4.5 PRECIPITATION EVALUATION OF THE NORTH DAKOTA CLOUD MODIFICATION PROJECT (NDCMP) USING THE ND ARBCON PRECIPITATION DATA

Paul A. Kucera[1*] and Eric A. Wise[1]

[1]Department of Atmospheric Sciences, University of North Dakota, Grand Forks, North Dakota

1. INTRODUCTION

The North Dakota Cloud Modification Project (NDCMP) is a summertime operational non-randomized cloud seeding program in Western North Dakota. The NDCMP has two objectives for their cloud seeding activities; to suppress hail damage on crops and to increase growing season precipitation. This study will focus on evaluating the success of increasing summertime precipitation.

This study evaluates the NDCMP success of enhancing precipitation over a 27-year period from 1977 to 2003. There have been two previous rainfall studies in North Dakota and South Dakota. One study focused on the NDCMP (Eddy et al. 1979) and the other studied a similar cloud seeding project in South Dakota (Pellett et al. 1977). Both studies reported a 5 to 10% increase in summertime rainfall due to seeding. An evaluation conducted by Johnson (1985) showed weak evidence of an increase of rainfall in and downwind of the target with respect to the control. Finally, an earlier study (Dennis et al. 1975) of randomized cloud seeding experiment in North Dakota also indicated a positive effect on rainfall due to seeding operations.

The rainfall evaluation in this study was quantified by using the North Dakota Atmospheric Research Board Cooperative Observer Network (ND ARBCON) rain gauge data. The ND ARBCON is a statewide network comprised of volunteers. The ND ARBCON was started in 1977 and is still operational today. The ND ARBCON records daily rainfall and hail amounts that occur at each observer location from April to September. Pervious evaluations of the NDCMP used the National Weather Service (NWS) rain gauge networks to conduct their studies. The ND ARBCON is a denser network than that of the NWS network. The hope is that the denser ND ARBCON may be able to better identify the effects of seeding in the NDCMP.

The statistics used in this evaluation are based on a ratio test for evaluating rainfall enhancement for cloud seeding projects defined by Gabriel (1999, 2002). This test shows the percent difference between the regions affected by seeding with control regions.

There are two distinct summertime wind patterns in North Dakota. The two dominate wind patterns are the southwest and northwest flows. Because of the two flow regimes, this study conducts the evaluation for target, control, and downwind regions based on these two flow regimes. For the few cases that the wind regime was not in southwest or northwest flow, precipitation data were not evaluated. The NDCMP operates during the months of June, July, and August. This study conducts an evaluation for each month and a seasonal evaluation for both flow regimes and districts.

2. DATA

Rainfall amounts from the ND ARBCON for June, July, and August for the years from 1977 to 2003, were the primary data source used in the study. Wind data from the NDCMP radar's Thunderstorm, Identification, and Tracking, Analysis, and Nowcasting (TITAN) software storm tracks, was used in determining the mean storm flow in relation to lower tropospheric wind flow on seeded days from 1999 to 2002. TITAN data for the years 1999-2002 were used to determine mean storm tracks. Storm track data were compared to NCEP/NCAR reanalysis wind data to provide information storm movement for all 27 years of NDCMP.

3. METHOLODOGY

The goal of this research is to statistically show if the NDCMP seeding activities in Western North Dakota enhance summer rainfall amounts in the target regions using rain gauge data. To study the effects of seeding, rain gauges were categorized into three regions: downwind, target, and control regions for both seeding districts in ND.

The downwind regions were determined by the mean storm flow on days seeded from 1999 to 2002. For each district and flow regime, a wind flow was determined where the majority of days seeded originated. The control regions were selected by determining areas not affected by seeding, but adjacent (upwind) to the target and downwind regions.

The storm flow for a given day was used to categorize (e.g. northwest or southwest flow regions) the subset of rain gauges for the analysis. The storm tracks wind data were only available from 1999 to 2002. Therefore, storm flow data were used for the same time period. NCEP/NCAR Reanalysis wind data were used to determine the mean wind flow. Three pressure levels were evaluated to determine which level best compared to the storm tracks data. Along with the comparison, the relative error was also calculated for the storm tracks and NCEP/NCAR reanalysis data having different storm regimes for a given day. The pressure level that compares the best and has the smallest error was used to estimate the daily wind flow for every day in the study.

---

* *Corresponding author address*: Dr. Paul A. Kucera, Department of Atmospheric Sciences, P.O. Box 9006, University of North Dakota, Grand Forks, ND 58202; E-mail: pkucera@aero.und.edu.

Next, precipitation amounts were calculated for each region. The wind direction for every day in June, July, and August from 1977 to 2003 was determined from the NCEP/NCAR reanalysis wind data. When the wind was from the northwest or the southwest, all the gauges in the regions for that wind regime were averaged to get a mean daily rainfall amount for that region. At the end of the month, all the daily means for each region were added together to get a monthly rainfall amount for each region. A seasonal rainfall total was calculated for each region by accumulating the monthly rainfall for June, July and August. A mean for each month and summer over the 27 year period was calculated for each region.

Summertime rainfall in North Dakota is not uniform throughout the state. The difference between the target and control regions and the downwind and control regions could be due to the natural variation in rainfall between the regions. To determine the difference between the target and downwind regions with the control regions, a climate adjustment was applied. Climatologic summertime rainfall data prior to seeding activities was used to determine the natural variation in rainfall throughout the state. The 1931 to 1960 climatologic rainfall data was used to adjust for natural summertime rainfall variants between the regions.

4. RESULTS

For both districts, the days seeded in the NDCMP were determined from 1999 to 2002. For District I there were 95 days seeded during this period, and 147 days seeded in District II. Next, the storm tracks data from the TITAN radar software was obtained for all days seeded from 1999 to 2002. The Bowman radar data were used for District I and the Stanley radar data were used for District II. Not all the days had storm track data, or had significant storm track data for every day seeded. For District I, of 95 days seeded, only 84 days had significant storm tracks data. For District II of 147 days there were 142 days that where significant storm tracks data was available.

For every day seeded, mean storm flows were calculated for a northwest and southwest flow for both districts. Then, an average total mean storm flow direction was calculated for the districts. For District I, mean storm flow was 60°, which is a wind flow from the southwest. The southwest mean storm flow direction for District II was 61°, which again is a wind flow from the southwest. The northwest mean storm flow for District I and District II was 112°, which is a wind direction out of the northwest.

Wind flow variability was calculated that included the majority of the daily storm flows. The southwest range for both districts was 45° to 89°. The range included 75% of the days seeded. The range had to start at 45° to allow the control regions to contain a significant number of gauges to be used in the project. The northwest range for District I & II was 91° to 142°. This range included 94% of the seeded days for district I and 90% of the seed days for district II.

Based on the ranges calculated for each district and flow region, the downwind regions were defined. Then, the control regions were defined by the areas that were not in the downwind regions, but still relatively close to the target and downwind regions. Figure 1 shows the southwest regions for both Districts I and II.

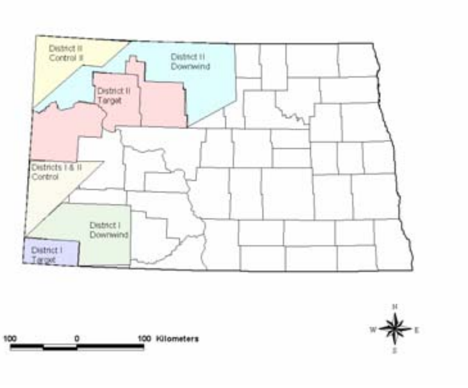

Figure 1: Southwest Flow regions for both District I & II.

District I and II both used the same control region, and District II also used another control region for this study. The regions for a northwest flow for both districts I and II can be seen in Fig. 2.

Wind flow analysis was conducted using the NCEP/NCAR Reanalysis wind data for the months of June, July, and August. For District I, NCEP/NCAR Reanalysis wind data from the constant pressure level of 600 mb at 18Z provided the best comparison with the storm tracks data for seeded days for District I. The R^2 value was calculated to be 0.62 and with an error of 16.5% for choosing the incorrect wind regime. For District II the pressure level of 600 mb and a mean wind direction for the synoptic times of 12, 18, and 0Z the next day times were calculated to have the best comparison. The R^2 value was 0.63 with an error of 13% for this wind regime.

The rainfall for the northwest and southwest regions was calculated based on the criteria described above. This was done from 1977 to 2003. Precipitation was then accumulated for the months of June, July, August, and the summer total for each region and regime.

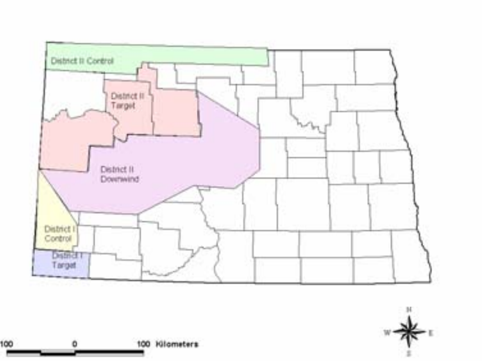

Figure 2: Northwest flow regions for both districts I and II.

Climatology rainfall amounts from 1931 to 1960 were applied for each region by creating a Cartesian grid over

North Dakota and weighting the climate gauges to each grid point. Then, all the grid points in a region were averaged to obtain one climate rainfall amount for each region. Next, a ratio was calculated between the target and the control regions, and between the downwind and control regions, for both districts and flow regimes. The ratios were calculated by dividing the target/downwind regions by the control regions.

The ratios were then multiplied to each control region. The ratios were applied to the control regions to obtain a climate adjusted precipitation amount. This adjustment should account for any climate variations summertime rainfall between the regions.

A percent difference was calculated between the target regions, and their corresponding control regions, and between the downwind regions and their corresponding control regions. The percent difference for the summer total for a northwest flow can be seen in Fig. 3.

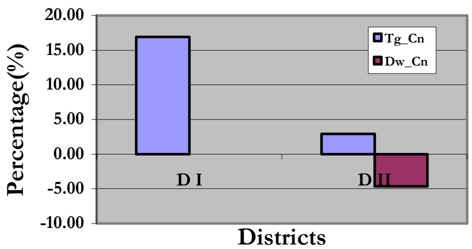

Figure 3: Summer mean total percent difference between the target/downwind regions with the control regions for a northwest flow for both districts.

For a northwest flow, District I target mean total summer rainfall amount was 16% greater than the control mean summer total rainfall amount. From 1999 to 2002, there were more seeded days when the wind was from the southwest than the northwest. This study found on average the wind was out of the northwest more days than it was out of the southwest in western North Dakota. The study also found that the greater amount of rainfall occurs when the wind is out of the southwest.

For District II the target region received less then 5% more rainfall than the control region, and the downwind region received more than 5% less rainfall than the control region for a northwest flow. The downwind region for District II when there is a northwest flow is the largest region by both area and gauge number in the study. The size of the region could have played a role in the downwind region receiving less rainfall than the control region. Also, the control region for this case is located along the Canadian boarder. There were no rainfall gauges in Canada close to the North Dakota boarder for the period of 1931 to 1960. When calculating the climatology rainfall amounts for each region, a boundary problem could occur because of the lack of gauges in Canada. There could also be recording errors of the rain gauges, where an amount for a control gauge should have been recorded on a seeded day but was recorded on the wrong day.

The percent difference between the target and control regions and the downwind control regions for a southwest flow can be seen in Fig 4. For a southwest flow, all the target and downwind flows received more rainfall than their corresponding control regions. Again, like in the case of the northwest flow, there could be a boundary issue with the second control region for District II. This region is located in the northwest corner of the state, and there was not a significant number of climate gauges to weight the control region.

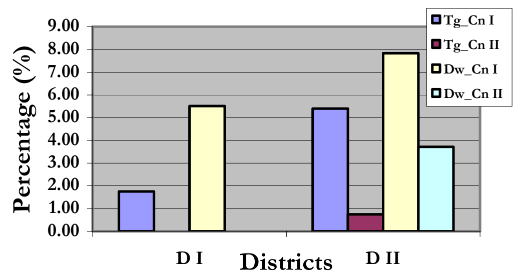

Figure 4: Summer mean total percent difference between the target/downwind regions with the control regions for a northwest flow for both districts.

5. CONCLUSIONS

On a yearly basis, there were four cases were the target/downwind region received 5% or more precipitation than the control. There was only one case where the control region received more precipitation than the target/downwind, and that was the downwind region of District II with a northwest flow.

The results in this paper showed similar results to those of pervious studies. There are indications from this study that seeding does have a positive effect on precipitation in western North Dakota.

6. REFERENCES

Dennis, A. S., J. R. Miller, Jr., D. E. Cain, and R. L. Schwalter, 1975: Evaluation by Monte Carlo tests of effects of cloud seeding on growing season rainfall in North Dakota. *J. Appl. Meteor.*, **14**, 959-969.

Eddy, A., E. Cooter and W. Cooter, 1979: An evaluation of operational cloud seeding in North Dakota: An exploratory analysis. Final Report to the North Dakota Weather Modification Board, Bismarck, ND, 146 pp.

Gabriel, K. R., 1999: Ratio statistics for randomized experiments in precipitation Simulation. *J. Appl. Meteor.*, **38**, 290-301.

Gabriel, K. R., 2002: Confidence regions and pooling—some statistics for weather experimentation. *J. Appl. Meteor.*, **41**, 505-518.

Johnson, H.L, 1985: An Evaluation of the North Dakota Cloud Modification Project. A final report to the North Dakota Weather Modification Board, June 1985. 35 pp.

Johnson, H. L., 1983: An Evaluation of the 1981 North Dakota Cloud Modification Project. *Operational Weather Modification*, **11**, Oklahoma Climatological Survey, Norman, OK, 40 pp.
Pellett, J. L., R. S. Lablong and M. R. Schock, 1977: Evaluation of Recent Operational Weather Modification Projects in the Dakotas. WMB Report 77-1, North Dakota Weather Modification Board, Bismarck, ND, 54 pp.