October and November. Mean daily rainfalls are 9.4 mm and 20.0 mm, respectively, during the southwest and northeast monsoon months. During the northeast monsoon season some of the cyclonic disturbances in the south Bay of Bengal move towards the Tamil Nadu coast and give heavy rainfall over the coastal belt. Since rainfall in Tamil Nadu during the southwest monsoon is low despite the high precipitable water vapour present, the feasibility of increasing rainfall through the modification of cloud microphysical conditions was explored. Aircraft observations made in north India had indicated fewer than one giant condensation nucleus per litre at cloud base under certain meteorological conditions during the southwest monsoon season (Biswas et al., 1968). Correcting this deficiency of giant condensation nuclei may help accelerate rain-formation through collision-coalescence.

A salt seeding experiment using ground based generator was undertaken during the years 1973 and 1975-1977, for exploring the feasibility of increasing rainfall through cloud seeding in the region. For the type of research described above, aircraft seeding would be ideal since it ensures precise targeting of the salt particles into the clouds and also facilitates to make in-cloud microphysical observations. However, the prohibitive cost of the aircraft operations has become the main factor for adopting the ground seeding. During the above experiment surface measurements of the concentration of giant ($r \geq 1\ \mu m$) condensation nuclei (GCN) were also made.

The experimental area with its network of about 1 raingauge per 30 to 160 km^2 (Fig. 1) was about 40 km inland (west) from the coast at Madras (13° 00'N, 80° 11'E, 16 m ASL). Target and control areas were 10000 to 12000 km^2.

During the southwest monsoon season (July-Sept) at Madras, moderate southwesterly to westerly winds prevail in the lower troposphere (Table 1). When the wind is southwesterly or westerly, airmasses travel over land before passing over the experimental area and may have fewer giant condensation nuclei. The average cloud base height is about 5000 ft. ASL.

During the northeast monsoon season (Oct-Dec) winds in the lower troposphere are mostly northeasterly to easterly, and are most gusty - during December. Skies are overcast on 8 to 12 days per month (Table 1). When it is not raining, low clouds are between 1000-3000 feet ASL in most cases. Maximum rainfall is received during November, when maritime airmasses bring giant condensation nuclei traveling over Bay of Bengal before crossing the east coast.

2. EXPERIMENTAL DESIGN AND RESULTS

The fixed target-control design was adopted in the experiment with day randomization. Target and control areas were delineated by the location of the seeding generator and the predominant wind direction in that area. The angular spread of the target area covers the 70 to 90° quadrant opposite to the mean wind direction, as indicated by the analysis. The control and target sectors fixed accordingly for the southwest and northwest monsoon seasons were:

	Target	Control
Southwest (June-Sept)	50° - 120°	230° - 300°
Northeast (Oct-Dec)	180° - 270°	0° - 90°

Correlations between average daily rainfalls of the target and control areas, for the 5-year period 1968-72, were 0.69 for the southwest monsoon and 0.62 for the northeast monsoon seasons. The criteria for seedable day were based on (i) forecast wind at 1.0 and 1.5 km levels, (ii) actual or forecast low cloud amount, and (iii) probability of rain occurrence in the region during the 12 hour period preceding the time of seeding. Days on which intermittent to continuous rain occurred, preceding and during the scheduled period of seeding, were not considered as seedable.

On the afternoons (1400-1700 IST) of seedable days, randomly selected for seeding, a pulverised mixture of salt and soapstone, in the ratio

10:1 with particle mode diameter of about 10 μm, was injected into the atmosphere from a single ground-based generator at Tiruvallur (Madras). Seeding at about 300 kg hr^{-1} continued for about 3 hours commencing from 1400 IST. The seeding rates adopted should yield about 10^{10} giant size hygroscopic particles per second. Cloud bases are about 5000 feet during southwest and 2000 feet during the northeast monsoon seasons. At 25 km downwind particle concentration will be of the order of 20000 m^{-3} (Biswas et al., 1967). Hence only a fraction of the salt particles released at the ground should reach the cloud base levels under favorable meteorological conditions and influence the microphysical state of the cloud.

After the initial year, 1973, with 20 days seeded and 16 not, no experiment could be undertaken during 1974. Thereafter the experiment could be carried out only sporadically (Table 2) which ultimately led to its termination in 1977 before statistically significant results could be obtained.

During the SOUTHWEST MONSOON (Jun-Sept), rainfall on 40 seeded days was compared to that on 34 non-seeded days (Table 2). The result was positive in 2 seasons and negative in 2 seasons, with increases of 7 to 355 percent and decreases of 5 to 8 percent (Table 3). The four seasons showed an increase in rainfall on seeded days of 32 percent, significant at 15 percent level according to Mann-Whitney test (Table 4).

During the southwest monsoon, the air has enough water vapour for cloud formation, but the windflow in the lower troposphere southesterly to westerly causes the air masses to travel over land. Such air masses may contain few of the hygroscopic nuclei required for rain-formation, and seeding them with giant condensation nuclei may help accelerate rain-formation through collision coalescence process. The surface observations showed fewer giant condensation nuclei during the southest monsoon season. Numbers per litre of giant nuclei were:

Year:	1973	1975	1976	1977	1978
Southwest monsoon:	10.2	2.6	4.1	5.9	4.4
Northeast monsoon:	23.8	3.2	7.0	7.0	5.5

During the Northeast Monsoon (Oct-Dec) of 1976 and 1977 rainfall on 16 seeded days (Table 2), compared to that on 20 non-seeded days, decreased by 17 percent, significant at 33 percent level (Table 4). The GCN concentrations were higher up to a factor of two during the northeast monsoon.

3. SUMMARY

The ground-based salt seeding experiment, with a fixed control target design and day randomization, on 56 days with 54 days as control during the monsoon seasons of 1973-1977 in Tamil Nadu State, South India showed:

1) Rainfall incrase of 32 percent, significant at the 15 percent level, during the southwest monsoon;

2) A 17 percent rainfall decrease, significant at 33 percent level, during the northwest monsoon;

3) Concentrations of giant condensation nuclei at the surface higher up to a factor of two during the northeast monsoon season compared to the southwest monsoon season.

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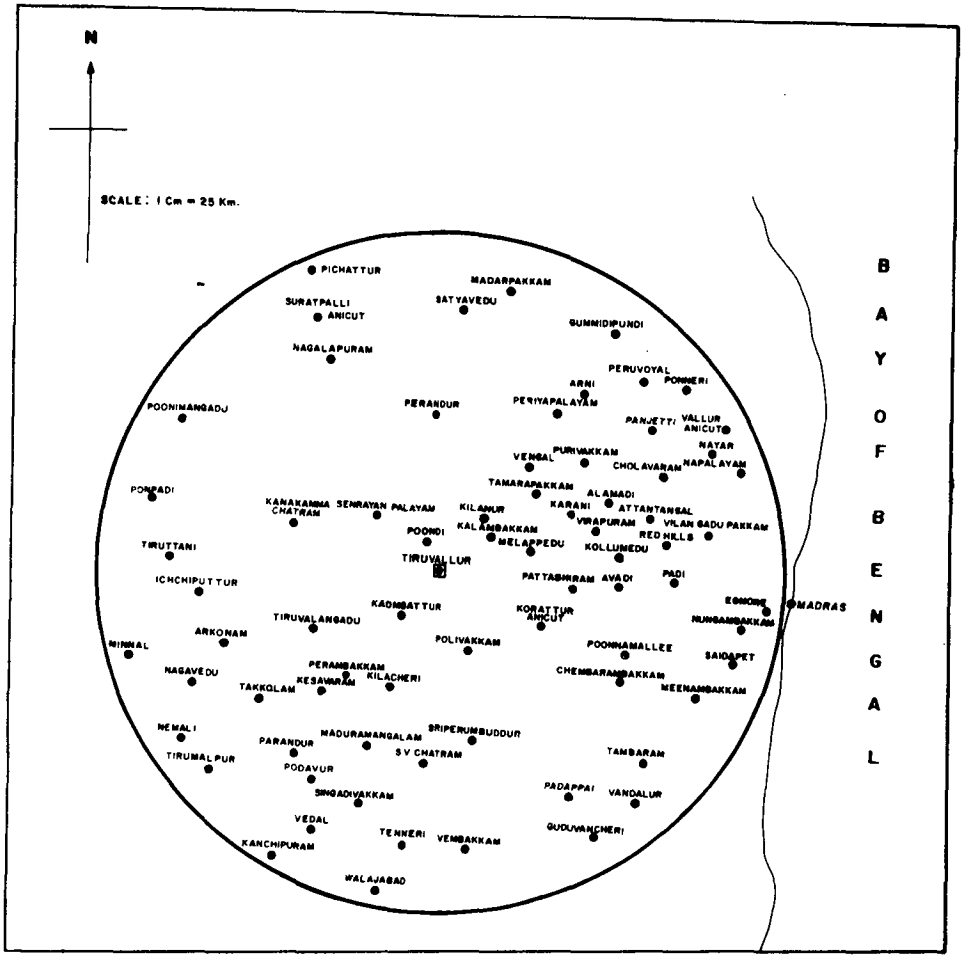

FIG. 1. Location of the experimental area (inside the circle) and the raingauge network.

Table 1. Meteorological Parameters, 1931-60, at Madras (13°00'N, 80°11'E, 16 m ASL).

		Southwest monsoon				Northeast monsoon		
		JUN	JUL	AUG	SEP	OCT	NOV	DEC
Relative humidity (%)		59	63	67	71	79	79	77
Days with low cloud > 3 ok		14	15	14	10	8	12	12
No. of rainy days		4.0	6.6	8.4	7.3	10.0	9.8	5.1
Rainfall (mm)		52.6	83.5	124.3	118.0	267.0	308.7	139.1
Mean wind speed (Km/h)		16.4	14.6	13.6	11.1	9.2	11.7	12.6
Percentage number of days with wind at surface from	SW	8	13	9	8	3	0	0
	W	11	19	13	10	3	1	0
	NE	1	2	2	2	22	45	53
	E	8	7	11	17	24	11	13

Table 2. Seeding details.

Year	Period	Number of days Seeded	Number of days Not-seeded	Seeding material (kilograms)
1973	JUN-SEP	20	16	16,050
1974	-	-	-	-
1975	JUN-JUL	3	7	1,825
1976	JUL-SEP	5	4	3,450
"	OCT-DEC	10	10	6,175
1977	JUN-SEP	12	7	10,500
"	OCT-NOV	6	10	4,850
	TOTAL	56	54	42,850

Table 3. Total rainfall (mm) per station in Target (T) and Control (C) sectors on seeded and not-seeded days.

Year	Month	Seeded			Not-seeded			$\frac{T\ C'}{C\ T'}$	Result
		T	C	T/C	T'	C'	T'/C'		
1973	JUN	6.24	10.05	0.641	3.03	6.83	0.444	1.444	+
	JUL	5.59	4.07	1.373	1.55	5.68	0.273	5.029	+
	AUG	31.02	1.35	22.977	1.32	0.00	-	-	0
	SEP	33.51	27.28	1.228	2.88	9.76	0.295	4.163	+
1974	-	-	-	- No experiments			-	-	
1975	JUN	0.99	0.34	2.912	25.06	9.54	2.627	1.108	+
	JUL	4.08	1.77	2.305	0.00	0.00	-	-	0
1976	JUL	13.63	9.22	1.478	46.46	48.24	0.963	1.535	+
	SEP	0.00	4.02	0.000	0.00	0.00	-	-	0
1977	JUN	1.27	0.26	0.488	1.65	0.00	1.650	0.488	-
	JUL	2.41	10.55	0.228	0.64	0.00	0.640	0.228	-
	AUG	26.57	27.97	0.950	10.16	15.62	0.650	1.462	+
	SEP	0.00	1.82	0.000	0.00	0.23	-	-	0
1976	OCT	5.41	0.82	6.598	1.27	0.13	9.769	0.675	-
	NOV	3.54	4.05	0.874	4.28	10.11	0.423	2.066	+
	DEC	3.11	1.04	2.990	0.32	0.00	-	-	-
1977	OCT	9.54	32.35	0.295	67.25	103.07	0.652	0.452	-
	NOV	3.79	6.62	0.573	15.92	17.05	0.934	0.613	-

Table 4. Average ratio values of total rainfall in Target (T) and Control (C) sectors on seeded and not-seeded days.

Year	Seeded T/C	Not-seeded T'/C'	$\frac{T\ C'}{C\ T'}$	%
		Southwest Monsoon (JUN-SEP)		
1973	1.791	0.394	4.55	+ 355
1974	-	No experiment		-
1975	2.403	2.627	0.92	- 8
1976	1.029	0.963	1.07	+ 7
1977	0.745	0.785	0.95	- 5
Total	1.272	0.967	1.32	+ 32*
		Northeast Monsoon (OCT-DEC)		
1976	2.040	0.573	3.56	+ 256
1977	0.295	0.652	0.45	- 55
Total	0.566	0.633	0.83	- 17**

Significance levels by one-tailed Mann-Whitney test : * = 15%
** = 33%