



## Common Questions and Answers about Cloud Seeding

Cloud seeding, often called weather modification, is a scientific process intended to enhance rain and snow, reduce hail damage, and alleviate fog. Current technology 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 over the last 60 years have led to vastly improved understanding of precipitation processes, and greatly enhanced seeding methods.

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.swc.nd.gov/ARB/](http://www.swc.nd.gov/ARB/).

# Cloud Processes and Seeding Methods

## 1. 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 silver iodide nuclei through seeding can increase the precipitation production of the cloud.

## 2. Are all clouds good candidates for seeding?

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

## 3. What are clouds seeded with?

North Dakota clouds are seeded with two different types of agents: silver iodide complexes, artificial ice nuclei that provide a crystalline structure on which supercooled liquid water (SLW) droplets can freeze; and dry ice (frozen carbon dioxide), which at -109°F is so cold that it helps create additional droplets from water vapor and freezes those droplets by thermal shock.

## 4. How long after seeding before a treated cloud starts to change?

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 both methods offer advantages in certain situations, both are employed in North Dakota.

## 5. What has research shown us about clouds and precipitation?

A number of scientific research experiments have been conducted, many in North Dakota, from which we have learned much about the basic processes of cloud and precipitation formation and development. Much of what has been learned has been applied to cloud seeding technology, thereby making cloud seeding more effective now than ever before.

**WHICH CLOUDS ARE SUITABLE?**  
To be successfully seeded, a cloud must pass three tests:

- 14° super-cooled**  
The cloud top must be significantly colder than 32°F. . . 14°F is ideal.
- ice-free** ❄️ ❄️  
If the cloud contains significant concentrations of ice, it need not be seeded, as nature is already acting efficiently.
- updraft**  
The cloud must sustain an updraft of at least several hundred feet per minute. This updraft conveys a continuing supply of moist air into the cloud.

## 6. Who decides when clouds are seeded?

The radar meteorologist is the director of operations for cloud seeding missions. A number of factors play a part in the decision-making process, including safety criteria, radar information, pilot observations, and aircraft instrument data.

## 7. If a cloud is seeded, does it rain somewhere other than where it would have rained naturally?

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. 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. Some redistribution of rainfall can occur within the scope of the storm itself, with computer models suggesting that regions of very intense precipitation may be slightly reduced while the total storm rain volume is increased.

## 8. How is 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.

## 9. Isn't flying aircraft around thunderstorms dangerous?

Flying around thunderstorms can be dangerous if pilots are not properly trained. For this reason, all pilots that fly seeding aircraft on the North Dakota project 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.

## 10. Why does hail sometimes fall from seeded storms?

Cloud seeding for hail suppression is just that: hail *suppression*, not hail *elimination*. The most recent study of crop-hail insurance data suggests that the North Dakota project reduces crop-hail damage by 45 percent. 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 safely and effectively seed targeted storms (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.

## 11. Why do some thunderstorms produce hail, while others don't?

Hail often occurs when atmospheric instability is great, and when other factors such as strong upper-level winds are 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 much larger percentage develop hail during their lifecycles that falls and melts before it reaches the ground. (See illustration on page 4.)

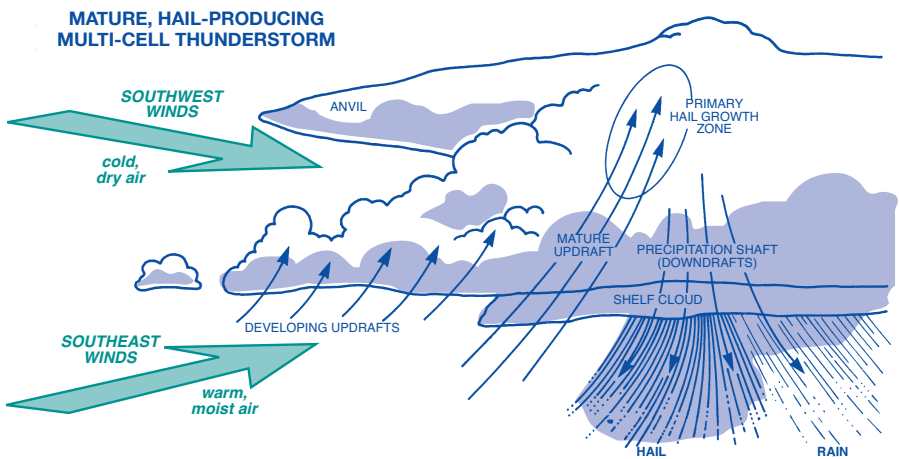
## 12. If it gets too wet, who tells the cloud seeders to stop?

In North Dakota each county participating in the cloud seeding program has two local delegates on the District Operations Advisory Committee, which advises

project personnel on operations strategies. For instance, if a county or part of a county is too wet, cloud seeding can be suspended until drier conditions return.

### 13. Who seeds clouds and what kind of training is required?

The Atmospheric Resource Board (ARB) via competitive bidding retains contractors who provide the aircraft, seeding equipment and pilots to seed the 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. In addition, the ARB conducts a three-day ground school prior to each project covering all pertinent aspects of the program. 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 intern program provides meteorology students a summer educational opportunity working as intern meteorologists at the Bowman and Stanley radar sites and at the ARB offices in Bismarck.



## Climate and Environment

### 14. What effects do cloud seeding chemicals have on the environment?

The 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. Also, the concentration of iodine in iodized salt used for human consumption is far above the concentration found in rainwater from seeded clouds. Because silver iodide is such an effective ice nucleus, it is used in minute quantities. Based on the average rate of silver iodide use in North Dakota each summer, it would take nearly 500 years for one gram of silver iodide (1/28th of an ounce) to be evenly spread out over an area equal to a full-sized basketball court!

### 15. Does rain water from a seeded cloud taste or smell different than natural rain?

No. There is no discernible difference between rainwater from a seeded cloud and rainwater from a non-seeded cloud.

### 16. 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 circulation patterns and ocean temperatures.

### 17. Can cloud seeding end droughts?

Though 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 production. Therefore, cloud seeding opportunities during these periods are few, often providing limited results (See Question #2). A long-term and well-designed cloud seeding program 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.

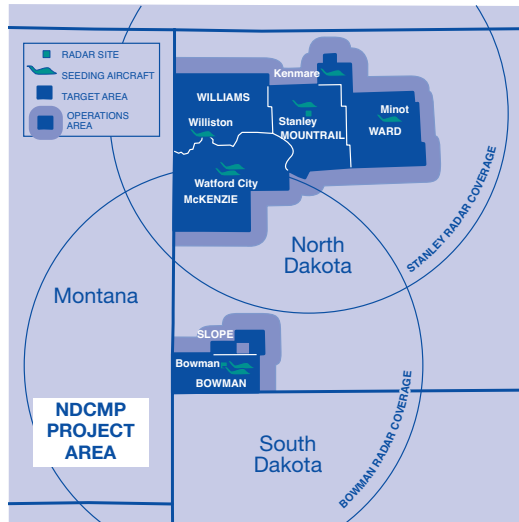
### 18. Does cloud seeding affect precipitation downwind?

Evidence suggests a slight increase in precipitation downwind (up to 90 miles in extreme cases) that diminishes with increasing distance from the target area (See Question #7). There is no scientific evidence that cloud seeding which enhances rainfall in one area produces dry conditions downwind.

## Programs, Evaluations, Economic Benefits and Costs

### 19. 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. The North Dakota Cloud Modification Project (NDCMP) locations are shown on the map at right.



### 20. How can we determine the effects of seeding?

Seeding effects and benefits can be demonstrated in a number of ways. The most direct method would be to

conduct a project over several years in which half of the storms were randomly seeded and the resulting precipitation from the seeded and unseeded storms were compared. The problem with this method, though, is that project sponsors usually want all of the seedable clouds treated, not just half, to attain the maximum potential benefit from the program. 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.

## 21. 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 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 rainfall 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.*

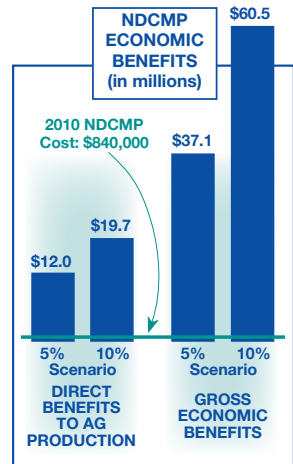
More recent North Dakota research projects include the Atmospheric Modification Program (AMP) in the 1980s and 90s and the Polarimetric Cloud Analysis and Seeding Test (POLCAST) in 2006 and 2008, though these programs have focused more on understanding cloud and precipitation development.

## 22. What is the dollar-impact of cloud seeding in North Dakota?

Bangsund and Leistriz (2009), Agricultural Economists at North Dakota State University (NDSU) studied the economic impacts of cloud seeding on North Dakota’s agriculture. North Dakota’s top eight crops from 1998-2007 (wheat, soybeans, corn, barley, canola, sunflower, flax, and dry edible beans) were evaluated for both NDCMP and statewide impacts. Alfalfa was also included in the study because of its value as a forage crop.

Results were based on a 45 percent reduction of crop-hail damage and rainfall increases of 5 and 10 percent. The total direct impact of the NDCMP in the 5 percent rainfall scenario is \$12 million or \$5.16 per planted acre annually. Those figures increase to \$19.7 million or \$8.41 per planted acre annually for the 10 percent rainfall scenario. These results yield benefit-to-cost ratios of 14 to 1 for the 5 percent scenario and 23 to 1 under the 10 percent scenario (based on 2010 project costs). The economic impacts don’t factor in the reduction of hail damage to property, which is also presumed to be substantial.

For a hypothetical statewide seeding program, the total direct impact from the 5 percent scenario is \$95.4 million or \$4.87 per planted acre, with a jump to \$134.5 million or \$6.86 per planted acre in combined direct impacts for the 10 percent scenario. Additionally, the estimated \$3 million annual cost of operating a cloud seeding program statewide is more than offset by a \$6 million increase in tax revenues.



## 23. Do urban residents benefit from cloud seeding, or is it just for farmers?

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 the impetus for an insurance industry-sponsored program in Alberta, Canada (See Question #28). Unfortunately, a suitable method and dataset to evaluate the economic impact on property in North Dakota has not been conceived.

### 24. What are the benefits of the ND 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) have found that rainfall was increased in the target counties (and downwind) from 4 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.

### 25. What is the cost of cloud seeding in North Dakota?

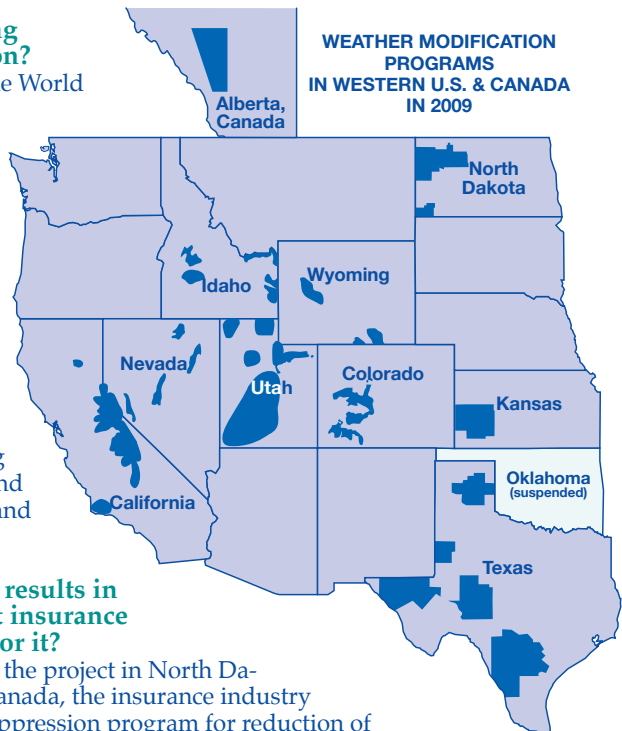
The benefits of the NDCMP far outweigh the costs (See Question #22). The cost of the 2010 NDCMP is expected to be 12.5 cents per-acre.

### 26. 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. In recent years, about two-thirds of the project was funded through county taxes, and one-third picked up by the State.

### 27. Who else is doing weather modification?

The latest data from the World Meteorological Organization compiled for 2009 listed more than 100 projects ongoing worldwide in more than 34 countries. The National Oceanic and Atmospheric Administration (NOAA) documented 45 projects conducted in ten U.S. states. Project objectives included fog dispersal, snowpack and rainfall enhancement and hail suppression.



### 28. If cloud seeding results in less hail, why aren't insurance companies paying for it?

They aren't paying for the project in North Dakota, but in Alberta, Canada, the insurance industry wholly funds a hail suppression program for reduction of

property damage. The program operates annually from June 1 through September 15 and completed its 14th year of operations in 2009.

### 29. How can I get my county into the ND Cloud Modification Project?

There are many ways for a county to join the North Dakota Cloud Modification Project. 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.

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