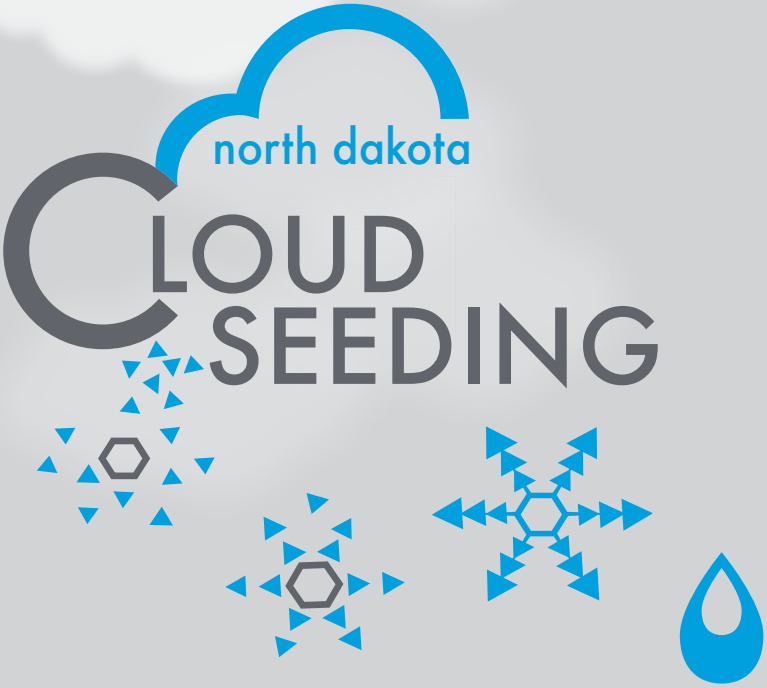
QUESTIONS & ANSWERS

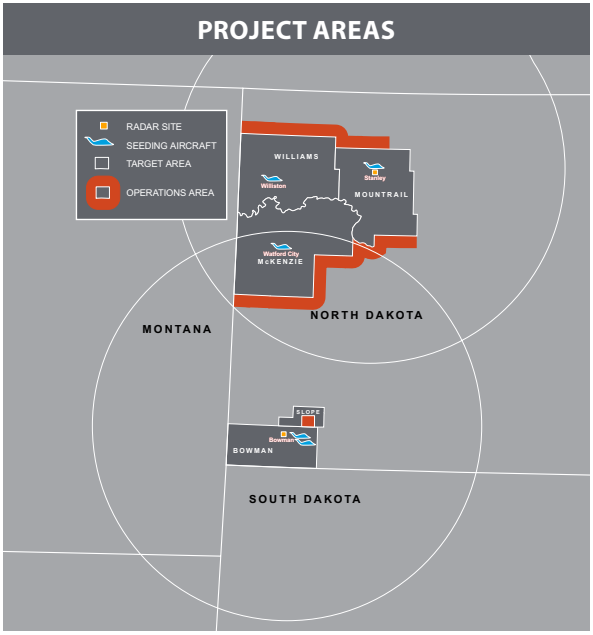


Cloud seeding, often called weather modification, is a process intended to enhance rain and snow, reduce hail damage, and alleviate fog. The science of cloud seeding dates back to 1946, when scientists working at the General Electric Research Laboratory discovered that silver iodide and dry ice could be used to enhance ice crystal formation in clouds. While silver iodide and dry ice are still used today, research and development efforts since 1946 have led to vastly improved understanding of precipitation processes, and greatly enhanced seeding methods and materials.

This brochure addresses the most common questions about the technology and provides the interested reader with references for additional information. If you would like to learn more about cloud seeding in North Dakota, please visit the Atmospheric Resource Board's website at www.dwr.nd.gov/ARB/.

WHERE IS CLOUD SEEDING DONE IN NORTH DAKOTA?

North Dakota's climate is typically drier in the western part of the state, with a higher incidence of hailstorms. Thus, western North Dakota has traditionally been the location for the state's long-running cloud seeding program. Current NDCMP operations areas are shown on the map above.

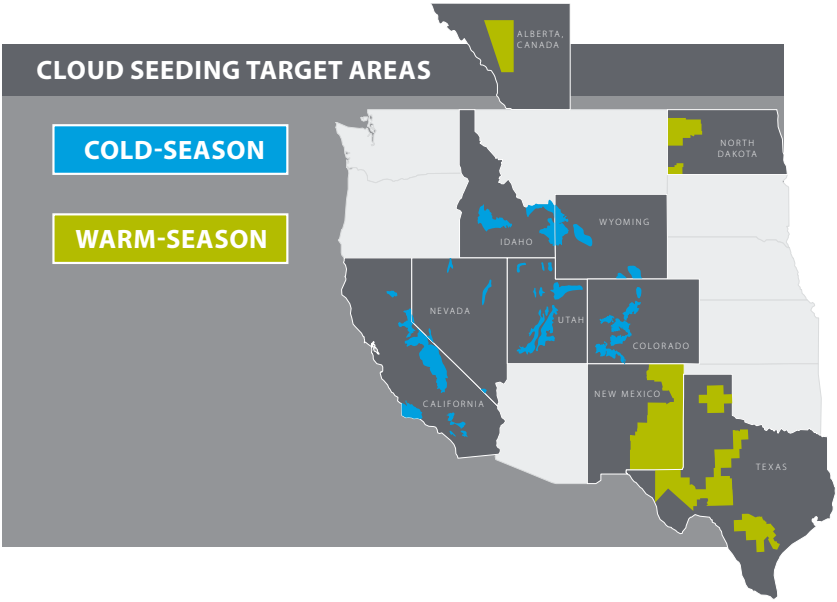


WHO ELSE IS DOING CLOUD SEEDING?

More than 50 countries worldwide participate in cloud seeding activities. The National Oceanic and Atmospheric Administration (NOAA) documented active programs in 10 U.S. states. Project objectives included fog dispersal, snowpack and rainfall enhancement and hail suppression. (See map on next page)

HOW CAN I GET MY COUNTY INTO THE NORTH DAKOTA CLOUD MODIFICATION PROJECT?

There are many ways for a county to join the NDCMP. A petition collecting signatures numbering at least **20 percent** of the ballots cast in the most recent gubernatorial election presented to the county commission would place the issue on the next countywide election ballot. A simple majority in the election would establish the authority to conduct cloud seeding. The



second possibility would be to collect signatures numbering at least **51 percent** of the ballots cast in the most recent gubernatorial election. This petition, when presented to the county commission, would immediately establish the cloud seeding authority.

The third option would be for the county water resource board to bring a resolution to the county commission for the creation of a weather modification authority. After a public hearing, a majority vote by the commission would allow the county to participate in a trial program for up to four years, with several options available to establish a full county weather modification authority after the trial period.

HOW CAN WE DETERMINE THE EFFECTS OF SEEDING?

Seeding effects and benefits can be demonstrated in several ways. The most direct method is to conduct a project over several years in which half of the storms are randomly seeded and the resulting precipitation from the seeded and unseeded storms is compared. From 2005-14, The Wyoming Weather Modification Pilot Program (WWMPP, 2014) accomplished this goal by setting up a randomized cloud seeding program to research and evaluate the enhancement of snowfall. The results point to an increase in snowfall of 5-15 percent during ideal seeding conditions. For operational cloud seeding programs in the U.S., project sponsors want all the seedable clouds treated,

not just half, to attain the maximum potential benefit from the program. In that scenario, evaluations using crop-hail insurance data, crop yield data, or rainfall and hail data are useful if done properly. These evaluations require long-term relationships to be established between seeded and unseeded areas, and a long period of operations for comparison purposes, but do not require that only half of the suitable clouds be treated.

ARE THERE NORTH DAKOTA PROJECTS THAT HAVE DETERMINED THE EFFECTS OF SEEDING?

Yes. The first such effort, which built the foundation of cloud seeding in North Dakota was called the North Dakota Pilot Project (NDPP) (Miller et al., 1975). Conducted in McKenzie County from 1969-72 (Mountrail and Ward Counties also participated in 1972), the NDPP was a randomized experiment, which provided for the best possible statistical analysis of the results.

Experimental protocol set up eight-day blocks in advance of each project season where six days were randomly designated "seed" days and two were "no-seed" days. Following the four-year project, data from 67 rain gauges in McKenzie County were subjected to a variety of statistical tests to determine the seeding effects. **Analysis of the data revealed strong evidence that silver iodide seeding of towering summertime clouds led to an increase in the frequency of rainfall events, an increase in the average rainfall per event, and an increase in the total rainfall in the seeded area.** Further, the total potential rainfall increase for the area was estimated at one inch per growing season. **Hail data from the NDPP showed less hail on seed days than on no-seed days and lower crop-hail insured losses on seed days versus no-seed days.**

WHAT ARE THE BENEFITS OF THE NORTH DAKOTA CLOUD MODIFICATION PROJECT?

Several independent evaluations of the NDCMP have been conducted to determine the effects of the project on rainfall, crop-hail damage, wheat yields, and economic impact. A study of crop-hail insurance data by Smith, et al. (1997) showed a 45 percent reduction of crop-hail damage in the seeded counties. Several independent studies (Miller et al., 1975; Eddy, 1981; Johnson, 1985; Wise, 2005; Tuftedal et al., 2022) have found that rainfall was increased in the target counties (and downwind) from 3 to 14 percent, an increase of up to an inch of additional growing season moisture. A study of wheat yields by Smith, et al. (1992) found an increase of 5.9 percent in the seeded counties versus an adjacent control area with no cloud seeding. Knowles and Skidmore (2021) found wheat yields 13 percent higher in seeded counties versus adjacent control counties.

WHAT IS THE DOLLAR-IMPACT OF CLOUD SEEDING IN NORTH DAKOTA?

Several studies of the economic effects of cloud seeding have been conducted by economists at NDSU's Department of Agribusiness and Applied Economics (e.g., Schaffner et al. 1983, Johnson et al. 1989, Sell and Leistritz, 1998, Bangsund and Leistritz, 2009). The most recent by NDSU's Bangsund and Hodur (2019) examined the benefits to the eight most common crops grown in North Dakota. Using long-term estimates of 5-10 percent increases in rainfall and a 45 percent reduction in crop-hail losses, they calculated a direct benefit to agricultural production of $28.1-$48.8 million annually. Estimated state tax revenues ranged from $576,000 to $999,000; more than double the amount of state cost share funds expended on the program. Benefit to cost ratios ranged from 31-53 to 1.

Knowles and Skidmore (2021) at Michigan State University evaluated the North Dakota Cloud Modification Project (NDCMP) and its effects on crop yields. Using 30 years of USDA Risk Management Agency data, their analysis sought to determine if there was any difference in crop yields (wheat and barley) and insurance loss ratios for NDCMP project counties versus surrounding counties not involved in the program. For the 1989-2018 period, they found that average annual wheat yields in seeded counties were 13 percent higher than wheat yields in non-seeded counties. A further analysis of economic benefits found a benefit to cost ratio of more than 36 to 1. In the words of the authors, "Our evaluation indicates that the cloud seeding program had significant positive effects on crop yields and improved loss ratios."

DO URBAN RESIDENTS BENEFIT FROM CLOUD SEEDING, OR IS IT JUST FOR AGRICULTURE?

Although the program was started to help farmers mitigate hail damage to crops, the reduction of hail size and amount is also presumed to reduce hail damage to homes, vehicles, and other property in the target counties. In fact, reduction of property damages has provided for an insurance industry-sponsored program in Alberta, Canada.

WHAT IS THE COST OF CLOUD SEEDING IN NORTH DAKOTA?

For approximately 15 cents per acre, the NDCMP provides benefits that far outweigh the costs of the program.

WHO PAYS FOR CLOUD SEEDING IN NORTH DAKOTA?

The costs of cloud seeding are paid with funds from the participating counties and cost-share funds from the State. About two-thirds (66 percent) of the project is paid through county funds, and one-third (34 percent) by the State.

DO CLOUD SEEDING CHEMICALS HAVE AN EFFECT ON THE ENVIRONMENT?

Published scientific literature clearly shows **no environmentally harmful effects** from cloud seeding with silver iodide aerosols (WMA, 2009). The silver concentration in rainwater from a seeded storm is well below the acceptable environmental concentration of 50 micrograms per liter as set by the U.S. Public Health Service. Because silver iodide is such an effective ice nucleus, it is used in very small quantities. Based on the average rate of seeding material used in North Dakota each summer, only one one-hundredth of a gram (0.01g) would be expected to fall on an acre of land during the summer project.

CAN CLOUD SEEDING CHANGE WEATHER PATTERNS OR AFFECT THE CLIMATE?

No. Cloud seeding changes individual clouds or groups of clouds. Changes to large-scale weather and climate patterns are determined by much greater forces such as global atmospheric circulation patterns and ocean temperatures.

CAN CLOUD SEEDING END DROUGHTS?

No. Although drought is sometimes the impetus for implementing a cloud seeding program, it is not generally advocated for such purposes. The reason for this is that droughts are caused by prolonged periods that do not produce clouds conducive to precipitation. Therefore, cloud seeding opportunities during these periods are few, often providing limited results. Long-term and well-designed cloud seeding programs can potentially soften the impact of drought, however, since increased precipitation before and after drought would temper the reduction of rainfall during the drought period. Cloud seeding should be viewed as a long-term water resource management tool.

DOES CLOUD SEEDING AFFECT PRECIPITATION DOWNWIND?

Evidence suggests a slight increase in precipitation downwind that diminishes with increasing distance from the target area (DeFelice et al., 2014). There is no scientific evidence that cloud seeding, which enhances rainfall in one area, produces dry conditions downwind.

CLOUD PROCESSES AND SEEDING METHODS

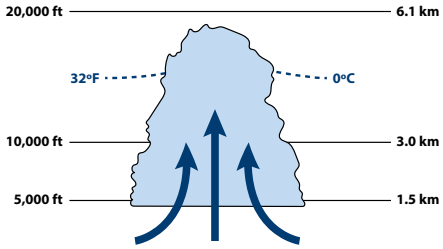
HOW DOES CLOUD SEEDING WORK?

Cloud seeding improves a cloud's ability to produce precipitation by adding tiny particles called ice nuclei (particles with an ice crystal structure that water needs to freeze). These nuclei help the cloud produce precipitation by freezing **supercooled liquid water (SLW)**, which are cloud droplets still in liquid form at temperatures colder than 32°F. Natural ice nuclei are often inefficient or lacking in sufficient numbers in the atmosphere. Adding more efficient ice nuclei through seeding can increase the precipitation production of the cloud.

ARE ALL CLOUDS GOOD CANDIDATES FOR SEEDING?

No. For summertime cloud seeding, only clouds that possess a sustained updraft of moist air, lack natural ice, and grow to heights cold enough to contain SLW are suitable for cloud seeding.

TOWERING CUMULUS STAGE

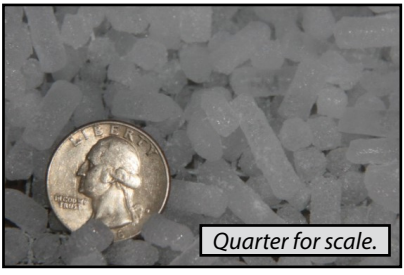


WHAT ARE CLOUDS SEEDED WITH?

North Dakota clouds are seeded with two different types of materials:

- Silver Iodide-Artificial Ice Nuclei that provide a crystalline structure on which SLW droplets can freeze;
- Dry Ice, which at -109°F is so cold that it helps create additional droplets from water vapor and freezes those droplets instantaneously.

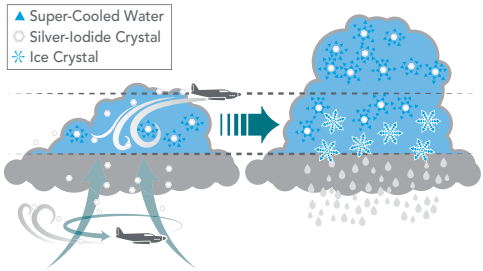
DRY ICE PELLETS


Quarter for scale.

Dry ice pellets are used on some cloud seeding programs. They are typically dropped by airplanes in towering cumulus clouds during summer seeding programs to accelerate the precipitation process.

CLOUD PROCESSES AND SEEDING METHODS

WARM SEASON CLOUD



HOW LONG AFTER SEEDING DOES A CLOUD START TO CHANGE?

The onset of seeding effects can range from almost immediate to up to 30 minutes depending on the seeding delivery method (**direct injection** at cloud top, or **base seeding** - releasing seeding agent in the updraft below the cloud base). Direct injection is more immediate, but involves flying in-cloud and working at higher altitudes, requiring aircraft with higher performance (and costlier) capabilities. Updraft treatment at cloud base is easier to accomplish, but requires the seeding agent be transported by the cloud's updraft to where it can become effective, thus taking a little longer. As each method offers advantages in certain situations, both are employed in North Dakota.

WHO DECIDES WHICH CLOUDS ARE SEEDED?

The radar meteorologist, an employee of the Department of Water Resources, is the director of operations for cloud seeding missions. In addition to weather conditions, a number of factors play a part in the decision-making process including input from participating counties, safety criteria, radar information, pilot observations, and aircraft instrument data.

HOW DOES SEEDING AFFECT THE DEVELOPMENT OF PRECIPITATION IN A CLOUD?

Evidence indicates that seeded storms often rain over larger areas than unseeded storms. This means some areas that would not have received rain often do as a result of seeding (Dennis et al., 1975). By seeding developing clouds before they start to produce precipitation, the precipitation process is accelerated and rain falls sooner, and from smaller clouds than it would naturally.

HOW IS THE SEEDING AGENT DELIVERED TO SUITABLE CLOUDS?

In North Dakota, all seeding is done by aircraft. Base-seeding aircraft release seeding agent into updrafts from below the developing storm using a combination of wing-mounted ice nucleus generators and burn-in-place flares. Cloud-top seeding aircraft use ejectable flares and dry ice released directly into the supercooled cloud.


Wing-Tip Generator


Ejectable Flare Racks

Burn-In-Place Flares

ISN'T FLYING AIRCRAFT AROUND THUNDERSTORMS DANGEROUS?

All pilots that fly seeding aircraft on the North Dakota Cloud Modification Project (NDCMP) are trained through classroom education, intern experience, and/or field experience with a qualified weather modification pilot instructor. With these requirements in place the flight safety record in North Dakota has been excellent.

WHY DOES HAIL SOMETIMES FALL FROM SEEDED STORMS?

Cloud seeding for hail suppression is just that: hail **suppression**, not hail **elimination**. Studies of crop-hail insurance data suggests that the NDCMP reduces crop-hail damage by 45 percent (Smith et al., 1997). Hail still occurs in areas with hail suppression cloud seeding. The reasons for this are many, but they involve storm structure (seeding works better on some storm types than others), the ability to seed targeted storms safely and effectively (sometimes safety criteria preclude effective treatment of targeted storms) and working with limited resources (sometimes there are more storms occurring at one time than there are resources available to adequately seed them). Also, occasionally storms already containing hail enter the target areas, and for this situation there is no remedy - the hail will eventually fall.

WHY DO SOME THUNDERSTORMS PRODUCE HAIL, WHILE OTHERS DON'T?

Hail often occurs when atmospheric instability is great, and when strong wind shear (strong variations of wind speed and direction with height) is present. Thunderstorm ingredients include atmospheric instability (warm air at the surface and cold air aloft), abundant moisture, and a weather feature such as a cold or warm front to initiate storm development. While a small percentage of storms produce hail on the ground, a larger percentage develop hail during their lifecycles that falls and melts before it reaches the ground.

WHO SEEDS CLOUDS AND WHAT KIND OF TRAINING IS REQUIRED?

The Atmospheric Resource Board (ARB) retains contractors who provide the aircraft, seeding equipment and pilots to seed clouds. Pilots-in-command must meet certification and flight-time requirements; meteorologists must possess a bachelor's degree in Meteorology or Atmospheric Science to qualify. The ARB also maintains an intern program through the University of North Dakota's John D. Odegard School of Aerospace Sciences for academic and field training of weather modification intern pilots. Another ARB program provides meteorology students a summer educational opportunity working as intern meteorologists at the Bowman and Stanley radar sites. In addition, the ARB conducts a ground school prior to each project covering all pertinent aspects of the program.

PIC and Intern Pilot in Stanley, 2021

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NORTH Dakota
Be Legendary.

Atmospheric Resource Board

WATER RESOURCES

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