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EVALUATION OF PRECIPITATION ENHANCEMENT IN ANANTAPUR DISTRICT OF ANDHRA PRADESH

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ABSTRACT

Precipitation enhancement experiments were carried out in 12 districts of Andhra Pradesh for a period of five years. The experiments involved primarily treatment of warm clouds in the monsoon season with hygroscopic cloud condensation nuclei (CCN) to enhance precipitation in the region. The cloud condensation nuclei used was calcium chloride in the particle size range of 1.0 microns to 10 microns. Radar data and ground truth were used to evaluate the impact of inducing the cloud condensation nuclei into the cloud bases using aircrafts. The Index of Coalescence Activity (ICA) has been calculated for the 12 districts as a predicator of the cloud collision coalescence activity. The data was found to be in the range on the positive side from +4.7 to as high as +23.2 indicating that warm cloud seeding mechanism has to be followed for tropical conditions. The regression equations were calculated and GIS based maps were drawn to analyze the influence zone and evaluate extent of precipitation enhancement. Statistical methods such as single ratio, double ratio method, impact coefficient, target control and downwind comparisons are used to arrive at the percentage increase in rain mass over this region. This paper details the operations and results in 12 districts for the period 2005-2007 with specific reference to Anantapur district. The results clearly indicate that the mechanism of precipitation enhancement in this region of India is through the coalescence process.

KEYWORDS: Index of Coalescence Activity, Hygroscopic Seeding, Cloud Condensation Nuclei, Impact Coefficient

INTRODUCTION

Clouds are formed and developed, depending on the environment and the type of Cloud Condensation Nuclei (CCN) distribution made available to the system. The possibility of affecting the condensation/collision – coalescence/break up growth processes by seeding the cloud with either hygroscopic material or with small water droplets, thereby tapping the potential precipitation efficiency of the cloud system leading to rain enhancement is examined during cloud seeding. Precipitation efficiency is the percentage of condensed water within a cloud system that reaches the ground as precipitation. Countries like China, Thailand, USA etc. have practiced cloud seeding technologies and have achieved a fairly large increase in precipitation. It was found that the growth of large clouds can be achieved artificially by inducing cloud condensation nuclei. Special radar has been developed to study development in clouds (Bringi et al 1989). Computer software has been used with conventional radar to track radar cells and quantify the increased merging caused by cloud seeding (Rosenfield 1987, Westislt 1990, Reinking et al. 1992). Warm stratus clouds give widespread rainfall at moderate intensity. They are presumed to operate on a coalescence mechanism because the cloud tops do not get adequately high and cold for development of ice crystals. Seeding aims to introduce large calcium chloride particles in to the cloud base so that they will nucleate condensation and result in large average droplet size which will then coalesce to produce rain. The technique of hygroscopic seeding to enhance rainfall by promoting the coalescence process has not received as much attention as AgI seeding. However, studies by Bruintjies et al, 1999 has suggested that hygroscopic seeding instills dynamic effects on convection clouds. Mather et al 1997 found the coalescence process initiated by cloud condensation nuclei could also be transmitted to other clouds in the meso scale convective cluster also.

Districts of Prakasam, Nellore, Chittor, Kadapa, Anantapur, Kurnool, Mahaboob nagar, Medak, Ranga Reddy, and Nalgonda in Andhra Pradesh, India were identified for precipitation enhancement experiments to be carried out for a period of five years. The seeding targets were semi-isolated, warm convective clouds, identified by a set of protocols for seeding. Those that did not meet the protocol were not seeded. The selected clouds were treated with calcium chloride particles as the seeding agent. The clouds were identified using ‘C’ band radar. TITAN (Thunderstorm, Identification, Tracking, Analysis and Now casting) was used to perform analysis of the cloud parameters during precipitation enhancement experiments conducted in Andhra Pradesh, India. TITAN was used to track radar data, convert it into Cartesian coordinates, identify storms, track and display the real time cloud picture (Dixon and Wiener, 1993). TITAN makes it possible to compute a number of relatively sophisticated storms and track parameters very easily in real-time (Mather et al. 1996). The data was analyzed for all study area districts and specific in-depth analysis was carried for Anantapur district of Andhra Pradesh.

Study Area

The experiments were carried out in 12 districts viz. Ananthapur, Chittoor, Kadapa, Kurnool, Medak, Mahaboob nagar, Prakasham, Guntur, Nalgonda, Karimnagar, Nellore and Ranga Reddy (Figure 1a).

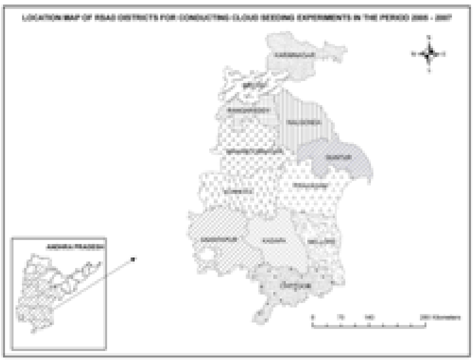

Figure 1(a): Study Area, 12 Districts of Andhra Pradesh

Figure 1(b): Anantapur District, Showing Various Studies Administrative Boundries

Anantapur is located at 14.68° N 77.6° E (Figure 1b). It has an average elevation of 335 metres (1099 feet). This District is coined to be the area wise biggest district in Andhra Pradesh. The boundaries of Anantapur district are Cuddapah district, Chittoor district and Karnataka State border, Karnataka State and Kurnool district in the East, South, West and North directions respectively.

It is one of the four districts of Rayalaseema and one of the four industrial development centers approved by the Government of India is in this district and is often affected by drought. The occupations are silk production and agriculture. Tungabhadra Upper Canal is the only source of water for Irrigation. Its area is 19,130 sq.km and with a temperature range in summer around 30°C - 40°C (81.56F - 108.75F Apx.) and winter at 20°C - 27°C (54.25F - 73.19F Apx.). The rivers that flow through the district are Penna, Chitravathi, Kunderu, Hagari. 10% of the area of the district is occupied by forest.

METHODOLOGY

Volume scan data from C band radar at 5min intervals were used to track each operation, from which the various radar estimated parameters were obtained. The statistical evaluation of the experiment was based on analysis of the seeded to unseeded experimental unit lifetime properties using Single ratio, double ratio and root double ratio methods.

RESULTS AND DISCUSSIONS

The index of Coalescence Activity (ICA) has been developed as a predictor of in cloud collision coalescence activity using an atmospheric upper air sounding. Index of coalescence activity was calculated using the formula ICA = 8.6 – T_{CCL} + 1.72 (PB). The ICA is a summation of the collision and collection efficiency, which results in the coalescence efficiency. Strautins et al (1999) documented the physics involved in the derivation of the index of coalescence activity and its relation to coalescence activity. The temperature at the convective condensation level (T_{CCL}) an approximation of the cloud base temperature and the PB is defined as the temperature difference at 500mb (18000ft msl) between the pseudoadiabat that runs through the cloud base and the environmental temperature. This data is retrieved from the atmospheric upper air sounding. The number of positive vs. negative ICA ratio values shows that there are a good number of opportunities to do hydroscopic seeding. Hygroscopic seeding is needed when ICA values are high and positive. This would make it possible to increase the level of success by introducing hygroscopic seeding to promote coalescence in continental clouds that have weak coalescence increasing the efficiency of rain bearing clouds and eventually rainfall. The possibility of increasing rainfall from warm convective clouds by cloud base release of hygroscopic particles is to promote the drizzle, which grows into rain by coalescence technology. As reported by Cotton and Pielke (1995) the predominant process for precipitation formation in warm clouds is collision and coalescence. Table 1 shows the index of coalescence activity in the study area districts of Andhra Pradesh. From table 1 it can be seen the ICA activity is high for three districts viz. Anantapur, Kurnool and Nellore districts of Andhra Pradesh based on the data collected for the months of July to September.

Table 1: Index of Coalescence Activity (Average) for the Selected Districts of Andhra Pradesh

District Name	T ccl	PB	ICA	T ccl	PB	ICA	T ccl	PB	ICA
	July			August			September		
Prakasam	23	-6.3	25.2	6	-0.5	1.7	5	-5.3	-5.5
Nellore	19	-6.3	21.2	21	-1.9	15.6	23	-4.7	22.4
Chittoor	20	-6.3	22.2	18	-1.9	12.6	16	-3.3	13.0
Kadapa	24	-4.7	23.4	15	-8.1	20.3	9	-5.3	9.5
Anantapur	23	-4.7	22.4	8	-8.1	-13.3	19	-6.3	21.2
Kurnool	9	-5.3	9.5	17	-1.1	10.2	20	-6.3	22.2
Mahabub Nagar	5	-5.3	-5.5	15	-1.1	8.2	15	-1.1	8.2
Karimnagar	23	-4.7	22.4	9	-5.3	9.5	21	-1.9	15.6
Ranga Reddy	7	-5.3	-7.5	12	-3.9	10.1	18	-1.9	12.6
Medak	16	-3.3	13.0	19	-5.5	19.8	21	-1.9	15.6
Nalgonda	11	-0.5	3.2	6	-5.3	-6.5	6	-0.5	1.7
Guntur	9	-5.3	9.5	5	-5.3	-5.5	15	-8.1	20.3

Mather et al (1997) reported that the smaller cloud systems appeared to respond to treatment first, the medium size cloud systems a little later, and the largest cloud systems last. The statistical assessment criteria that are used in this study are based on the previous research by Tukey et al, (1978), Braham (1979), Gabriel (1981), Gabriel (2000). The ICA values are high for Anantapur district of Andhra Pradesh and hence an in-depth analysis is presented in this paper.

The district is terms as rain shadow as it receives less than 1000mm of annual rainfall. The percent departure from normal for the season in which the operations were carried is calculated and presented in Table 2.

Table 2: % of Departure from Normal for Rainfall for the Season from 1st June to 30th September

Year	'96	'97	'98	'99	2000	'01	'02	Normal $	'03	'04	'05	'06	'07
Anantapur	87	18	72	13	59	32	-43	310.3	-37	-04	50	-36	81
$ Area weighted Rainfall Normal based on data 1941 – 1990 (0.42)													

During the analysis of the radar data the clouds were classified into various types depending on the lifetime. A type clouds have average time of 20 – 35 mins, while B type time is 60-70mins and C type average time is 60-120 mins. A total of 151 seeded clouds were selected in the district of Anantapur against 119 non-seeded clouds that satisfied the selected criteria. The non-seeded clouds were chosen only from the days on which the experiments took place. Table 3 shows the distribution of the cloud clusters used for the study of various TITAN parameters.

Table 3: Cloud Clusters Selected in Anantapur District

	2005 S (US)	2006 S (US)	2007 S (US)	Total
Type A	16 (14)	09 (07)	21 (07)	46 (28)
Type B	10 (10)	11 (05)	10 (08)	31 (23)
Type C	24 (30)	14 (17)	36 (21)	74 (68)
Total	**50 (54)**	**34 (29)**	**67 (36)**	**151 (119)**
S:- Seeded clouds, US:- Unseeded clouds / Control clouds				

The control area is chosen upwind of the target area. This area is geographically similar to the target area. Clouds in the control area which are similar to the clouds in the target area are chosen for statistical evaluation. The TITAN parameters have been used to evaluate the seeding effect. It was found that the average growth difference between the seeded and unseeded clouds was approximately 1.5km, with a P value of 0.005. 90% of the storms were found to be seeded in the first 20mins after decision time and therefore except in the case of the Type A clouds the rain flux differences in the first 10mins would not be normally attributed to the seeding. Silverman et al (1994) has indicated that large hygroscopic particle seeding leads to improved precipitation efficiency of the warm convective clouds. Bruintjes et al (1999) also found that seeded clouds tended to live longer than unseeded clouds in the Mexico experiment.

Table 4 gives the details of the 13 TITAN derived parameters. It can been seen from Table 4 that the efficiency in Type A clouds is increased by 38% while in type B clouds it is 50% and type C clouds 75%. It can be also seen that the lifetime for the type C clouds of seeded and unseeded vary by almost 97% which means that the lifetime is increased by two indicating that the corresponding efficiency is also increased.

The percentage of rain rate for A clouds is 66, B type clouds is the highest at 93, while for C type cloud is the lowest of 3 indicating that the clustering has an definitive impact on the rain rate. Similar results have been reported Mather et al (1997) in which statistical evidence that hygroscopic flare seeding increased rain mass in the experiment. Silverman and Sutkarnjanaset 2000 have shown that the seeding near cloud base with calcium chloride particles produced larger seed/ no seed ratios than near cloud top seeding and that the seed / no seed ratios increase with increasing concentration or dosage. Table 5 shows the average precipitation fluxes (m^3/ sec) data and its relation to maximum height of the cloud. For a subset of control and seeded samples an analysis of the anvil losses (top debris) was carried out to study the lifetime of the top debris. It was found that for the seeded clouds had a height of 7.2 km, while for the control cloud this value is 7.1 km, for a difference of 0.1 km = 328 feet. The average top debris of the single seeded clouds was higher than the top debris of the corresponding control clouds, which indicates that there is considerable loss of moisture at the top level.

Table 4: Average Data for the Couples of Cloud Clusters

	Type A Clouds				Type B Clouds				Type C Clouds			
Variables	Seeded (S)	Unseeded (US)	S Vs US	[%] Increase	Seeded (S)	Unseeded (US)	S Vs US	[%] Increase	Seeded (S)	Unseeded (US)	S Vs US	[%] Increase
Time [min]	35	20	1.75	75	69	65	1.06	6	126	64	1.97	97
Area [Km2]	53.6	15.8	3.39	239	85.17	66.21	1.29	29	159.27	120.93	1.32	32
Volume [Km3]	242.75	55.6	4.36	336	352.08	281.42	1.25	25	741.62	484.86	1.53	53
C. Top [Km]	8.27	4.94	1.67	67	6.73	5.94	1.13	13	8.5	7.8	1.08	8
C.Mass [Kilotons]	110.75	27	4.1	310	164.86	108.73	1.51	51	319.86	234.4	1.36	36
P. Flux [m3/Sec]	128.62	39.8	3.23	223	232.17	129.84	1.79	79	378.72	303.33	1.25	25
P mass [K.tons] P Flux *Life time	270.10	47.76	5.65	465	1476.6	646.6	2.28	128	2863.1	1164.78	2.46	146
VIL [Kg/m2]	6.11	3.4	1.79	79	8.36	4.48	1.86	86	8.65	10.52	0.8	20
C.Thick. [Km]	6.95	4.34	1.60	60	5.64	4.54	1.24	24	7.11	6.54	1.09	9
LWC [VIL/Thick] (gm/m3)	0.9	0.78	1.15	15	1.48	0.98	1.51	51	1.2	1.6	0.75	25
Efficiency [P MASS/C.MASS]	2.44	1.76	1.38	38	8.96	5.94	1.50	50	8.95	5.1	1.75	75
Rain = P Mass/ Area [Mm]	5.04	3.02	1.66	66	17.34	5.77	3.0	200	17.97	9.63	1.87	87
Rain rate =[[Z/200] **.625] {mm/hr}	24.09	14.51	1.66	66	27.86	14.45	1.93	93	26.76	27.58	0.97	3

Table 5: Average Precipitation Fluxes (M^3/ Sec) Vs Height of the Cloud

Max Height (Km)	Seeded Mean Precipitation Flux(M^3/ Sec)	Max Height (Km)	Unseeded Mean Precipitation Flux(M^3/ Sec)	Seed / Unseed Ratio
8.0	128	5.0	40	3.2
6.5	232	6.0	130	1.8
8.5	378	7.8	303	1.24

Results from the TITAN data have shown that there is significant increase in the amount of rainfall in Anantapur district due to the seeding operations carried out for the last three years. The next attempt was to calculate the increase in rainfall using ground truth measurements. Because of the problems associated with the highly skew nature of the monthly and seasonal rainfall distributions for each site and large regional differences in rainfall, it was found beneficial to take the long-term mean and standard deviation for each station (period 1960-2000) and then to standardise monthly or seasonal rainfall by expressing it as a ratio relative to the mean. Taking the logarithm of this ratio gives a clear indication of positive and negative anomalies within the data and reduces strongly skew distributions to a more ‘normal’ form.

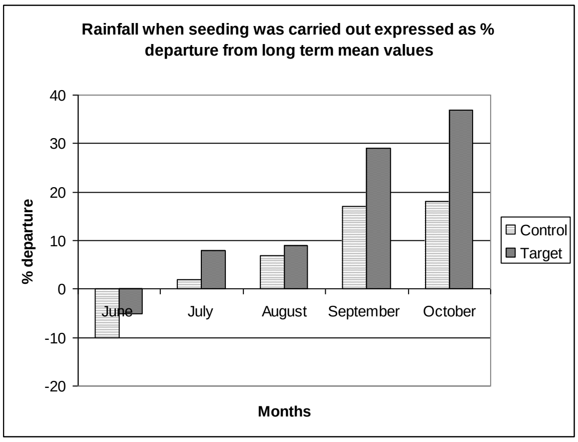

Figure 2: % Departure from the Long Term Mean Values for Target and Control Cases

Figure 2 shows the simpler representation of the monthly rainfalls as percentage variations from the long-term mean. It can be seen that the distribution of monthly rainfall for a long-term station upwind of the target area, reveals the influence of mainly above average monthly rainfalls. Results indicate a greater efficiency in the seeded clouds, and the important feature that always the precipitation mass of a rain cloud is greater than its cloud mass. The efficiency of 'the average seeded cloud' as a rain factory was estimated around 10, which means that the precipitation mass was 10 times the cloud mass, whereas for 'the average control cloud,' the corresponding value was only about 7. The relative efficiency was then increased by 30%.

The Single Ratio [SR], Double Ratio [DR] and Root Double Ratio [RDR] statistics were calculated using the actual ground truth measurements obtained by the reading in the rain gauges (Table 6). Using the DR statistics it was found that the target area received 13% increase in rainfall for 'A' type clouds with a P value of 0.020, 15% increase for 'B' type clouds with a P value of 0.023 and a 23% increase for 'C' type clouds with a P value of 0.013. Similar results were derived using the RDR methods of analysis.

Table 6: % Increase in Rainfall for Various Cloud Types in Anantapur District

	SR Method		DR Method		RDR Method	
	% Increase	P Value	% Increase	P Value	% Increase	P Value
Type A	17	0.30	13	0.16	15	0.008
Type B	19	0.45	15	0.15	15	0.009
Type C	21	0.42	23	0.13	24	0.002
Single ratio [SR] indicates simple ratio between seed / no-seed Double ratio [DR] (Gabriel 1999) Root double ratio [RDR] (Gabriel 1999)						

Studies carried out by Fowler et al 2001, have shown that the differences between seeded and non-seeded rain mass were statistically significant with the p-value <0.05. It was also found that the log of rain mass data showed both the mean and median values of the seeded group higher than those of the non seeded group. Based on the results obtained an attempt was made to estimate an average benefit / cost ratio with relation to the amount spent on the seeding operations and the enhancement that could be attributed to seeding and was estimated to be 3.5: 1.

CONCLUSIONS

Precipitation enhancement experiments were carried out in Andhra Pradesh in 12 districts for a period of five years. This paper attempts to showcase the results for Anantapur district. ICA values were calculated for 12 districts, and the highest was found to be districts of Anantapur, Kurnool and Nellore. Clouds were divided into type A, B and C and their efficiencies were of the order of 38, 50 and 75 respectively. Results have shown that the difference for the anvil losses for seeded to unseeded was around 0.1km. The efficiency increase in the rain was estimated to be around 30% and the cost benefit ratio was 3.5: 1.

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