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Cloud Seeding Operations for Drought Mitigation

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Abstract : Cloud Seeding for Precipitation Enhancement has been carried out by Government of Andhra Pradesh, India in the Rain Shadow (<600 mm) Region of Andhra Pradesh between latitudes 12°36' to 19°08' and longitudes 76°38' to 80°55' covering an area of 1,35,680 km^2 in the 12 districts during 2003-2009. Mostly the cloud seeding has occurred between the altitudes of 1200-2500 m above mean sea level with an updraft velocity of 0.5-3 m/s. This conforms that these clouds are warm clouds well below the freezing level (5800 m) in the seeding area. Most of the clouds are seeded at the base by releasing hygroscopic material (mostly Calcium Chloride) with the help of pressurized aircrafts fitted with hygroscopic flares. C-Band analogue weather RADARs with TITAN (Thunder Strom Identification Tracking and Now casting) software were used to identify the clouds and to analyze the cloud growth. On an average not more than 23% of the seedable clouds are seeded with the existing infrastructure. It is observed from the RADAR data that there is an increase in Cloud Volume, Area, Reflectivity, Life and Lowering of Centroid after seeding indicating that the Clouds are responding to seeding material. It is also observed in general that, cloud seeding is more effective if we get active monsoon clouds and it is less effective if we get weak monsoon clouds. Overall about 17% of total rainfall could be attributed to cloud seeding during the years 2005-2009.During the Phase-I component of the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) by Government of India, it has been inferred that warm rain processes are suppressed due to the presence of heavy haze over the Indo-Gangetic plains, indicating the necessity of introducing Hygroscopic Giant Cloud Condensation Nuclei artificially to trigger the precipitation processes.

INTRODUCTION

Thirteenth world meteorological congress in May 1999 noted that the weather modification for rainfall enhancement is one of the tools in the total gamut of water resources management (WMO, 1999). In the Indian context it is well established fact that even if we achieve ultimate irrigation potential, we can irrigate only 30% of cultivable land, remaining 70% is under rain fed conditions where erratic and low rainfall is the problem (IWRS, 1999). Research shows that even the watershed management activities in the rain fed agriculture may not yield good results if the rainfall deficiency is more than 20% (ICHWAM, 2002). In India the Meteorological drought is declared if the rainfall deficiency is 25% and above (Subramanya, 2005). If the cloud seeding programme could cover the above deficiency of rainfall it is worth taking up. This was the background under which cloud seeding operations in Andhra Pradesh were started in the year 2003 and has been continued till 2009.

What is cloud seeding for rainfall enhancement?

Cloud seeding for rainfall enhancement is a process of introducing Cloud Condensation Nuclei (CCN) of appropriate size of hygroscopic (for warm cloud) or glacio-genic (for cold cloud) nature in to the cloud to enhance the cloud's ability to precipitate. Usually to produce a rain drop a cloud condensation nuclei is required surrounding which water vapor condenses and forms as rain drop that falls on the earth under the gravity. The CCN is naturally produced by aerosols emanated from various mechanisms including evaporation from the oceans (Sodium Chloride) and continents, apart from wind blown dust and various gaseous emissions from industries, transport and burning of forests etc. Not all these aerosols contain required size and number of CCN to produce natural rain. Whenever such depletion of CCN is observed in the natural clouds we introduce required CCN in to the clouds artificially to enhance the rainfall known as cloud seeding for rainfall enhancement.

Some earlier Cloud Seeding Experiments in India

In India as early as 1951, TATA firm has used Silver Iodide through ground generators to seed the clouds over the Western Ghats (CAIPEEX , 2009a). The rain and cloud physics research unit under the aegis of Council of Scientific and Industrial Research has conducted long term cloud seeding programme over North India, using ground based salt generators during the period 1957-1966. The results showed an increase in rainfall by 20% (Ramana Murty et al, 1968). Indian Institute of Tropical Meteorology has conducted several cloud seeding experiments during 1973-74, 1976 and 1979-86. The results showed 24% increase in the rainfall (Murty et al, 2000). During the decade 1980-1990, the world has witnessed many advances in the airborne instrumentation, radars, flares and software's. They got imported to India in new millennium. In the year 2003 the Government of Karnataka has initiated cloud seeding with modern gadgets like radars and aircrafts Government of Maharashtra followed a month later.

Cloud seeding operations of Andhra Pradesh.

The Government of Andhra Pradesh has declared nearly 555 Mandals (revenue and administrative divisions with in the district) as Rain Shadow Area mainly in the districts of Ranga Reddy, Nalgonda, Medak, Karimnagar, Mahaboobnagar, Guntur, Prakasam, Nellore, Kurnool, Anantapur, Kadapa and Chittoor. In these Mandals the average annual rainfall is less than 600 mm and below. That is why they were declared under Rain Shadow Area in the year 2005. The Cloud Seeding is aimed to enhance the rainfall as well as to narrow down the dry spells during the monsoon season. In Andhra Pradesh Cloud Seeding was started in the year 2003 and has been continued year after year till 2009 - perhaps one of the biggest and longest operational cloud seeding program in Southeast Asia with an average cost of around rupees 25crores per year. In 2003 the Cloud Seeding was monitored by Water And Land Management Training and Research Institute (WALAMTARI) while it was Panchayati Raj Department, Government of Andhra Pradesh in the year 2004. Later from the year 2005 onwards the Government of Andhra Pradesh has created Rain Shadow Areas Development (RSAD) Department and entrusted the monitoring of the Cloud Seeding to Jawaharlal Nehru Technological University Hyderabad (JNTUH) in view of the program's Scientific and Technological nature. The JNTUH in turn has established a separate department namely Centre for Earth, Atmosphere and Weather Modification Technologies (CEA&WMT) and has been monitoring the Cloud Seeding Programme with experienced and expert Meteorologists since the year 2005.

Cloud seeding operations in the 2009 drought year

Never before the state has witnessed both severe drought and floods as in the year 2009. The A.P Cloud Seeding Programme for the first time has faced the severe drought situation and tried to mitigate it as much as possible. The result is that the cloud seeding has helped in mitigating the drought to some extent but could not avert it since the number of seedable clouds available in the severe drought situation is far less when compared to normal situation. An analysis of the rainfall data of seeded mandals provided by the Bureau of Economics and Statistics, Government of Andhra Pradesh has thrown an interesting fact that it is only 41.38 % of excess rainfall mandals in the state lies in the Rain Shadow Area at the beginning of the Cloud Seeding Programme, while the same figure has increased to nearly 95.65% by the end of the Cloud Seeding Programme in the year 2009 (Table.1). This figure has been achieved even before the floods in the Krishna Basin. The seeding locations during the monsoon period for the year 2009 and the corresponding rainfall for the same period is shown in Fig.1. From the figure it can be observed that most of the excess rainfall areas are located in the intense cloud seeding zones of Andhra pradesh.

Preliminary Results of the CAIPEEX Experiment by Government of India

The government of India has taken up a national experiment namely "Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX)" through Indian Institute of Tropical Meteorology (IITM). The main aim of this experiment is to understand microphysical properties of the clouds in the interaction between aerosol and the cloud apart from conducting cloud seeding experiments to enhance the rainfall in various parts of the country. This experiment was started in the year 2009 and will be continued till the year 2012. As part of the first phase, they have measured the microphysical properties of the clouds from May to September in the year 2009 at various parts of the country by flying with specially instrumented Cloud Physics aircraft for the purpose (CAIPEEX Implementation Plan, 2009). The preliminary results of these measurements are indicating that the clouds over Telangana and Rayalaseema regions are seedable to enhance the rainfall and observed that the

Table.1 : Weekly Cumulative rainfall status of Andhra pradesh for the monsoon period of year 2009.

Week	No of EXCESS rainfall mandals			No of NORMAL rainfall mandals			No of DEFICIENT rainfall mandals			No of SCANTY rainfall mandals			No of No Rain mandals		
	ANDHRA	RSAD	% in RSAD	ANDHRA	RSAD	% in RSAD	ANDHRA	RSAD	% in RSAD	ANDHRA	RSAD	% in RSAD	ANDHRA	RSAD	% in RSAD
01 JUN-10 JUN 2009	195	132	67.69	124	72	58.06	217	115	53.00	326	180	55.21	242	154	63.64
01 JUN-17 JUN 2009	153	146	95.42	163	121	74.23	263	176	66.92	466	188	40.34	59	22	37.29
01 JUN-24 JUN 2009	157	152	96.82	161	136	84.47	294	180	61.22	461	173	37.53	31	12	38.71
01 JUN-01 JUL 2009	159	128	80.50	197	129	65.48	374	222	59.36	363	168	46.28	11	6	54.55
01 JUN-08 JUL 2009	108	75	69.44	212	115	54.25	504	283	56.15	278	178	64.03	2	2	100.00
01 JUN-15 JUL 2009	[illegible]	36	**41.38**	[illegible]	107	**48.86**	[illegible]	318	**59.22**	[illegible]	120	**72.80**	[illegible]	0	**0.00**
01 JUN-22 JUL 2009	51	14	27.45	187	86	45.99	568	308	54.23	298	245	82.21	0	0	0.00
01 JUN-29 JUL 2009	27	13	48.15	118	44	37.29	536	280	52.24	423	316	74.70	0	0	0.00
01 JUN-05 AUG 2009	22	5	22.73	111	37	33.33	494	265	53.64	477	346	72.54	0	0	0.00
01 JUN-12 AUG 2009	17	3	17.65	79	20	25.32	459	251	54.68	549	379	69.03	0	0	0.00
01 JUN-19 AUG 2009	21	12	57.14	132	70	53.03	556	349	62.77	395	222	56.20	0	0	0.00
01 JUN-26 AUG 2009	42	31	73.81	207	140	67.63	670	381	56.87	185	101	54.59	0	0	0.00
01 JUN-02 SEP 2009	80	68	85.00	291	215	73.88	662	332	50.15	71	38	53.52	0	0	0.00
01 JUN-09 SEP 2009	56	51	91.07	310	222	71.61	673	340	50.52	65	40	61.54	0	0	0.00
01 JUN-16 SEP 2009	66	58	87.88	303	223	73.60	667	332	49.78	68	40	58.82	0	0	0.00
01 JUN-23 SEP 2009	60	58	96.67	283	207	73.14	688	341	49.56	73	47	64.38	0	0	0.00
01 JUN-30 SEP 2009	92	86	93.48	345	254	73.62	621	285	45.89	46	28	60.87	0	0	0.00
01 Jun- 07 Oct 2009	122	115	94.26	346	233	67.34	614	286	46.58	22	19	86.36	0	0	0.00
01 Jun- 14 Oct 2009	107	104	97.20	305	211	69.18	672	321	47.77	20	17	85.00	0	0	0.00
01 Jun- 21 Oct 2009	96	95	98.96	273	193	70.70	696	339	48.71	39	26	66.67	0	0	0.00
01 Jun- 28 Oct 2009	90	89	98.89	253	178	70.36	709	357	50.35	52	29	55.77	0	0	0.00
01 Jun- 04 Nov 2009	83	82	98.80	236	165	69.92	717	358	49.93	68	48	70.59	0	0	0.00
01 Jun- 11 Nov 2009	96	95	98.96	298	228	76.51	676	312	46.15	34	18	52.94	0	0	0.00
01 Jun- 18 Nov 2009	86	85	98.84	321	242	75.39	672	310	46.13	25	16	64.00	0	0	0.00
01 Jun - 25 Nov 2009	[illegible]	88	**95.65**	[illegible]	259	**73.58**	[illegible]	298	**46.06**	[illegible]	8	**61.54**	[illegible]	0	**0.00**

Total No of mandals in Andhra Pradesh is1104
Total No of mandals in Rain Shadow Area Development Region (RSAD) is 653

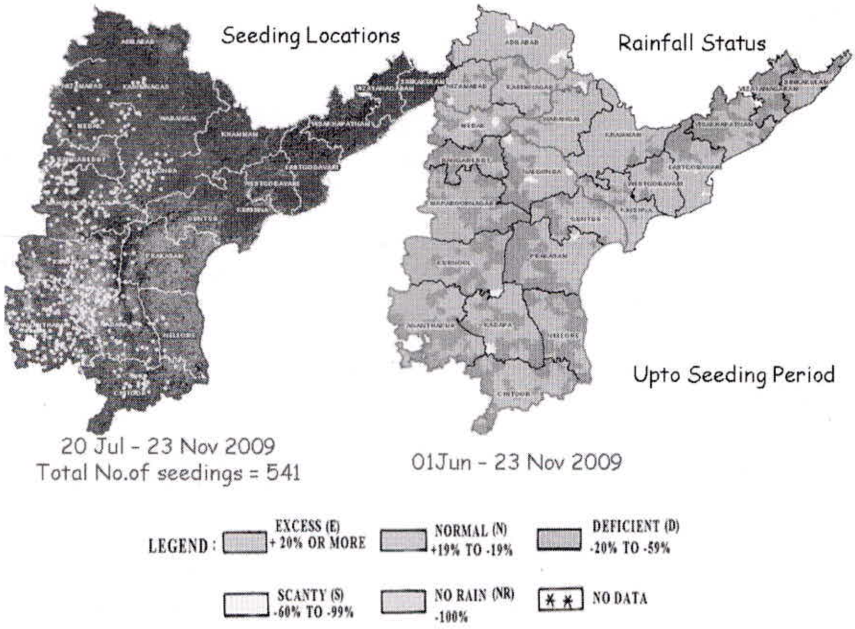

Fig. 1: Cloud seeding locations and rainfall status during the 2009 drought year.

natural Cloud Condensation Nuclei (CCN) over these regions is of the order of 0.5 microns (CAIPEEX, 2009b). In the cloud seeding programme it is the general practice that we introduce giant nuclei artificially which is having the size more than the natural CCN size to enhance the rainfall.

Meanwhile the CEA&WMT of JNTUH has tested the flares used in the Cloud Seeding programme of A.P by utilizing the above Cloud Physics Aircraft. In these tests it came to know that the flares being used are capable of producing the CCN size of the order of one micron and above which is more than the natural CCN size as mentioned above (Table.2). Infact these flares

Table 2 : Size of the CCN in the Natural clouds and Hygroscopic Flares.

HYDERABAD REGION		ANANTHAPUR REGION		FLARE	
Particles Size (Microns)	% of Total	Particles Size (Microns)	% of Total	Particles Size (Microns)	% of Total
0.2	41.60%	0.1	41.60%	0.8	28.50%
0.4	33.30%	0.3	33.30%	1	12.50%
0.6	16.60%	0.5	16.60%	0.2	14.60%
0.8	8.30%	0.7	8.30%	0.4	10.20%

were tested on the ground, the actual particle size near the cloud base during the operations will be more as per the cloud seeding Experts. According to existing literature the artificial CCN size has to be further increased to about 2 to 3 microns to get the better results. Infact the CAIPEEX programme will examine the resulting rainfalls with varying CCN materials and sizes during the years 2010 and 2011. We have to wait for the results at least for one more year. In view of these findings it can be said that the A.P. Cloud Seeding programme has been progressing well with the latest scientific and technological advancements.

Necessity of application of cloud seeding experiments in the Indo Gangetic Plains

During the Phase-I component of the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) by Government of India, it has been inferred that the monsoon clouds over the Indo-Gangetic plains occur with heavy haze, which is able to suppress the warm rain and the same heavy haze over this region appears to suppress even convection causing no rain in spite of the presence of synoptic scale convergence (CAIPEEX, 2009b). This scenario is indicating the necessity of introducing Hygroscopic Giant Cloud Condensation Nuclei (GCCN) artificially to trigger the precipitation processes. Similarly such experiments can be attempted in other parts of the country particularly low rainfall regions of western, northern and central India where natural CCN depletion is observed.

Infrastructure & equipment for cloud seeding Operations.

The cloud seeding operations over Andhra Pradesh were conducted with the aid of two C-Band Weather RADARs located at Hyderabad and Anantapur (Fig.2) and two Cessna Pressurized Aircrafts operated from Hyderabad and Bangalore. Most of the seeding was done with the Hygroscopic material (Calcium Chloride) which is burnt below the cloud base where the updrafts are maximum. Generally the seeding activity was covered in the districts of Southern Telangana and Rayalaseema region with latitudes of 12^{0}36’ to 19^{0}08’ and longitudes of 76^{0}38' to 80^{0}55’. The raw data of RADAR has been processed with the help of TITAN (Thunderstorm Identification, Tracking, Analysis and Now casting) software (Dixon et al, 1993) and used to vector the aircrafts towards the seedable clouds. Usually the seedable clouds are having the reflectivity of at least 20 dBZ and appeared mostly in the monsoon season between the months of June to November covering both South West and North East monsoon.

The success of the cloud seeding experiment is evaluated by analyzing the TITAN processed RADAR data with Target and Control Method, Double Ratio Method and Chemical Analysis of Rainwater samples. Moreover the altitudes of the seeding operations, associated updrafts at the cloud base and the availability of clouds in a given season were also analyzed.

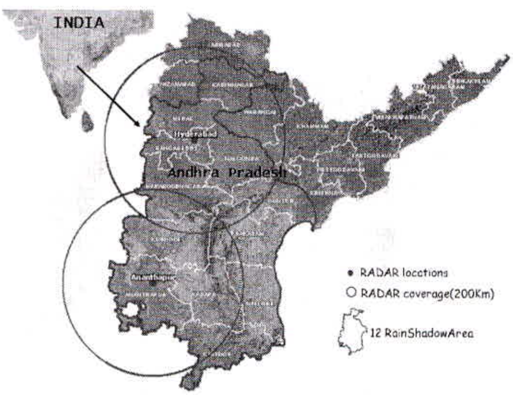

Fig. 2 : Geographic coverage of Hyderabad and Anantapur RADARs.

Target and Control Method

In this method the target means the seeded cloud, while the control means the unseeded cloud, which are selected in such a ways that they are

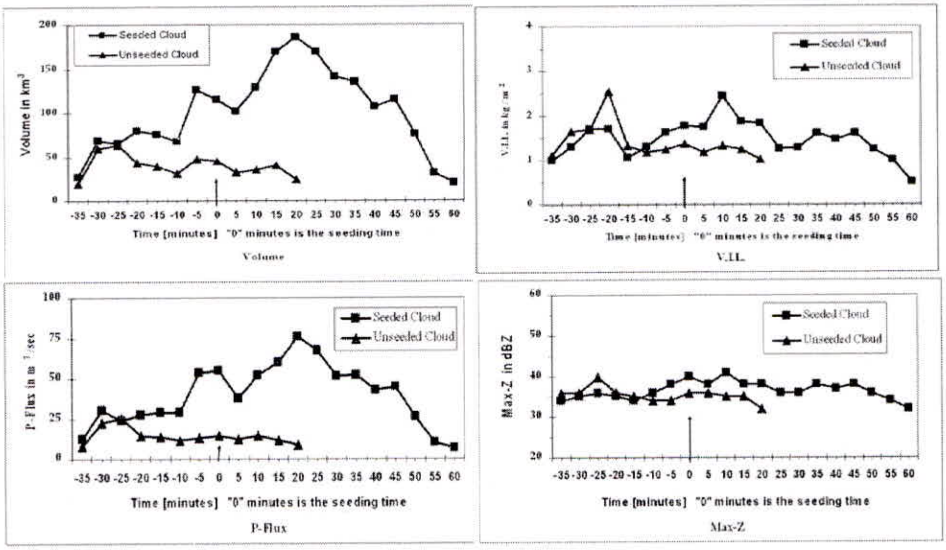

Fig. 3 : Temporal variation of various parameters of the seeded and unseeded clouds on August 11, 2008.

50-60 km apart in cross wind direction, appearing at same time within in the 90 km radius of the RADAR vicinity and they should possess the similar magnitude of microphysical properties up to the time of seeding. The results are analyzed by plotting the temporal variation in the parameters such as Volume, Area, Mass, Vertical Integrated Liquid Content, Precipitation Flux, Height of Maximum Reflection, Cloud Base Height, Cloud Top Height. However only four parameters are discussed as shown (Fig.3) for a case study on August 11, 2008, 11:20GMT.

From the Fig.3 it can be observed that, all the four parameters of the seeded cloud have shown increase in magnitude, though they are in decreasing stage at the time of seeding, while the same is not happened for the unseeded cloud. The increase of dBZ value after seeding, followed by increase in Vertical Integrated Liquid content indicates that there is a formation of liquid water droplets. This in turn is well supported by increase in Precipitation flux, indicating that there is an increase of mass at the base of the cloud. Similarly the growth of the Volume of the cloud after seeding may confirm that there is a release of heat energy due to the formation of water droplets in the cloud. Moreover the seeded cloud has lasted for longer duration, compared to the unseeded cloud.

In order to remove the bias in selection of the individual clouds for comparison purpose, 20 seeded and 20 unseeded clouds are selected from the same region, in such a way that they have the life time of 50 to 60 minutes and seeding was occurred with in the first 30 minutes of the cloud genesis. The graphs (Fig.4) are drawn for the temporal variation of the total rain mass of the seeded and unseeded clouds. From the graphs it can be observed that, initially both seeded and unseeded clouds have shown intense growth during first 15-20 minutes, however the seeded clouds have shown higher magnitude of rain mass and lasted longer than the unseeded clouds.

Double Ratio Method

It is the ratio of two ratios and is given as follows (Ali Umran, 2008).

$$I.C = \frac{[S / NS]}{[H / K]} \qquad (1)$$

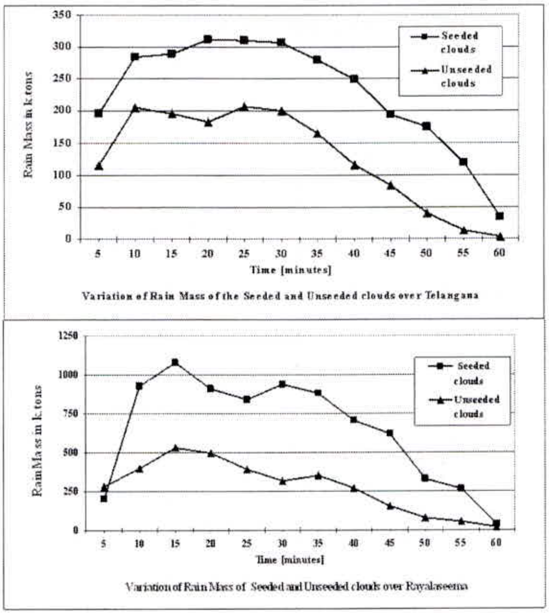

Fig. 4 : Temporal variation of Rain Mass of the 20 seeded and 20 unseeded clouds over Telangana and Rayalaseema regions of Andhra Pradesh in the year 2008.

Table 3 : Calculation of Impact Coefficients using Double Ratio Method for Nalgonda (Target) and neighboring districts (Control).

Correlations coefficients for Nalgonda district vs. Control districts				
↓Target /Control districts→	Mahaboobnagar	Ranga Reddy	Medak	
Nalgonda	0.78	0.6	0.45	
Impact Coefficients for the year2008 for 17 Days of Cloud Seeding operations				
	A = S/NS	b = H/K	I.C= a/ b	Change %
Nalgonda vs. Mahaboobnagar	1.68	1.07	1.57	57
Nalgonda vs. Ranga Reddy	1.61	0.85	1.89	89
Nalgonda vs. Medak	1.52	0.83	1.83	83
Impact Coefficients for the year 2007 for 21 Days of Cloud Seeding operations				
	a = H/K	b= S/NS	I.C= b/a	Change %
Nalgonda vs. Mahaboobnagar	1.41	1.07	1.32	32
Nalgonda vs. Ranga Reddy	1.18	0.85	1.39	39
Nalgonda vs. Medak	1.84	0.83	2.22	122

Where IC = Impact Coefficient, S = Total rainfall in the target area during seeding period, NS = Total rainfall in the control area during seeding period, H = Total rainfall in the target area during 10 unseeded years, K= Total rainfall in the control area during 10 unseeded years.

If I.C>1, then it indicates the influence of seeding. In the present paper, target area and control area are selected in such a way that, they are from the same climatic zone and the correlation coefficient between rainfalls of target and control areas for the 10 unseeded years is maximum. The results are as shown in Table.3. From the Table.3 it can be observed that, Nalgonda district is taken as target and the neighboring districts are taken as controls. Nalgonda and Mahaboobnagar are highly correlated in their natural rainfall occurrence with a correlation coefficient of 0.78. The Impact Coefficient of 1.57 between these districts indicates that there is a 57% change in the rainfall in the target district during the seeding days, indicating the influence of seeding by way of rainfall enhancement up to 57% in the target district.

Chemical Analysis of Rain Water Samples

Rain water samples for the years 2007 and 2008, from Nalgonda and Chittoor districts were collected during seeded and unseeded days and analyzed for the concentrations of Calcium and Chloride - the prime cation and anion present in the Hygroscopic material used for seeding. The results are as shown in Fig.5. It can be observed from the Fig.5 that, from the majority of the cases the magnitude of the calcium and chloride is more in rainwater samples collected from the seeded clouds than that of the unseeded clouds, confirming the fact that the Hygroscopic material

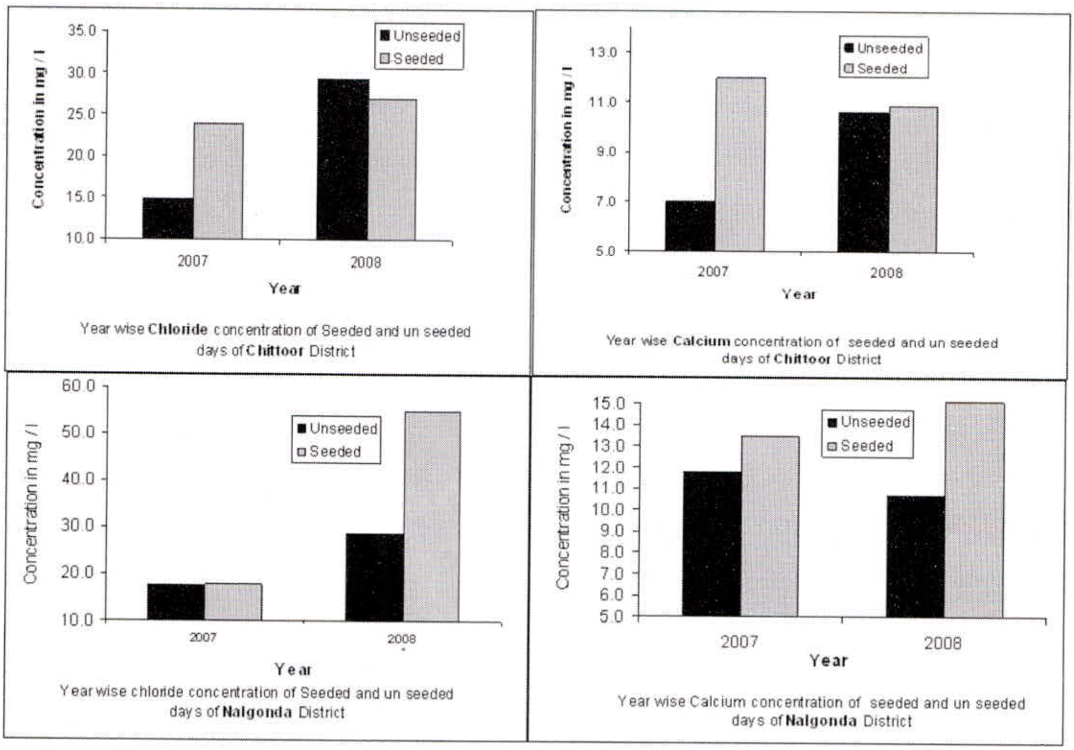

Fig. 5 : Concentrations of Calcium and Chloride in the rainwater samples of the seeded and unseeded days.

is released at the base of the clouds is acting as Cloud Condensation Nuclei.

From the above three analyses it can be reasonably inferred that, the clouds in this region are responding to the seeding. And the magnitude of the growth is quite substantial. In order to further probe in to the seeding details the updrafts and seeding altitudes are also analyzed.

Seeding Altitudes and Updrafts

The altitudes and updrafts at which the seeding occurred over the years (2005-2008) were recorded from the flight logs and are shown in Fig.6 and 7. From the Fig.6 it can be observed that most of the seedings were performed at an altitude range of 1 to 2 km, indicating that warm cloud seeding is predominant. Moreover during the initial years like 2005 and 2006,

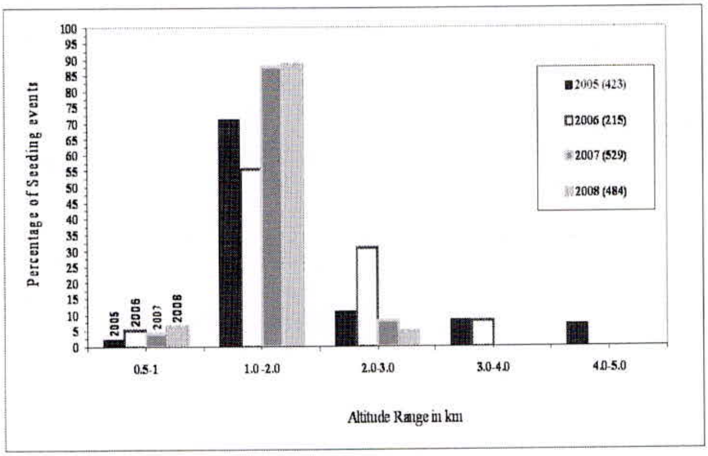

Fig. 6 : Seeding Altitudes over the years 2005-2008.

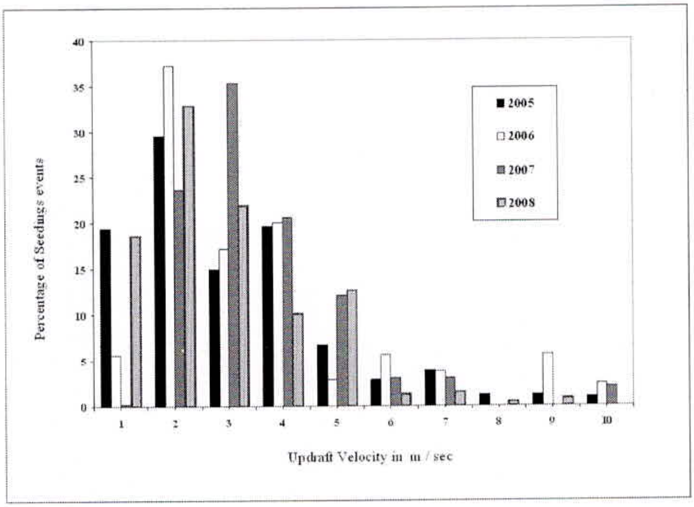

Fig. 7 : Updrafts observed at the cloud base over the years 2005-2008.

cold cloud seeding too (above 4 to 5 km) was also experimented, but from the operational point of view it was observed that it is better to seed warm clouds in view of their large number of availability over the region.

From the Fig.7 it can be observed that the updrafts observed at the base of the cloud during the time of seeding is varying between 1 m/sec to 5 m/sec in most of the times, but occasionally it is reaching up to a maximum of 10 m/sec. Since most of the clouds were seeded within the first 30 minutes after their genesis, the updrafts indicated above gives suitable updraft range for effective seeding in this region and prevalence of convective activity in the cloud during this time.

Influence of Active and Weak monsoon over cloud seeding operations

During 2009 cloud seeding operations there was a continuous weak spell followed by active spell in the South West monsoon. The responses of the clouds due to seeding in these spells were observed by analyzing various microphysical properties of the seeded clouds. Based on the growth observed in the properties of the cloud after seeding, the responsiveness of the clouds was determined and is depicted in the Fig.8.

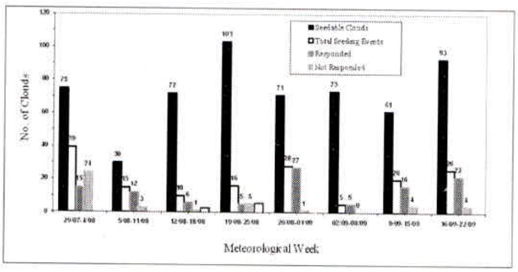

Fig. 8 : Responsiveness of the Clouds for Cloud Seeding during 2009 over Rayalaseema Region.

From the Fig.8 it can be observed that, the more the active the monsoon, the more is the number of clouds available for seeding and the more is the responsiveness of clouds for seeding. It means that rainfall enhancement is more during the active monsoon due to increased moisture feeding.

Success rate and number of clouds seeded

For the year 2009 an analysis has been carried out to calculate number of clouds seeded and their success rate as identified from the RADAR data of Hyderabad and Anantapur stations and is shown in Table.3. From this table it can be observed that the overall success rate of the cloud seeding programme is of the order of 76%. It means that nearly 25% of the clouds are not responding to the seeding operations and the reasons for the same could be attributed to variations in the microphysical properties of the clouds at the time of seeding in the same synoptic situation. Therefore in-depth observations of microphysical properties of the clouds before and after seeding are necessary to enhance the success rate for a given seeding material. Similarly there is a necessity of observing the microphysical properties of the clouds for different seeding materials by varying the particle size and chemical composition. More over it can also be observed from the Table.3 that we could able to seed hardly 23% of the available seedable clouds on a seeding day leaving nearly 77% clouds unseeded. This indicates that there is huge scope of development of infrastructures such as RADARs and aircrafts for cloud seeding operations in this region.

Computation of Rainfall Enhancement through actual ground truth observations

Ground truth is often difficult to establish as the existing Rain Gauge network is insufficient. For such an experiment more Radio Reporting Rain Gauges are required to compliment the operations. However with existing Rain Gauge Network (i.e. one rain gauge per mandal covering an average area of 268.62 km^2), the rainfall analysis is carried out. In each Rain Gauge, previous 24 hours rainfall is recorded and reported daily at 03:00 GMT. The total rainfall occurred on a particular day in a Rain Gauge is taken as the

Table 4 : Summary of performance of clouds to seeding activity for Hyderabad and Anantapur in the year 2009

	Hyderabad Radar	Anantapur Radar
Total No of Seedable Clouds Appeared	1305	1046
Total No of Seeding Events	188	335
Total No of Seeding Events Visible on Radar Screen	174	272
Total No of Seeding beyond Radar + Seeding Not Visible Clearly + Pilot Seeded on his own	14	63
Total No of Responded Clouds	118	227
Total No of Not Responded Clouds	56	45
Percentage of Seeding (Total No of Seeding Events / Total No of Seedable Clouds)	=((188/1305)*100)=14.4%	=((335/1046)*100)=32%
Percentage of Responded clouds in Seeded Clouds (Responded / Total Seedings)	=((118/174)*100)=68%	=((227/272)*100)=83.45%
Percentage of Not Responded clouds in seeded clouds	=((56/174)*100)=32%	=((45/272)*100)=16.5%
Average Percentage of Responsiveness of the Clouds (HYD and ATP Radars)	75.7%	
Average Percentage of Not Responsiveness of the Clouds (HYD and ATP Radars)	24.3%	

rainfall resulting out of seeding, if that Rain Gauge falls under zone of influence of the seeding. The zone of influence is taken as the area covered by the circle with a radius of 50 km from the point of seeding. Though exact calculation of enhancement of rainfall due to seeding is not possible with the present day rainfall measurements, but it has been estimated that on an average about 17% of rainfall may be attributed due to cloud seeding operations over Rain Shadow Region of Andhra Pradesh during the period 2005 to 2009 (Table.4). Out of the five years 2007 is a active monsoon year and 2009 is a weak monsoon year. From the Table.4, it can be found that the more the vigorous the

Table 5 : Summary of rainfall enhancement estimation over Andhra Pradesh during 2005-2009.

Year	No. of Mandals Seeded	Cumulative rainfall during seeding period (mm)	Cumulative rainfall under zone of influence due to seeding (mm)	Average Rainfall per Mandal due to seeding (mm)	Average Rainfall per Mandal during seeding period (mm)	Rainfall attributed to cloud seeding operations in%
1	2	3	4	5 (5=4/2)	6 (6=3/2)	7 (7=5/6*100)
2005	492	292770.9	37633.8	76.49	595.06	12.85
2006	377	68356.0	11788.3	31.26	181.31	17.24
2007	575	322921.1	61910.4	107.6	561.60	19.15
2008	505	232022.3	42357.5	83.87	459.45	18.25
2009	481	230556.7	39239	81.57	479.32	17.01

monsoon the higher is the rainfall enhancement due to cloud seeding.

Other applications of weather modification

The Cloud Seeding Operations in Andhra Pradesh though mainly applied for enhancing the rainfall by controlled seeding, the other weather modification techniques includes suppression of hail storms during pre monsoon season, dissipation of Clouds during flooding season by over seeding and dissipation of fog during winter season by controlled seeding techniques. These applications are already being in use in many other countries. The biggest example is that during Olympics in China, they have stopped the rain during opening and closing ceremonies.

CONCLUSIONS

Cloud Seeding operations for rainfall enhancement over Rain Shadow Region of Andhra Pradesh have clearly demonstrated that the clouds are responding substantially to the Hygroscopic seeding as has been observed from the RADAR data with respect to growth in cloud Area, Volume, Mass, Vertical Integrated Liquid Content and Precipitation Flux after the seeding. The same is confirmed from the presence of Calcium and Chloride- the basic Hygroscopic material used for seeding in the rain water samples. Similarly the ground truth rainfall analysis has also shown that on an average 17% of rainfall could be attributed to cloud seeding in the Rain Shadow Region. It has been found that most of the seedable clouds in the area are warm clouds occurring at an average altitude of 1 to 2 km with an average updraft of 2 to 5 m/sec. it was also observed that the more the vigorous the monsoon the more is the success of the cloud seeding operations in enhancement of the rainfall. Hardly 23% of the clouds are seeded with the available infrastructure leaving a huge scope for infrastructural improvement in terms of deployment of additional RADARs and Aircrafts. During the Phase-I component of the Cloud Aerosol Interaction and Precipitation Enhancement Experiment (CAIPEEX) by Government of India, it has been inferred that warm rain processes are suppressed due to the presence of heavy haze over the Indo-Gangetic plains, indicating the necessity of introducing Hygroscopic Giant Cloud Condensation Nuclei artificially to trigger the precipitation processes.

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