8.3 POLARIMETRIC ANALYSIS OF HYGROSCOPIC SEEDING

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1. INTRODUCTION

The Polarimetric Cloud Analysis and Seeding Test (POLCAST) was a research project designed to help determine if hygroscopic seeding could be detected by polarimetric radar observables (e.g. differential phase, differential reflectivity, etc.) or derived radar fields. The experiment was conducted on convective systems that were observed in Eastern North Dakota. The operational phase of the program, a cooperative study between the North Dakota Atmospheric Resource Board (NDARB), University of North Dakota, Weather Modification Inc., and Ice Crystal Engineering, was conducted from 10 July to 5 August 2006.

Ice Crystal Engineering provided the flares used during the project. Weather Modification Inc. operated the seeding aircraft while the University of North Dakota (UND) C-Band Polarimetric Doppler Radar (NorthPol) observed the clouds that were seeded (and unseeded). NorthPol collected a variety of radar observables, which included radar reflectivity, Doppler velocity, differential reflectivity, differential phase, specific differential phase, and correlation coefficient (see Bringi and Chandrasekar (2001) and references therein for complete descriptions of polarimetric parameters).

From the radar observations, liquid water content, rainfall rates, differential reflectivity and hydrometeor type were analyzed. POLCAST was a continuation of a study during the summer of 2005, in which NorthPol was used to better understand the internal characteristics of thunderstorms using polarimetric radar observations. This paper gives a brief description of the experiment and highlights the key results of the analysis.

2. DATA

For the summer of 2006, a total of eight cells were seeded during POLCAST. On days that convection was forecasted, the radar scientist and seeding pilot were put on standby. Once cells started to develop on radar, the seeding aircraft was directed to an area of isolated cells that had new convection forming. After the aircraft intercepted the cells, the pilot assessed the clouds to determine if a cell that was a good seeding candidate. The goal was to target cells that had updrafts that maintained velocities of 2-4 m s^{-1}, was deep enough to have supercooled liquid water, and was not already producing significant precipitation. Therefore, radar observations were used to help specify a general location of a target area. Most of the seeded cells were in the new growth stage and were not detected by the radar until after being seeded. Once the targeted cell was seeded, the UND radar operated in sector scan mode, which provided high temporal (3-4 minute repeats) and spatial (125 m) resolution volume scans. Sector scans were recorded until the cell either dissipated or it was out of range.

3. METHODOLOGY

A variety of polarimetric liquid water content (LWC) algorithms were tested in the study. Based on several intercomparison studies, the most reasonable algorithm was chosen. Based on this analysis, a horizontal reflectivity – differential reflectivity (Z_H-ZDR: differential reflectivity is the ratio between observed reflectivity in the horizontal and vertical polarization) algorithm produced the best results. The algorithm is given by:

$$W(Z_H,ZDR)=0.6*10^{-3}*Z_H^{(0.85)}*10^{(0.1*-2.36*ZDR)} \quad (1)$$

where W is LWC in g m^{-3} and Z_H is in units of mm^6 mm^{-3}. Typical values of LWC ranged from 0.5 to 4 g m^{-3}.

A study by Yan Yin et al. (2001) indicated that the hygroscopic seeding should initiate the rain earlier, produce more and last longer than an unseeded cloud. The rainfall rate was calculated using the Marshall-Palmer (M-P) reflectivity – rainfall (Z-R) relationship of:

$$Z_H = 200\ R^{1.6} \quad (2)$$

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where R is the rainfall rate in mm h^{-1}. Solving this equation for the rainfall rate R produces the equation:

$$R = [Z_H/200]^{1/1.6} \quad (3)$$

Many different effects, such as hail contamination, beam blockage, attenuation and non-uniform beam filling, can affect the relationship. According to Yan Yin et al. (2001), it is not realistic to expect the same Z-R relationship to work for both the seeded and unseeded cases since seeding changes the drop size distribution. As a result, the M-P relationship is probably not the correct transformation to obtain the absolute amount of rainfall. However, we were interested in examining the relative change in rainfall between targeted and non-targeted cells in which this issue should have a small impacted on the interpretation of the results.

The radar data collected during POLCAST were used to look at the average differential reflectivity and liquid water content at 1 km $\pm$ 0.5 km intervals above cloud base to a maximum height of 10 km. Data were separated into levels above and below the freezing. The aircraft reported the cloud bases during the assessment of the cell. The reported cloud bases and the corresponding reported cloud base temperatures are given in Table 1.

Table 1. Cloud base heights and Temperatures.

Date	1st Reported Cld Base Height	2nd Reported Cld Base Height	Cloud Base Temps
	ft	ft	C
11 Jul 2006	8000	9000	10
24 Jul 2006	6800	8000	12
25 Jul 2006	3000	5000	
27 Jul 2006	8200		12
04 Aug 2006	11000		
05 Aug 2006	8700		10
05 Aug 2006	3700		23

The LWC and rainfall attributes were compared between seeded and a selection of unseeded cases. Unseeded cases were selected on having similar characteristics (size, shape, orientation, intensity, etc.) as the seeded cases. An unseeded case was selected as close to the time of the seeded case as possible to minimize differences in environmental conditions. The cases were also physically separated such there was no influence from the seeded case. The main focus of analysis was on the effects of seeding in the core of the cell. For this study, the core was defined as an area with radar reflectivity exceeding a threshold of 30 dBZ.

5. RESULTS AND DISCUSSION

The seeded cases showed some positive results overall. Seven of the eight cases showed an increase in LWC after the initial seeding. The one case on 04 August 2006 showed a decrease in LWC after seeding was located along the edge of a larger more stratiform precipitation area with embedded convection. This cell did not last very long as they combined with the stratiform precipitation and was no longer discernable after a couple scans. The data from the 25 July 2006 cases may be in error. There was a large amount of attenuation that took place due to the heavy rain that occurred over the radar. This caused a great decline in the differential reflectivity (ZDR) and a slight decrease in reflectivity in the two cells that were seeded. Since the LWC algorithm included differential reflectivity and reflectivity in the calculations, it may be in error even after quality control.

The maximum liquid water content for both the seeded and unseeded cases is shown in Fig. 1. The seeded cases have a larger average maximum LWC than the unseeded cases. The unseeded cases have the largest average LWC at 2 km above cloud base while the seeded cases had a larger average maximum at 3 km above cloud base.

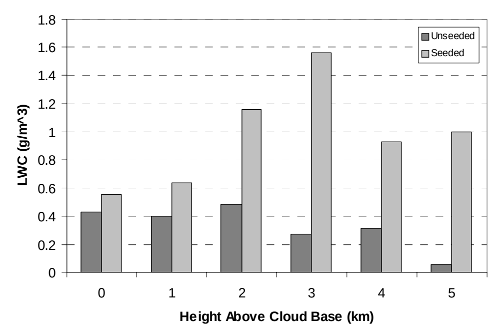

Figure 1. The average maximum LWC for each height level above cloud base for the seeded and unseeded cases.

The seeded cases had a higher average maximum LWC than the unseeded cases by 0.65 $\pm$ 0.43 g m^{-3} or about 66% greater. There is a large standard deviation with the results since there are not a lot of cases, and there is a lot of variability in the range of LWC values. The time for the cases to reach the maximum LWC after first detection by radar is shown in Fig. 2. The unseeded cases reach the maximum LWC more rapidly after first detection than the seeded cases except for 2 km above cloud base in which the times are close to the same. The greatest difference between the seeded and the unseeded cases occur at 5 km above cloud base with a difference of approx 9 minutes. The seeded cases took 4.73 ± 3.08 minutes longer to reach the maximum LWC than the unseeded cases.

In summary, the average LWC does show a greater period of increase after first detection by radar for the seeded cases than in the unseeded cases. The unseeded cases also fluctuated a lot more between increasing and decreasing of the LWC. The maximum LWC that is reached by the cells occurs faster in the unseeded cases than in the seeded cases except for the 2 km level above cloud base. The average LWC maximum that occurs for the seeded cases is slightly greater than in the unseeded cases at heights of 0-1 km and by a fairly large amount in heights of 2-5 km. Overall, the LWC analysis has shown some positive results for indicating that the effects of seeding appear able to be observed by polarimetric radar.

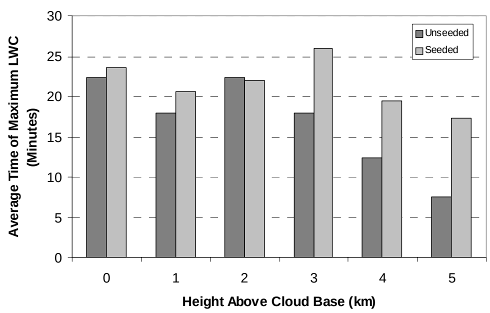

Figure 2. Average time of maximum LWC after first detection by radar for the seeded and unseeded cases.

For the rainfall analysis, rainfall rates were averaged over the base scan of 0.5° for each time interval. Yan Yin et al (2001) found that hygroscopic seeding should initiate the rain earlier, produce more rain and have a longer duration. Figure 3, shows that the time it takes to reach the average maximum rain rate is 4.0 ± 2.8 minutes longer in the seeded than in the unseeded. The duration of the cells was 8.3 ± 5.8 minutes longer in the seeded than the unseeded. The maximum peak rain rate was 1.5 ± 1.1 mm h^{-1} greater in the seeded cases, or about 14.8%. Again, the rainfall rate analysis shows positive differences between seeded and unseeded cells.

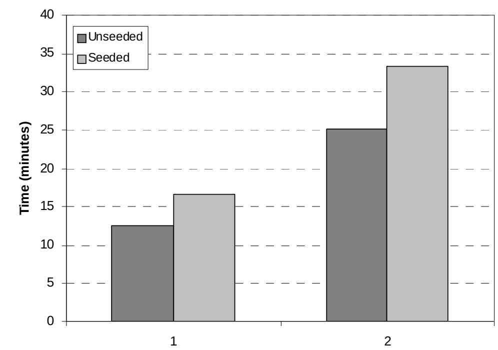

Figure 3. Average time of peak rain rate (1) and rain duration (2) for the seeded and unseeded cases.

6. CONCLUSIONS

The results show that the LWC on average increased after hygroscopic seeding. The cases that did not show an increase in LWC were found to have the similar properties. They tended to be located near the edge of larger more stratiform precipitation areas. Larger changes in LWC could have occurred by were not observed because of the uncertainties associated with using just one algorithm for the LWC. However, the results showed a positive effect (increase in LWC) in the targeted cells. The rain rate also showed positive results with an increase in average maximum rain rate and rain duration.

Based on all these results, there is indication that polarimetric radar can observe the effects of hygroscopic seeding.

Acknowledgements

This work was supported by the North Dakota Atmospheric Resource Board (Fund #: ARB-UND-05-01).

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