

AN UPDATE ON THE NORTH DAKOTA CLOUD MODIFICATION PROJECT

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Abstract. Operational cloud seeding has been conducted over parts of western North Dakota since the 1950's. Operations began with ground based seeding in the early years, but by the early 1960's airborne delivery of seeding agents became the preferred method. Currently, a combination of cloud base and cloud top seeding is employed on the North Dakota Cloud Modification Project (NDCMP) using an acetone-based AgI solution, end-burning AgI flares, ejectable AgI flares, and dry ice pellets (CO₂) as seeding agents. The goals of the dual-purpose project are to increase growing season precipitation and reduce crop and property damage caused by hail. The project is funded by county tax levies and limited state cost-sharing. Operations are conducted from June 1 through August 31 each year, twenty-four hours a day, seven days a week.

Every evaluation of the project has indicated beneficial results, but with varying statistical confidence. Rainfall increases on the order of 7 to 15% have been realized in and slightly downwind of the target counties. Crop-hail damage has been reduced by 45% and wheat yields have increased by 5.9%. A benefit-to-cost ratio of 35:1 has been realized for wheat production alone.

1. INTRODUCTION

Western North Dakota's climate is classified as semi-arid with normal growing season precipitation (April – September) ranging from 10.5 to 12.5 inches. Precipitation amounts are nearly 50% greater in southeast North Dakota versus the northwest (Jensen, 1963). While other variables also play a part, the climatological deficiency of growing season moisture has a major negative impact on dryland farming and ranching in western North Dakota.

Likewise, the high hail frequency in western North Dakota also creates problems with farming and ranching. Western North Dakota experienced some of the highest hail insurance loss costs in the nation for the years 1948-1967, with southwest North Dakota's loss-cost at \$12.10, worst in the nation (Changnon, 1977). (Loss cost is defined as: (Loss/Liability)x 100.) This exposure to damaging hail provided the motivation for the initiation of cloud seeding in western North Dakota.

Operational cloud seeding in North Dakota began in the 1950's with a few counties, or portions thereof, participating. By the early 1960's a number of North Dakota counties participated in operational cloud seeding and airborne delivery of seeding agents became the preferred method of delivery. In 1975 the North Dakota Weather Modification Board (later renamed the North Dakota Atmospheric Resource Board) was established by the North Dakota legislature to regulate

weather modification activities. This marked the beginning of the North Dakota Cloud Modification Project (NDCMP). In 1997, the NDCMP consisted of

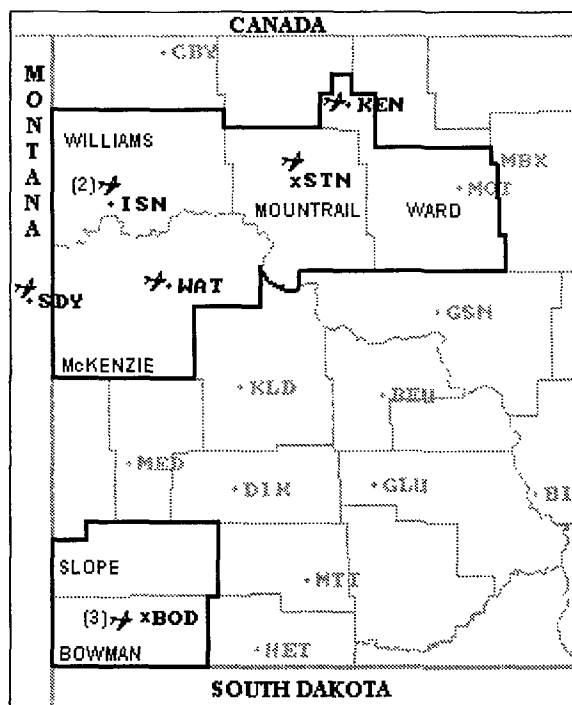


Figure 1. Target areas are outlined. Radar locations are denoted by an X. Airplanes denote location and number of aircraft at each site.

two separate target areas, shown in Figure 1, composed of six western North Dakota counties. District I, in the southwest, included Bowman and Slope counties. District II in the northwest, included McKenzie, Mountrail, Ward, and Williams counties. The total project area for both districts was 29,407 km², or 7.27 million acres.

2. SEEDING CONCEPTUAL MODEL

As stated earlier, the NDCMP is a dual-purpose program emphasizing rainfall enhancement and hail suppression. The seeding conceptual model has been developed, reviewed, and refined over a number of years. A number of field research programs, most notably the North Dakota Thunderstorm Project (1989) and the North Dakota Tracer Experiment (1993), have shed light upon the inner-workings of Great Plains thunderstorms and led to refinements of the previous work of the NDCMP Hypothesis Description and Assessment Committee (1984). With today's knowledge and technology, the focus of NDCMP operational cloud seeding is the new growth region of the thunderstorm commonly known as the feeder clouds (NDARB, 1997).

Feeder clouds usually develop on the upshear sides of thunderstorms and contain significant quantities of supercooled liquid water (SLW), which often exists at temperatures well below 0°C. It is the artificial nucleation of SLW which creates the desired effect of increased rainfall and reduced hail.

During rain enhancement seeding operations, the developing feeder clouds are treated either from cloud base or by direct injection at or near cloud top. Candidate clouds must have a cloud base below 3700 m above ground level (AGL) with cloud tops colder than 0°C and preferably around -5°C. Artificial ice nuclei, most commonly AgI, are introduced into the updraft region of the clouds by direct injection, or by dispersion at cloud base to speed the ice nucleation process. Dry ice creates ice nuclei as well, but by shock-freezing SLW as it falls through the feeder's updraft. For more information on the specifics of the ice phase processes, see Smith et al., 1997. Nucleation with AgI occurs at temperatures about 5 to 10°C warmer than would naturally occur. Given typical cloud growth rates, this accelerates precipitation development by approximately 3 to 5 minutes (Smith et al., 1997).

In the case of more isolated convection (i.e. towering cumulus), glaciogenic seeding may accelerate hydrometeor growth sufficiently to allow the cloud to produce precipitation-sized particles during its relatively short lifetime. The latent heat release of increased ice production should add buoyancy,

stimulate the updraft, and prolong the cloud's lifetime (NDARB, 1997).

The hail suppression concept is predicated largely on beneficial competition, which assumes a deficiency of natural ice nuclei in the supercooled updraft. Since Great Plains thunderstorms frequently lack sufficient concentrations of efficient natural ice nuclei, more efficient artificial ice nuclei are introduced, improving the storm's precipitation efficiency. The artificial nuclei become active at warmer temperatures creating ice in the cloud sooner than natural nuclei. As with rain enhancement, cloud top temperatures during hail suppression seeding must be below 0°C, preferably from -5 to -10°C. As the feeder cloud grows taller and colder, the natural ice nuclei begin to create ice crystals. The ice particles created with artificial nuclei then compete with nature's particles for the storm's available SLW. In this scenario, hydrometeors will be smaller than they naturally would have been and will be less likely to survive the fall through the warm sub-cloud layer. If they do survive they will be smaller and possess lower kinetic energies, and therefore, less damaging. Candidate clouds should exhibit vigorous growth, with seeding commencing prior to the first detectable radar echo.

Target storms should be within, or up to 30 minutes travel time upwind of the target area. Since the NDCMP presently lacks sufficient buffer zones, especially over Montana and South Dakota, where no seeding is presently permitted, targeting for storms more than 30 minutes upwind of the target area is extremely difficult.

2.1 Methodology

Seeding on the NDCMP is accomplished through two modes: via cloud base updrafts and by direct injection at cloud top. This is conducted solely by twin-engine aircraft, with higher performance aircraft performing the cloud top duties. Top seeding aircraft penetrate feeder clouds at the -5°C to -10°C level dropping dry ice or AgI flares. Base seeding aircraft treat feeder cloud updrafts with an acetone-based AgI solution and burn-in-place AgI flares. Target updraft rates range between 1.5 and 2.5 m/s, typical for developing feeder clouds. Stronger updrafts are indicative of maturing cells, and are not suitable for seeding. Though accomplished through different means, these seeding strategies have the same ultimate goal: producing nucleation of supercooled vapor and condensate at temperatures warmer than what would occur naturally, starting the deposition and riming process sooner, and speeding the precipitation process.

2.2 Silver Iodide Solution

In 1997 the NDCMP changed its acetone-based formulation from a solution producing an aerosol of $\text{AgI}_{0.8} \text{Cl}_{0.2} - 4\text{NaCl}$ to a new solution which

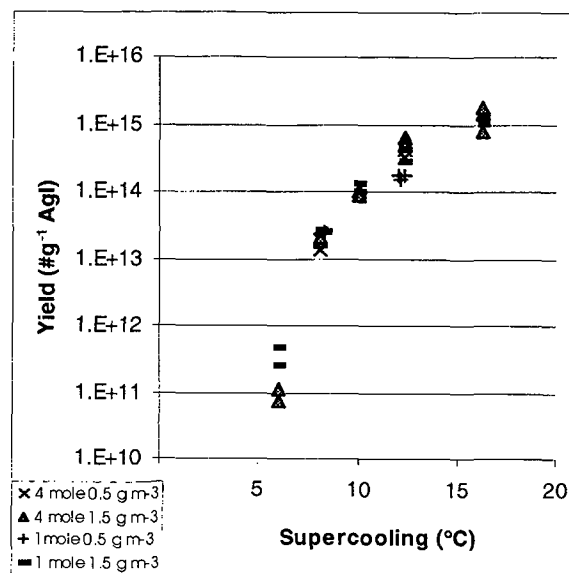


Figure 2. Yield comparison of 4-mole and 1-mole aerosols (DeMott, 1997).

produces an aerosol of $\text{AgI}_{0.8} \text{Cl}_{0.2} - \text{NaCl}$. While the old solution produced high yields, its 4:1 NaCl:AgI molar ratio posed generator reliability problems in the field. The new solution with its 1:1 molar ratio was expected to reduce the generator reliability problems, but questions remained about its effectiveness.

Testing of the solution was conducted by Dr. Paul DeMott at the Colorado State University Cloud Simulation and Aerosol Laboratory. Both solutions were tested and compared using the identical Lohse-type generator employed on the NDCMP. Tests were conducted in the CSU Isothermal Cloud Chamber at supercooled temperatures ranging from -6°C to -16.3°C and liquid water concentrations (LWC) of 0.5 and 1.5 g/m^3 . Results of these tests showed the 1-mole aerosol having a higher yield (ice crystals formed per gram of AgI) at warmer temperatures (-6°C) by approximately half an order of magnitude (Figure 2), with similar yields at colder temperatures (DeMott, 1997).

Although the 1-mole aerosol contains less salt, its fundamental ice formation mechanism is still condensation-freezing (DeMott, 1997). This is a distinct advantage because the nuclei, like the former aerosol, are capable of essentially forming their own cloud droplets before they freeze. This leads to much faster ice formation rates than some previously used

aerosols, such as $\text{AgI-NH}_4\text{I}$, which depended on contact-freezing. With less dissolved solids, it also burns much more readily than the 4-mole salt solution thereby increasing generator reliability. After consideration of these factors, DeMott recommended that the NDCMP switch to the 1-mole aerosol. In response to the change, project generator reliability in 1997 improved by 9.5% over 1996 project performance and by 6.3% over the 1992 – 96 five year average of 82.2%.

3. FORECAST SUPPORT

Daily forecasts for each target district are prepared by the NDCMP meteorology staff in Bismarck. Forecasts are prepared using National Center for Environmental Prediction (NCEP) model data, satellite imagery, National Lightning Detection Network data, and local synoptic observations. The North Dakota Atmospheric Resource Board (NDARB) obtains many types of raw and derived data products from the Regional Weather Information Center at the University of North Dakota. A Hewlett Packard workstation running the GrADS (Grid Analysis and Display System) software serves as the primary forecasting system. Forecasts are faxed to the field meteorologists at 12:00pm CDT each day. A briefing via conference call follows, allowing the field meteorologists to discuss the specifics of the forecast with the forecaster. Forecasts are focused on the probability and magnitude of convective weather development in and upwind of the target areas. A confidence factor is assigned to each forecast period. This factor, 5 being the lowest and 10 the highest, indicates the forecaster's relative confidence that the forecast will verify. Situational updates are given if conditions warrant. Each field radar site is also equipped with a PC, providing field meteorologists access to the wide array of weather data available on the World Wide Web.

4. OPERATIONS

As stated earlier, the 1997 project target areas included six western North Dakota counties in two districts covering a combined total of 7.27 million acres. The NDCMP operates on a 24 hour-a-day, seven day-per-week schedule. Flight operations are conducted whenever the need arises, with missions frequently occurring after dark.

Safety is the first priority on the NDCMP. Operation of aircraft in inclement weather can be a dangerous activity and every precaution is taken to ensure the job is completed safely. While meteorologists determine when conditions are favorable

for seeding, it is the pilot's final decision whether or not conditions allow safe flight operations. Although not frequent, there are occasions when weather conditions such as poor visibility, low ceilings, or severe turbulence preclude operations. During these instances, conditions are continuously monitored by the field meteorologists and pilots. Flight operations resume only after weather conditions sufficiently improve. In the twenty-two years of cloud seeding in North Dakota, since the NDARB was created, no one has been lost to a project-related accident.

4.1 Training

North Dakota's program provides rigorous and thorough training of project personnel prior to startup operations. A three day ground school is held prior to every project, which all project personnel are required to attend. Topics covered in ground school include safety, opportunity recognition, seeding strategies, and record keeping. Personnel also participate in a cloud seeding computer simulation program, developed in-house, which gives them an indication of what is involved in real operations and fosters teamwork between pilots, interns, and meteorologists.

Intern pilots and meteorologists are placed on the project through a cooperative agreement between the NDARB and the University of North Dakota (UND). Intern pilots have normally completed a significant portion of their undergraduate coursework. In addition to their other courses, they must have completed two semesters of weather modification theory and applications. The top students from the second semester class are selected and placed on the project. Academics are not the only requirement, though, as they must be multi-engine-rated and instrument-rated to qualify. The UND-NDARB weather modification pilot training program is the only one of its kind in the U.S.

Meteorology interns, like their aviation counterparts, have also completed a significant portion of their undergraduate work and have completed courses on topics such as synoptic meteorology, weather analysis and forecasting, and radar meteorology. The NDCMP internship gives them valuable work experience in a challenging operational setting.

4.2 Daily Operations

Radar operations centers were located at Bowman and Stanley, ND. Both were 5 cm wavelength (C-band) digital weather radars equipped with digital data recording systems. The Bowman set is a WSR-74C acquired by the NDARB through the Government

Service Agency in 1996. For the 1997 project, it was equipped with the TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting) data recording system through contract with Weather Modification, Incorporated (WMI).

The Stanley radar system was leased, also through contract with WMI. The Enterprise Electronics WR-100-2 was equipped with WMI's PC-based digital color radar display system.

The Bowman field site was staffed with one meteorologist and a meteorologist intern, while the Stanley site was staffed with two meteorologists and an intern. A total of nine aircraft, leased through contract with WMI, were stationed at six locations. Top seeding aircraft were Cessna 340's. Both were equipped with a 150 lb. capacity dry ice hopper, and a 102 position belly-mounted ejectable flare rack. The C340 stationed in Bowman was also equipped with two wing-tip Carley ice nucleus generators. Base seeding aircraft included four Piper Seneca II's and three Piper Twin Comanches. Each base seeding aircraft was equipped with two wing-tip Lohse generators and two 12 position flare racks for burn-in-place flares. Each aircraft had a two-person crew. Pilots-In-Command (PIC) were employed by the contractor and in most cases had a prior year of intern or PIC experience on the program.

Each day, after the weather briefing, the field meteorologists brief each PIC and accordingly place them on Weather Watch, Standby, or Alert status. If no weather is expected all personnel are placed on Weather

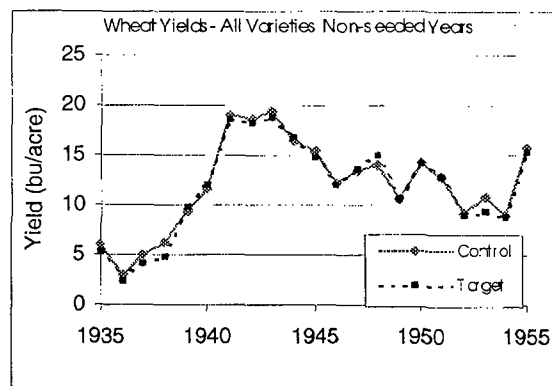


Figure 3. Historical relationship between NDCMP target areas and adjacent control areas.

Watch. Every day a specified number of aircraft are placed on Standby status, meaning they must be within easy contact of the field meteorologist and be ready to launch within 15 minutes of notification. When weather is imminent, crews are placed on Alert, meaning they

must be ready to launch immediately after a launch is requested. Once weather develops, operations decisions are the responsibility of the field meteorologists. Seeding decisions are made based on a number of factors including forecast conditions, radar information, visual observations, and pilot reports.

5. EVALUATIONS

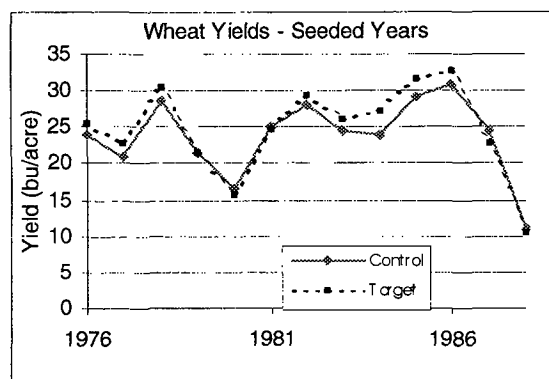


Figure 4. Wheat yields during the NDCMP project years.

A number of statistical evaluations of the NDCMP have been completed since 1975, all showing positive benefits, but with varying levels of statistical confidence. Among the data sources used in the evaluations: Crop-hail insurance data compiled by the Crop-Hail Insurance Actuarial Association (CHIAA), National Weather Service rainfall data, and wheat yield data compiled by the National Agricultural Statistics Service.

The most recent rainfall study was a target-control analysis of NWS rainfall data for the seven years, 1976-82 (Johnson, 1985). Evidence showed an increase in rainfall of 14% in the target area on days with heavier rains. Also noted was an increase in overall precipitation slightly downwind of the target on the order of 15%, however, results were not statistically significant.

A target-control analysis of wheat yields was conducted to determine if the NDCMP was showing a direct benefit in the wheat fields of western North Dakota. The results indicated a 5.9% greater average yield in the target areas versus the control area (Smith *et al.* 1992). Figure 3 shows the wheat yield for the target and control areas before cloud seeding began. There is no discernable difference in the yields from those years. Figure 4 shows the comparison of wheat yields during the NDCMP years. An obvious difference is seen in most years, with the exception of dry years

where no effect is apparent. This adds credence to the results, for dry years are characterized by a lack of suitable candidate clouds.

Finally, a recent study on hail reduction efforts of the NDCMP found a reduction in crop-hail damage in the target areas of 45% when compared to an upwind control area (Smith *et al.* 1997). This study was a more rigorous continuation of another Smith, *et al.* study in 1987 that found a reduction in crop-hail damage in the NDCMP target area of 43.5%. The 1997 study included the years 1976-88, whereas the 1987 study covered the years 1976-85.

6. SUMMARY

The 1997 NDCMP was one of the busiest in recent history. Total flight time for the nine project aircraft was 974 hours. Of those, 745 hours were classified as hail suppression operations, 87 hours as rain enhancement, and 142 hours for reconnaissance and ferrying. During seeding operations a total of 246.81 Kg of AgI and 2,773 Kg of dry ice (CO₂) were released.

The success of the NDCMP has spurred interest in using hail suppression technology for mitigation of property damage in the state. An interim legislative committee is currently studying the feasibility and desirability of implementing hail suppression cloud seeding for the reduction of property damage in urban and rural areas, essentially a state-wide program. Although the outcome of the study won't be known for some time, the mere fact that it is underway indicates North Dakota's continuing interest in cloud seeding technology.

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