Available online www.jsaer.com

***Journal of Scientific and Engineering Research*, 2017, 4(1):81-88**

Research Article

ISSN: 2394-2630
CODEN(USA): JSERBR

Identification of Seeding Signatures in the Radar Response Variables of the Cloud Cells Seeded with Hygroscopic Flares

Chandra Bharadwaz S.S.[1], P. Sreedhara Reddy[1], B. Venkateswara Rao[2], C.V. Narasimha Murthy[3]

[1]Sri Venkateswara University, Tirupati, India
[2]Jawaharlal Nehru Technological University, Hyderabad, India
[3]Jawahar Bharati college, Kavali, India

Abstract The cloud cells seeded by dispersing the hygroscopic material near the updrafts regions at the cloud base. Various seeding signatures have been identified in the radar response variables of the cloud cells seeded with hygroscopic flares. It was possible to compare the variations in vertical structure, distribution of maximum reflection (Max-Z) and various other parameters of seeded to not seeded cloud volumes with the help of TITAN software. The results suggest that the seeding works by hygroscopic CCN being embryos of raindrops. Hygroscopic flares produced a detectable effect, probably due to presence of giant CCN. These signatures suggests that hygroscopic flares found to be releasing the CCN of theoretically optimal size, diameter and produced consistent, repeatable signatures of added drizzle drops that increased in size with height above cloud base. The seeding signatures identified in the variation of the maximum reflection (Max-Z), height of maximum reflection (Ht-maxZ), vertical integrated liquid content and precipitation flux of the cloud cells have been discussed in this paper.

Keywords hygroscopic flares, characterization, seeding signatures

Introduction

The results of the randomized cloud seeding experiment in South Africa using hygroscopic flares have prompted renewed interest in seeding with hygroscopic particles. Availability of water for rain based crops has always been a critical issue in Andhra Pradesh, as the state is vulnerable to drought and the associated lack of rainfall in many regions coming under the rain shadow region, which forms at the eastern side of the Western Ghats. The Rain Shadow Area Development Department of Andhra Pradesh state has identified 12 regions (whose average annual rain fall is <600mm) prone to severe droughts and the cloud seeding programme has been initiated for precipitation enhancement in the operational mode. The first rainfall enhancement efforts in India date back to the early 1970s (11-year experimental programme of air-borne cloud seeding experiments was in progress in the Pune region ($18^0$32'N, $73^0$51'E, 559 AMSL) India from 1973 to 1986 except during 1975, 1977 and 1978) and the Andhra Pradesh state has initiated operational mode "precipitation enhancement program" in the year 2004, in which the CCN was injected in to the clouds from burning flares at the premises of the cloud base where the updrafts are found to be suitable during the SW monsoon and NE monsoon periods.

A review on the status of modification of precipitation from warm clouds has been discussed in an excellent paper by Cotton (1982) [1]. And the later progress was reviewed by Ramanamurty (1984) and Czys and Bruintjes (1994) [2-3]. The whole scenario of weather modification up to the year 1995 has been discussed by Orville (1995) in his report on the WMO Scientific Conference on Weather Modification held at Paestum, Italy during 30 May – 4 June 1994 [4]. Most of the warm rain processes have been simulated in the laboratory as well as in modeling work. Although favorable from the theoretical point of view, the experiments for rain enhancement from warm clouds, conducted up to the present time, do not have the necessary physical observations for clear-cut evaluation and possible technology transfer [5]. Cloud simulations and observations showed that hygroscopic seeding is most effective with ~1 µm and more than 1µm diameter particles [6]. From this discussion it is clear that there is need to identify the influence of the seeding material on the variations and changes in the cloud parameters seeded with hygroscopic CCN. Various case studies have been made with the help of post processing facility available in the TITAN software to know the changes that occurred in the radar response variables of the clouds seeded with the hygroscopic flares and the case study made on 02, September 2009 has been discussed in this paper.

Instrumentation and Data Analysis

Two C-band weather RADARs have been installed to monitor the clouds that appear over the 12 rain shadow regions identified by RSAD department, one RADAR was kept on the top of the Government Engineering College, Ananthapur district and the other was kept on the top of the Institute of Science and Technology Building, JNTUH. The clouds data observed have been analyzed by TITAN (Thunderstorm Identification Tracking Analysis and Now-casting) software which can process, display the raw data of the clouds and convective systems as described by Dixon and Weiner (1993) [7]. This software runs on a high performance personal computer using the Linux operating system in an X-Windows environment. TITAN has five main purposes (a) Ingestion of RADAR data, (b) Pre-processing and storage of data, (c) Application of real-time algorithms on data, (d) Display of data and algorithm output, (e) Provision of post-analysis. TITAN is capable of many different real-time and post-analysis operations including: CAPPI (Constant-Altitude Plan Position Indicator) - a two dimensional, composite display of the RADAR echoes observed at the specified height over the area observed by the RADAR, Vertical cross-sections through any portion of the echoing cloud mass, Aircraft flight track display capability, Display of storm history, including storm motion and intensity, Projection (forecast) of storm motions, Precipitation mapping. The definition of a “cell” for storm tracking purposes on the TITAN was defined as a RADAR echo of 20 dBZ or greater, with an echoing volume greater than 12 km^3 above 3000 ft MSL. As cells develop, they are automatically assigned tracking identification numbers (Ids) by TITAN. The RADAR operator could then display a variety of parameters related to the history of a selected cell like maximum cloud top height and maximum reflectivity height (HT-MaxZ). The cloud seeding Infrastructure equipment included: two C-Band Weather Radars, RDAS, Real-time Air Link Telemetry, two Cessna 340A seeding-equipped aircrafts and one Cessna 188 AGWAGON seeding-equipped aircraft. This operational cloud seeding programme was monitored by a Technical Monitoring Committee of eminent people from different branches of Meteorology appointed by Jawaharlal Nehru Technological University, Hyderabad (JNTUH). The changes in the radar response variables due to the injection of CCN particles emanating from the burning flares have attracted attention of the committee members during every TMC Meeting and motivated this analysis.

Identification of Seeding Signatures in the cloud cells seeded with hygroscopic flares.

From the analysis made on the radar response variables of the unseeded and seeded cloud cells with the help of TITAN software it is observed that there is a marked difference in the variation of some of the radar response variables of seeded cloud cells like “maximum reflection (MaxZ [dBZ]), height of maximum reflection (Htmax-Z) and precipitation Flux (P-flux)” than unseeded cloud cells after the time of seeding. Images of the seeded and unseeded cloud cells processed by TITAN software are shown in figures 1a and 1b.

In the figure 1(a) we can observe 5 windows giving various details of the clouds processed by TITAN software. There are two windows on left half side of the image and three windows on right half of the image. We can see the images of the unseeded cloud cell (track no 1077) considered for the case study (encircled with red color), path of the aircraft embossed on the cloud images in white color (encircled in yellow color) and the cloud cell which is going to be seeded (encircled with orange color dots) in the upper left corner window called as main window. We can also observe the time line in the window just below the main window. Similarly the right hand side of the figure contains three sub-windows. Starting from the upper right corner to lower right corner window, the first window called as “storm-time history window” shows the radar response variables of the unseeded cloud cell (1077).

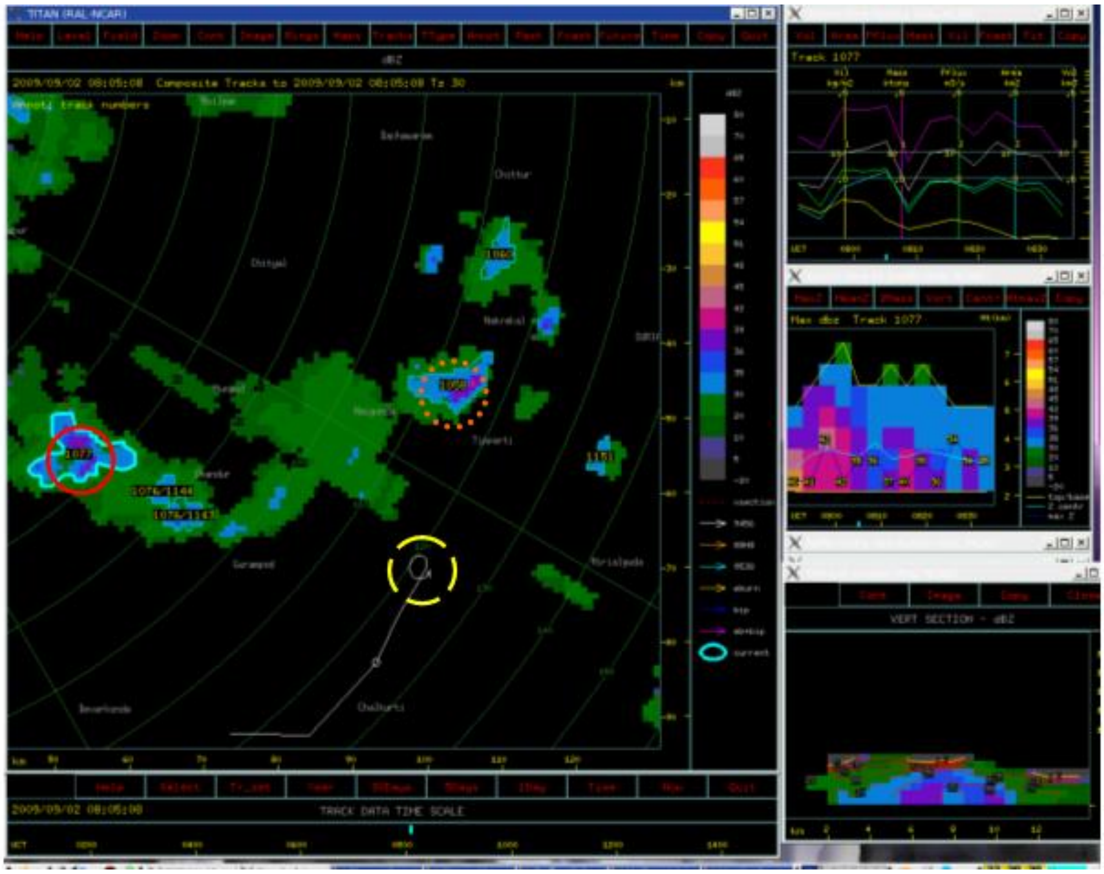

Figure 1(a) Image of seeding flight track (encircled in yellow color), unseeded cloud track no 1077 (encircled in red color) and seeded cloud track no 1058 (encircled in orange color dots), along with storm-time history, storm time-height and vertical view of the unseeded cloud cell in upper right, middle right and lower right corner windows on 02-09-2009.

The “storm-time-height history” window which is just below the upper right corner window shows the distribution of Max-Z, cloud base height, cloud top height, Ht-MaxZ of the unseeded cloud cell 1077. The window which is at the lower right corner of the image shows the “vertical cross sectional view” of the unseeded cloud cell 1077 derived by TITAN software. From “storm-time history window” of the figure 1(a) we can see the distribution of Max-Z, Ht-MaxZ, cloud base height and cloud top height. From that window we can observe that the magnitude of the Max-Z value was 46 dBZ in the initial scan at a height below 3km and then decreased to 41 at 3km altitude by second scan and has again increased to 42 dBZ at 4km by third scan and the reflection value was same in the fourth scan with a decrease in Ht-MaxZ to below 3km altitude. From the overall observation of the variation of Max-Z and the height associated with it (Ht-MaxZ). We may assume that the unseeded cloud cell considered has generated with maximum reflection (46dBZ) at height below 3km indicating the presence of large number of cloud droplets initially and the Max-Z values have under gone many variations along with the height associated with it which may be an indication of the occurrence of collision and coalescence due to vertical mixing caused by the updrafts entering from the base of the cloud. This entire mixing phenomenon seems to be occurred several times during its life time and contributed to the increase of the size of the droplets by changing number concentration indicating decrease and increase in reflection values as well as the values of Ht-MaxZ. But the decrease in Ht-MaxZ can be considered as indication for the increase in the size of the cloud droplets and these droplets increased in size (due to collision and coalescence) might have came down towards the base of the cloud due to the gravitational pull and have precipitated in the form of rain. The rain fall observed in the area covered under this cloud cell also discussed in the next sections.

Similarly the data of the seeded cloud (Track No.1058) processed by TITAN software is presented in the figure 1b.

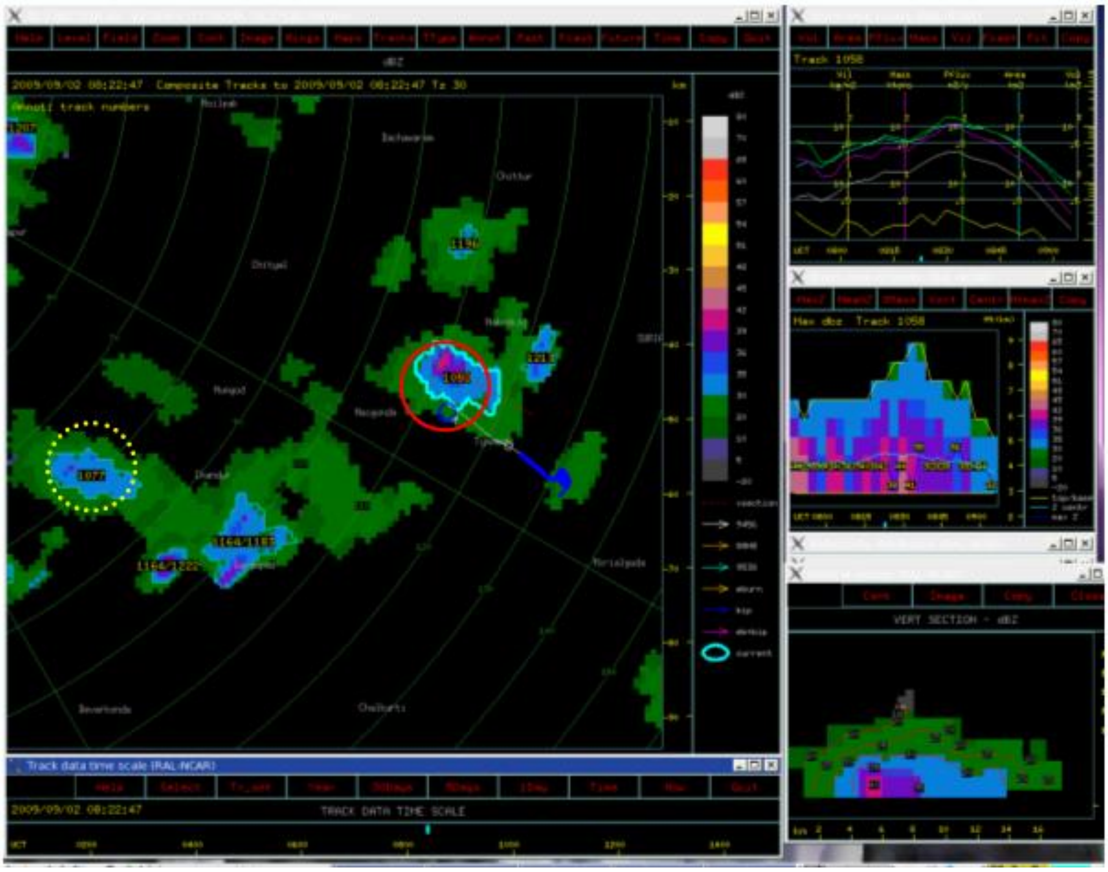

Figure 1(b). Image of the seeded cloud cell (Track no 1058) at the time of seeding (encircled with red color), image of the unseeded cloud cell (Track no 1077) (encircled with yellow color) in the upper left window of the figure.

From the figure 1(b) we can see that the cloud cell with track no 1058 has been seeded with hygroscopic flare consisting of an amount of 1kg flare material. In the same figure we can observe the path of the aircraft used for seeding the cloud in white color line. Normally the color of the flight path will be shown in white color, where as at the time of seeding an arrangement is made to change the color of flight path from white color to any other color depending up on the type of flare and aircraft we are using to seed the cloud cells with the help of software. For example in the present case an arrangement is made to change the flight path color from white to blue at the time of burning of the flare near the base of the cloud cell with track no 1058. And we can also observe the storm time history (upper right corner window), storm time height profile (right side middle window just below the upper right corner window) along with the vertical cross sectional view (lower right corner window) of the cloud cell seeded with hygroscopic flare in the figure 4b. The time of seeding and date of seeding of the cloud cell are also given in the lower left window of the figure 4b. From the lower left window it is clearly shown that the cloud cell with track no 1058 has been seeded at 08:26:18 GMT on 02 September 2009. similarly a blue color dot can also be observed in the lower edge of the upper right corner and middle right and lower right corner windows of the cloud images indicating the time of the event. From the "storm time height profile of the track 1058 shown in figure 1b we can observe that the Max-Z value was 42 dBZ at a height of nearly 4km before the time of seeding. Where as the Max-Z has decreased to 38 dBZ along with the decrease in the height associated with it to 3km in the next scan after the time of seeding. This may be an indication of immediate formation of less number of larger cloud droplets. And the Max-Z has again increased to 44 dBZ with an increase in Ht-MaxZ at 4km in the second scan followed by a decrease in Ht-MaxZ (~3 km) with the Max-Z of 41 dBZ in the third scan made by the radar after the time of seeding. From the variations in the Max-Z and the height associated with it we can assume that the decrease in Max-Z and Ht-MaxZ in the scan made just after the time of seeding may be an indication of immediate formation of less number of large cloud droplets. And the increase in Max-Z with the increase in Ht-MaxZ is an indication of formation of large number of small size droplets due to vertical mixing and the decrease in Ht-MaxZ with a Max-Z of 41 dBZ in the third scan made after the time of seeding is an indication of the formation and downward movement of bigger size cloud droplets due to the process of collision and coalescence during vertical mixing of cloud droplets caused by the updrafts entering into the cloud from the base. More precisely we can assume that the changes in the Max-Z and Ht-MaxZ in the second, third and fourth scans made after the time of seeding by the radar are the strong indications of occurrence of collisions and coalescence due to vertical mixing. And the bigger size cloud droplets that have formed after these processes have moved towards the base of the cloud due to the gravitational pull exerted by the earth on each droplet and precipitated in the form of rain. The differences in the variation pattern of seeded and unseeded cloud variables are considered as the signatures of seeding material on the variables of the clouds and discussed with the results of the case study made on 02 September, 2009. Various graphs have been plotted to observe the temporal variation of various radar response variables (shown in figures 2a to 2d) and also to distinguish the signatures of hygroscopic seeding material on the radar response variables of the seeded cloud cells in comparison with the unseeded cloud variables.

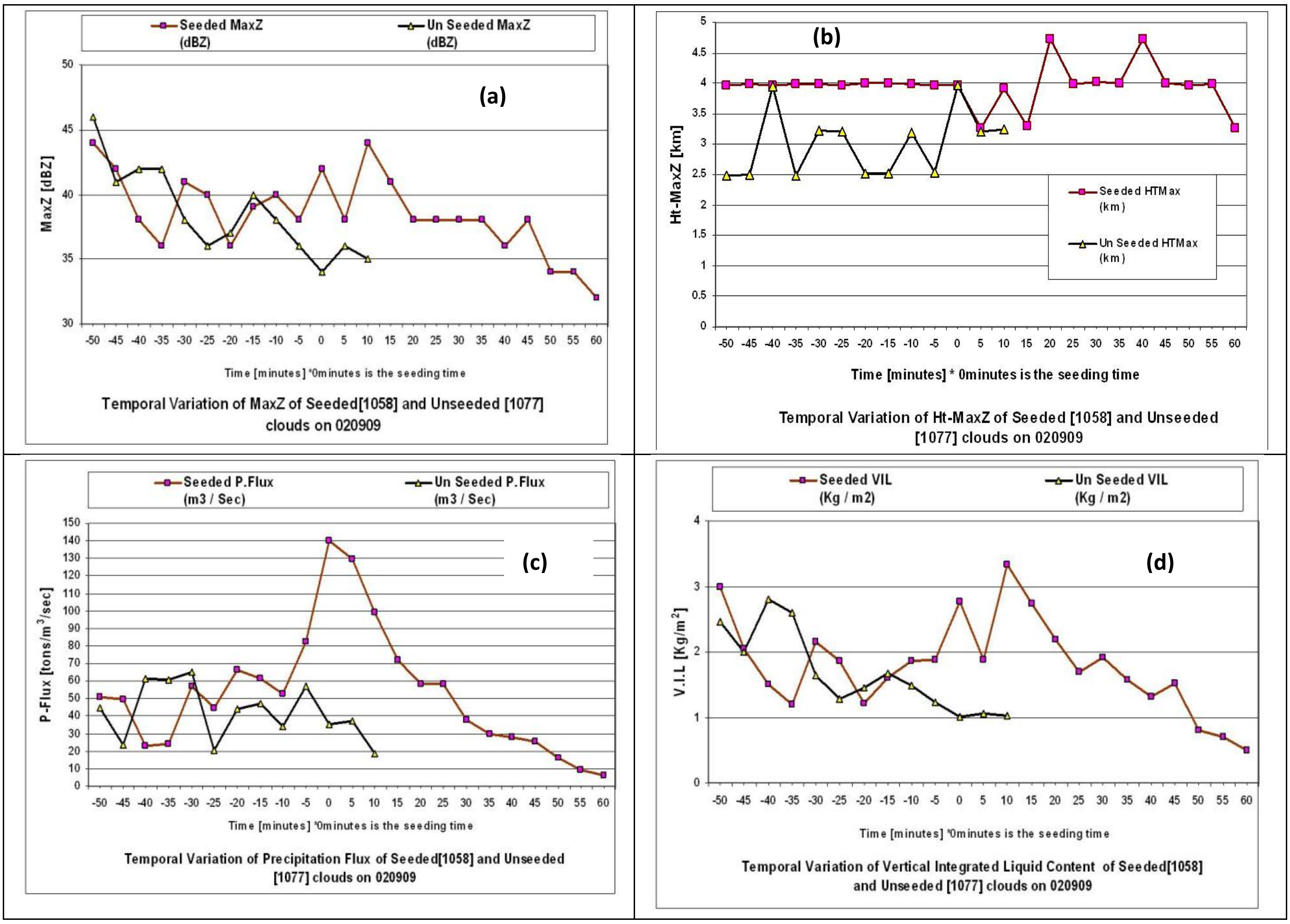

Figure 2: (a) Temporal variation of Max-Z , (b) temporal variation of Ht-MaxZ, (c) temporal variation of precipitation flux (P-flux), (d) temporal variation of Vertical Integrated Liquid content (VIL) of both the seeded and unseeded cloud cells.

From the line diagrams shown in the figures 2a to 2d, we can observe that the Max-Z of the unseeded cloud has started from more than 40 and has undergone many variations during its life time. But the Max-Z of the unseeded cloud has never reached again to its initial maximum value (40 dBZ) with a decreasing trend from the time of genesis. And the Ht-MaxZ of unseeded cloud cell has started from 2.5 Km and reached to a maximum between 3 and 3.5 Km by the end of its life time with slight variations. It informs that the Ht-MaxZ has reached to a maximum value than its initial value by the end of its life time indicating the lack of bigger rain drops for precipitation by the end of its life time. Where as if we observe the changes in the Max-Z of the seeded cloud cell, the Max-Z of the seeded cloud cell has also undergone several variations with a decreasing trend initially, same as unseeded cloud cell. But the Max-Z of seeded cloud cell has again reached to its maximum of >40 (dBZ) after 15 to 20 min (same as the time required for collision and coalescence) after the time of seeding which was not observed in the case of variation of Max-Z of unseeded cloud cell. On comparison with the variation pattern exhibited by the Max-Z of seeded and unseeded cloud cell, it confirms that definitely the CCN injected into the cloud from the burning flares might have interacted with the cloud droplets that are already present in the cloud and changed their characteristics (both in number and size). Similarly if we observe the variations in the Ht-MaxZ of the seeded cloud cell, the Ht-MaxZ of seeded cloud cell was stable at an altitude of 4 Km till the time of seeding and has decreased to an altitude between 3 to 3.5 Km after the time of seeding. The decrease in the Ht-MaxZ with an increase in Max-Z after the time of seeding clearly indicates the formation of dense mass composed of larger cloud droplets that might have formed after the interaction of artificial CCN with the matter present in the cloud and came down to lower altitude due to the gravitation pull. Similarly if we observe the entire variations in Ht-MaxZ of the seeded and unseeded cloud cell, the variations of Ht-MaxZ is not same in seeded and unseeded cloud cells. Increase in the Max-Z followed by a decrease in the Ht-MaxZ after seeding with hygroscopic flare clearly indicates that definitely bigger size cloud droplets might have formed in the cloud cell seeded with hygroscopic flare. More precisely we may assume that the variations in Max-Z are due to the formation of larger cloud droplets due to the process of collision and coalescence. And the changes in Ht-MaxZ can be assumed due to the down ward movement of the larger droplets formed at those altitudes and the entire mass increased at those altitudes came down to lower altitudes in the form of precipitation due to the gravitational pull exerted by earth. All these assumptions can be confirmed from the GIS maps showing the rainfall pattern observed over the regions which came under the coverage area of both the seeded (track no 1058) and unseeded cloud cell (track no 1077) presented in the figures 3(a) & 3(b).

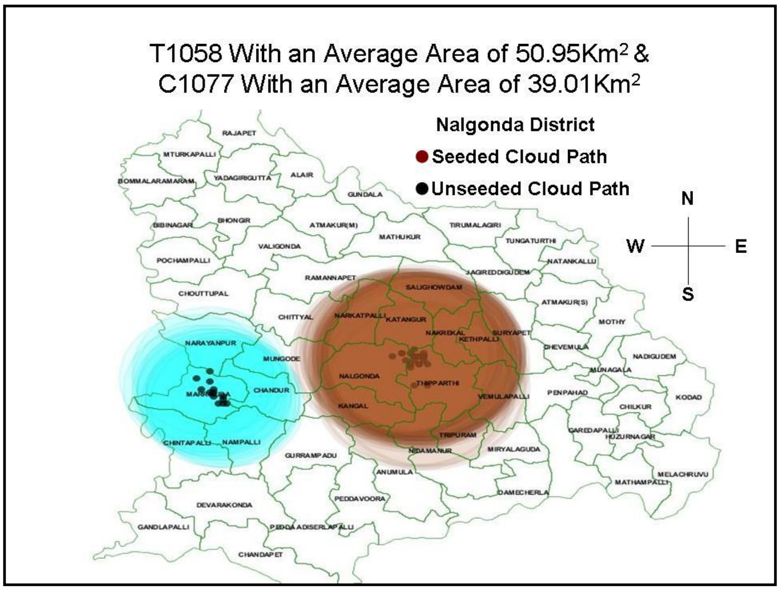

Figure 3(a). Regions came under the coverage area of the seeded cloud are shown in the brown color shade and the regions came under the coverage area of the unseeded cloud are shown in the pale blue color shade.

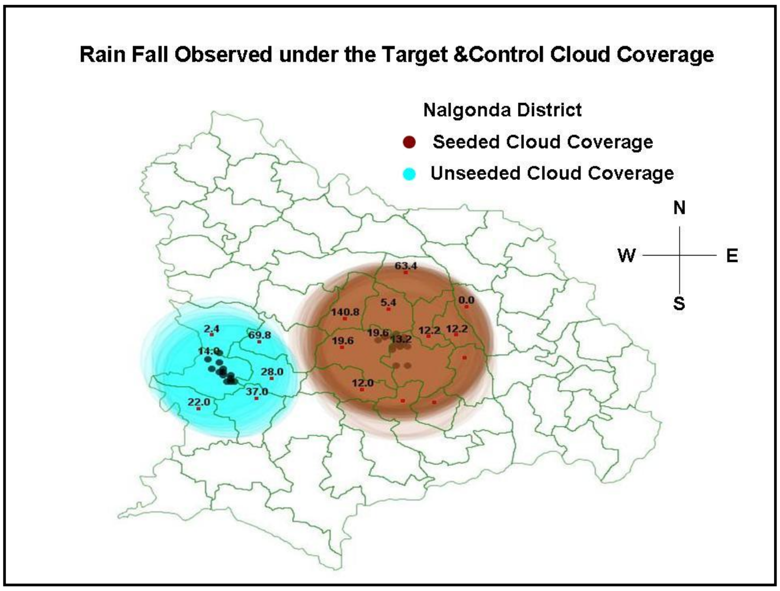

Figure 3(b): Rainfall observed in the regions came under the coverage area of the seeded cloud are shown in the brown color shade and the rainfall observed in the regions came under the coverage area of the unseeded cloud are shown in the pale blue color shade.

From the figures 3(a) and 3(b) it can be observed clearly that, the average area of the cloud cell seeded with hygroscopic flare was more than the average area of the cloud cell left unseeded. One may still quote that there is a biasing in selection of the clouds after observing the temporal variation of the cloud variables. This can be cleared from the explanation that the magnitudes of various radar response variables are almost same for both the cloud cells at the time of their genesis and both of them are selected on the same meteorological day, meteorological condition during same synoptic hours and from the same climatological regions. Even then also if any gets a doubt regarding the selection of the cloud cells and associated biasing. There are some other confirmations also to assume that the hygroscopic seeding material interacted positively with the water vapor present in the cloud cell and led to the precipitation enhancement in the form of rain by the forming larger cloud droplets through the process of collision and coalescence. They are the changes in the Max-Z, Ht-MaxZ and cloud top height after the time of seeding in the radar images processed by TITAN software that we can see. The change in the cloud top height is an indication of increased convection and vertical mixing which can be observed in the case of the seeded cloud cell after the time of seeding. These are one type of seeding signatures identified which may express the interaction of the seeding material with the cloud. And the other signatures that we can observe are from the line diagrams plotted for the temporal variation of radar response variables for both the seeded and unseeded clouds. From these diagrams we can see the considerable increase in the magnitude of Vertical Integrated Liquid content and the precipitation flux after the time of seeding. So from the entire observation of TITAN images and line diagrams these variations are identified as the seeding signatures which explain the positive interaction of the seeding material with the matter present in the cloud. And the rainfall pattern observed over the regions which came under the coverage area of both the seeded and unseeded cloud cells presented in the GIS maps also shows that the rainfall observed in the regions under the coverage of cloud cell seeded with hygroscopic flare is more than that of the rainfall over the regions which came under the coverage area of unseeded cloud cell. This also confirms the positive interaction of the particles released from the burning hygroscopic flares at the premises of the cloud base. There is an another logical understanding we can make that, if the particles released from the burning hygroscopic flares are not interacting positively with the moisture available in the cloud then the cloud cell seeded with hygroscopic flare might have disappeared or might not have rained otherwise minimum rainfalls have been obtained in the regions which came under the coverage area of the seeded cloud cell.

Results and Discussion

The results obtained from the case study made on the seeded and unseeded cloud cells on the day of 2nd September 2009 also confirmed that the CCN released from the burning hygroscopic flares has interacted positively with the moisture present in the cloud cell. The changes observed in the Max-Z values in the cloud cell after the time of seeding indicates that the CCN released from the burning flare has formed larger cloud droplets due to vertical mixing caused due to updraft currents entering into the cloud from the base. The changes in the Ht-MaxZ confirmed the occurrence of collision and coalescence process which led to the formation of larger cloud droplets. The changes in the cloud top height also confirmed the release of latent heat due to the formation of cloud droplets, increased convection and vertical mixing. Increase in the magnitude of the precipitation flux along with the increase in Vertical Integrated Liquid content also indicated the increase in the liquid water content in the form of water coating on the droplets formed in the cloud. The rain fall pattern observed in the regions which came under the coverage area of the seeded cloud cell confirmed that the CCN released from the hygroscopic flares has enhanced the precipitation in the form of rain by the formation of larger cloud droplets.

From the overall observations made in the results obtained in the present study it is understood that continuous measurement of the droplet spectrum at the cloud base starting from the genesis of the cloud to till its decay or dissipation with suitable technology is a must to know the influence of the seeding material on the clouds and also to know whether there is increase in the size or increase in the number concentration of the cloud droplets due to the introduction of the artificial CCN into the clouds. It is also understood that, there is a need for thermal imaging of the unseeded and seeded cloud cells to know the amount of latent heat released due to the formation of droplets in the clouds and to know the heat transfer mechanism in the cloud during the process of vertical mixing, collision and coalescence. It is understood that further research is required to understand various micro scale mechanisms and there is a need to develop cloud chambers for *in-situ* observations to understand more about the aerosol cloud interactions and heat transfer, heat releasing mechanism of the tropical clouds.

References

[1]. Cotton, W.R., 1982: Modification of precipitation from warm clouds – A review. *Bull. Amer. Meteor. Soc*. **63**,146-160.

[2]. Czys, R.R. and R.T. Bruintjes, 1994: A review of hygroscopic seeding experiments to enhance rainfall. *J. Weather Modification* **26**, 41-52.

[3]. Ramanamurty, Bh.V., 1984: *Review of warm cloud modification*. WMO/TD-No.5, World Meteorological Organization, Geneva, Switzerland, 43pp.

[4]. Orville, H.D., 1995: *Report on the Sixth WMO Scientific Conference on Weather Modification*, Paestum, Italy, 30 May – 3 June 1994.

[5]. World Meteorological Organization (WMO), 1994: *WMO Statement on the Status of Weather Modification, Proc. Sixth WMO Scientific Conference on Weather Modification*, Paestum, Italy, 30 May 1994-4 June 1994, Appendix – 1-9.

[6]. Cooper, W.A., R.T. Bruintjes, and G.K. Mather, Calculations pertaining to hygroscopic seeding with flares. J. Appl. Meteor., 36, 1449-1469, 1997.

[7]. Dixon, M. J. and G. Wiener, 1993: TITAN - Thunderstorm Identification, Tracking, Analysis and Nowcasting - a Radar-based Methodology. J Atmos Oceanic Tech, **10**, 785-797.