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## *Does Weather Modification Really Work?*

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For thousands of years, humans have tried to coax the weather into performing the way we would like it to.

In most cases, the goal was to produce more rain. The Mayans threw middle aged women into water wells to appease their rain god. In 18th century England, bell ringers were ordered to make noise in the church towers to shock moisture from the clouds. In the mid-1800s, experiments with weather modification and rain making were widespread in many parts of the U.S., including Texas. Many soldiers that took part in the Civil War believed that rains increased after heavy battles because of the shells that were fired into the sky and the sounds they created. That may be why cereal king C.W. Post, who founded Post City in the Texas Panhandle, performed experiments where dynamite was exploded into the sky in the hopes of producing rain.

In 1946, the modern science of weather modification was born. Vincent Schaefer was working at the General Electric Laboratory in upstate New York. He was trying to find a way to induce artificial clouds to produce precipitation in a cold cloud chamber (a modified freezer) in his lab. Schaefer was worried that conditions were getting too warm, so he slid a chunk of dry ice into the freezer. Immediately, ice crystals formed a cloud around the dry ice. Shortly afterwards, Schaefer's colleague Bernard Vonnegut searched the literature until he found a chemical, silver iodide, that is almost exactly like ice in its molecular structure, but can be carried and applied more easily. That provided the groundwork for the idea that the rainfall can be artificially augmented and encouraged future research. Largely as a result of this work, research about weather modification to increase rainfall and suppress hail was funded by many Federal and State agencies.

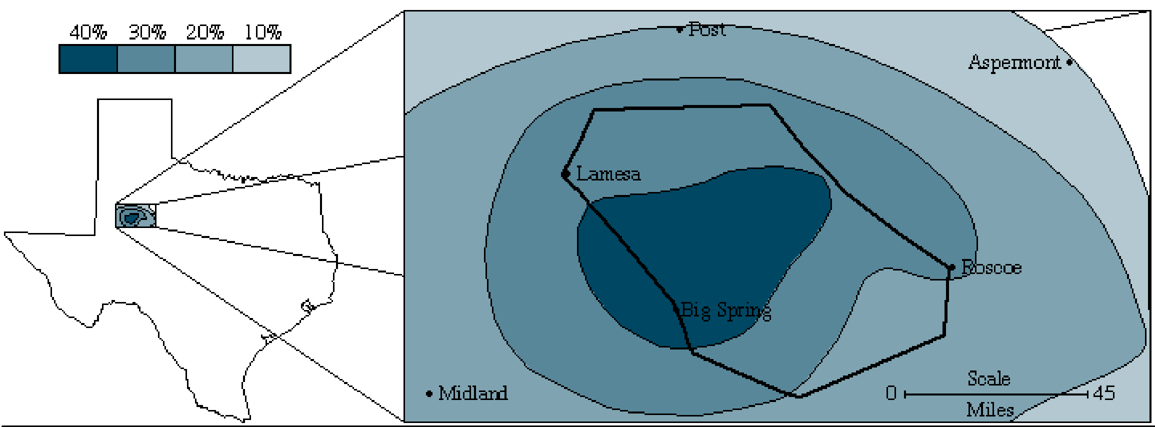
By the 1960s and 1970s (the "glory days" of weather modification) Texas became the site for many weather modification studies. Projects to reduce hail damage were initiated in the High Plains. Cloud seeding was investigated as a way to ward off droughts in the Edwards Aquifer area, Corpus Christi, and West Central Texas. San Angelo and the Colorado River Municipal Water District (MWD) in Big Spring sponsored lengthy tests to find out if weather modification could increase the amount of water in lakes and boost cotton yields.

By the late 1970s, few experts agreed on whether cloud seeding was scientifically valid and much of the enthusiasm diminished. The reasons can be grouped into many categories. First, many critics charge that it is hard to prove the effects of cloud seeding. They argue that it is difficult to predict how much rainfall would have occurred had clouds not been seeded. Second, these criticisms led to decreased funding and support of weather modification projects by State and Federal agencies. Federal funding for weather modification studies has plummeted from $25 million in the early 1980s to only a few million today. That has limited the amount of research that is taking place and has dissuaded young scientists from entering the field. Third, still others feel that man should not interfere with natural processes like climate and rainfall. Fourth, weather modification projects have generated ill will between groups that feel that increasing rainfall in one area may be "stealing" water from nearby regions. In the 1970s, farmers using irrigation to grow crops in the High Plains sponsored weather modification studies to reduce hail damage. Angry nearby dryland farmers sued to halt the operation. They believed the project would lessen the amount of rain they would receive. Public perception is also a problem. Many feel that rain making is still more associated with the barnstormers and charlatans of the 1800s than with modern science.

Still, there are those who believe that weather modification may be a successful strategy to help extend Texas' water supplies. "Weather supply yield enhancement" through weather modification is a component of the Texas Water Development Board's (TWDB) Water Plan. George Bomar, a meteorologist with the Texas Natural Resource Conservation Commission (TNRCC), has investigated weather modification for more than 20 years. The Colorado River MWD operates the longest ongoing weather modification program in the nation. Weather modification has also been utilized to increase winter snowpacks and disperse fog.

## *The Science of Cloud Seeding*

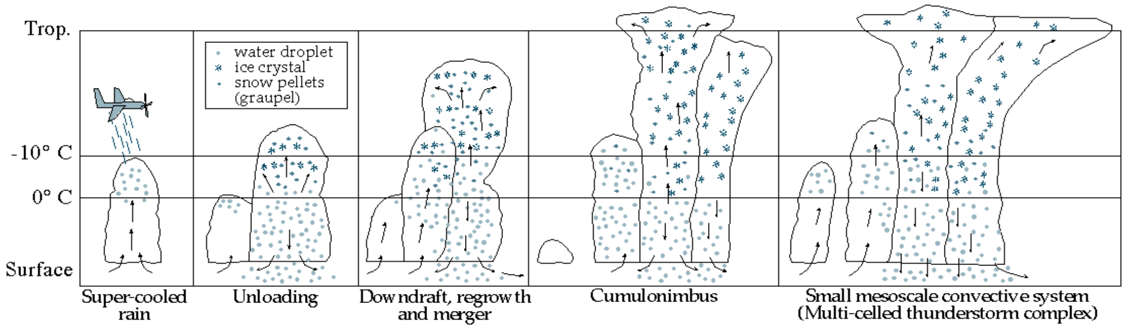
To understand cloud seeding, you first have to know some basic facts about the weather. All air contains moisture. When warm air rises from the Earth's surface and begins to cool, some of the moisture condenses into tiny droplets that cause clouds. More than 99% of a cloud is air. Before these tiny droplets can form raindrops or hailstones, they have to merge with millions of others before they are heavy enough to fall to the ground. For precipitation to form, temperatures inside the cloud have to be less than the freezing point of water. When droplets of this supercooled water encounter specks of dust, salt, or sand they form small ice crystals. Water vapor in the cloud then freezes directly onto the surface of these crystals and they gain weight and fall. Cloud seeding introduces silver iodide and other agents that mimic the structure of ice and serve as a template or nucleus for crystal formation. Cloud seeding increases the number of nuclei in cloud formations and hastens the transformation of water vapor in the cloud into droplets. This condensation and freezing releases a large amount of heat that makes clouds more buoyant and may double their size and height. As clouds grow taller, their updraft increases, they draw in more moist air from near the surface, and their ability to efficiently process water increases.




*This map displays how cloud seeding projects near Big Spring may have affected Summer rainfall in the region. The target area is the oblong shape that stretches from Big Spring to Roscoe to Lamesa. The percent increase in rainfall is indicated by the bar at the left.*

Weather modification research projects typically operate like this. First, suitable cloud formations are identified. In Texas, efforts center on finding small "feeder" cells that are near developing cloud formations, with cloud tops that are colder than 23deg. F. The flow of air into the clouds and the liquid water content also influence if a cloud is likely to produce rain. Then, planes take off and fly into and above the clouds. In research flights, pilots and scientists take a supply of sealed envelopes with them. When they find a suitable cloud, they open an envelope that contains instructions on whether or not to seed it. This ensures that the experiments are carried out randomly. Only about half the flights result in cloud seeding. The planes release plumes of microscopic silver iodide particles using flares. When the particles meet cool moisture in the clouds, they trigger the formation of ice crystals and raindrops. The amount of silver iodide that is used is small enough that it doesn't pose a pollution risk.

Typically, clouds won't produce rain until 20 or 30 minutes after they have been seeded. Therefore, it's critical to seed clouds that are well upwind of where you want rain to fall, and to seed them before they arrive at the intended destination. TNRCC research suggests that clouds with a warm base, a vigorous updraft, and enough latent heat to carry water vapor to the cloud tops are the best candidates for seeding in Texas.




*How Cloud Seeding Increases Rainfall Production*

It's important to note that different types of clouds will be seeded, depending on the goal of each project. To lessen hail damage, large thunderstorms that are likely to produce hail would be seeded. If the aim is to increase rainfall, smaller clouds that are likely to grow would be seeded.

A commonly asked question is, "Do weather modification projects increase rain in one area at someone else's expense?" Bomar says that's a common misconception. Clouds are inefficient in the way they distribute moisture and don't gather and release a*ll the* moisture that is available. Clouds only contain an average of 1% of the total atmospheric moisture at any time. Therefore, even if cloud seeding doubled the efficiency of a cloud formation, it would probably only contain 2% of the available moisture, leaving roughly 98% for all other uses. He adds that *no* scientific studies have shown that some residents get rain at the expense of their neighbors.

## *A Brief History of Weather Modification in Texas*

In Texas, man's efforts to modify the weather date back to the 1880s, when the U.S. Department of Agriculture sponsored efforts by General R. G. Dyrenforth in the High Plains. The project used balloons to carry explosives into the sky where they would bombard convective clouds and make them rain. In 1910, Post began experiments near Post City. He had workers attach dynamite to 15 or 20 kites. After the kites had risen to 100 feet high or higher, the dynamite would be detonated. Post had what can best be termed as occasional success. Sometimes rain fell after the explosions, but often it didn't. Post continued to believe that this form of weather modification would work, until the tests were stopped in 1914.

The use of weather modification to control hail provides some insights as to why cloud seeding can be controversial.

In 1959, ranchers who lived downwind of the Davis Mountains in Jeff Davis County filed suit against Southwest Weather Research, Inc. The ranchers were concerned that cloud seeding would lessen the amount of rain that would ordinarily fall on their lands. They claimed that the people carrying out the weather modification project did not have the right to affect the weather over their lands. The case went to the Texas Supreme Court, which ruled that the cloud seeding could continue because a*ll* Texans are entitled to the water above them, even if it was in the clouds.

Similar arguments for and against the use of cloud seeding to minimize hail losses surfaced in the High Plains in the 1970s. More than 300 ranchers and farmers who worked 70,000 acres of land protested a hail suppression program that was operated in Hale, Floyd, Bailey, and Lamb counties from 1970-73. The program used airplanes to seed cumulus clouds with silver iodide. Each summer, damaging hailstones fall on 20 to 30 days. Operators of the program say that seeded areas suffered far less hail damage, while unseeded areas suffered 3 times the normal amount of hail losses. Opponents formed the Ranchers and Farmers Association for Natural Weather and claimed that cloud seeding efforts lowered the amount of rain their area would normally receive. The Association protested to the TWDB and the Legislature that cloud seeding programs to control hail should not be allowed, unless a majority of property owners in a region approved of them. As a result, the hail suppression programs were discontinued in 1977 and have not been attempted in Texas since.

In June of 1971, "Project T Drop" was initiated to relieve a drought that afflicted large areas of West and South Texas. Planes equipped with silver iodide flares were dispatched to an area stretching from San Angelo to Port Aransas. As the drought worsened, the planes were sent into North Central and East Texas. The drought was broken at the end of June by widespread rainfall, and the program was suspended. At roughly the same time, ground-based generators were utilized in Oklahoma to increase the chance that clouds would produce rain as they moved into Texas.

Texas has been the site of many efforts sponsored by State and Federal agencies. The High Plains Experiment was a joint study that was carried out by the U.S. Bureau of Reclamation (BuRec) and the TWDB from 1974 to 1980. The goal was to determine if seeding warm-season clouds that form over West Texas could significantly increase rainfall. The study revealed that most of rainfall in the region is formed when small raindrops merge to form larger drops. This implies that seeding large convective cloud formations (or thunderheads) with more than one cell is more likely to produce rain than seeding isolated cumulus clouds. The studies suggest that cloud seeding can help cloud formations convert water vapor into raindrops when the updraft and liquid water content are sufficient, and when the clouds live at least 15 minutes. The study assessed the economic impact of successful cloud seeding programs that boost rainfall by 10% during the growing season. It showed that they would increase annual agricultural production by $4 million and personal income by $2 million, while decreasing irrigation costs by $500,000.

The Southwest Cooperative Program in Weather Modification Research was conducted from 1983 to 1990. The goal was to increase the efficiency of cloud clusters that produce 75 to 80% of Texas' rainfall each Summer. Research used aircraft to seed the towers and tops of "suitable" super-cooled convective clouds with silver iodide. Suitable clouds were defined as multi-cell convective formations with adequate water vapor. During the project, 34 flights were made into suitable cloud formations and 17 clouds were seeded. Data were analyzed through the use of three-dimensional weather radar data and cell tracking software. Results show that cloud seeding increased the amount of rainfall by 130%, cloud heights by 7%, cloud area by 43%, and duration by 36%. Cells that were seeded were twice as likely to merge and form rain-producing convective clouds than non-seeded clouds.

The City of San Angelo sponsored a cloud seeding program from 1985 to 1989 to increase rainfall and to fill Twin Buttes and Fisher reservoirs and nearby rivers. Clouds were seeded in a 60 square mile area north, west and northwest of San Angelo. City officials credited cloud seeding with a 30% increase of rainfall and a 28% decrease in water use (less water was applied to landscapes because rain was plentiful). The program was discontinued because of the cost (roughly $200,000 annually), even though water levels in area reservoirs jumped from 40,000 acre feet (AF) to more than 230,000 AF during the program.

The Colorado River MWD in Big Spring has operated a cloud seeding program since 1971. Aircraft are deployed annually from April to October. The goal is to augment rainfall and runoff into the District's reservoirs and to boost water supplies for agricultural irrigation. Virtually all the seeding is done in vigorous updrafts near the cloud base. The project has increased average annual rainfall by 140% (4 inches) in target areas, including Big Spring and Snyder. One way to judge the success of the program is to examine the amount of water in the District's reservoirs. At the time the program was begun, the level of Lake Spence was only 14,000 AF (its capacity is 484,000 AF), and Lake Thomas was down to 26,000 AF (it's designed to hold 204,000 AF). Now, Lake Spence contains 200,000 AF and Lake Thomas holds 30,000 AF. Lake Ivie (a reservoir built after cloud seeding began) now stores 540,000 AF.

The Colorado River MWD has worked with the Plains Cotton Growers Association to study if weather modification efforts have increased non-irrigated cotton yields in the areas that were targeted for cloud seeding. Yields from the years before the seeding program began (1940-70) were compared to yields after the weather modification program was begun (1971-88). No adjustments were made for technological advancements, differences in farming practices, or ecological factors. The results show that yields in the target area (Borden, Scurry, Howard, and Mitchell counties) increased by 46% since seeding began. Dryland cotton yields in the region have averaged 319 lbs./ acre since 1971, compared to an average of 312 lbs./acre statewide.

## *Legal and Policy Issues*

Texas regulations concerning weather modification are contained in Chapter 18 of the Texas Water Code, which is commonly known as the Texas Weather Modification Act. It was passed in 1967 by the Texas Legislature.

The code sets requirements for operators of these programs. No one may engage in weather modification activities without a license issued by the TNRCC. Licenses will only be issued to those who "demonstrate competence" in the field. A permit is required for each project. Permits must demonstrate that weather modification operations "will not significantly dissipate the clouds and prevent their natural course of developing rain in the area" and will not be to the "material detriment" of persons or property in that area. The rules also require that a public hearing be held in the area where a project will be carried out, if 25 people request one.

Special conditions govern the use of weather modification to limit hail damage. People living in the affected area can vote on whether their area (which can be as small as part of a county) will be included in a cloud seeding project. A simple majority vote can cancel a project that has been proposed for their area.

There are some cloud seeding operations that do not need licenses and permits. These include research experiments and technology development carried out by State and Federal agencies, universities, and nonprofit organizations; activities to protect against fire, frost, sleet or fog, and programs that are not conducted to increase, decrease, or prevent rain or hail.

The law also establishes a weather modification advisory committee that makes recommendations to the TNRCC. This committee assists TNRCC staff in reviewing the merits of individual permits. The rules also call upon the TNRCC to "promote continuous research and development" in the theory and development of methods to modify the weather, and the use of weather modification for agricultural, industrial and commercial uses. Since the Act was passed in 1967, permits have been issued for more than 30 weather modification projects to increase rainfall (few permits have been granted to suppress hail).

Nationally, there are efforts underway to develop a section of a model water code that will address weather modification. The efforts to develop a revised code are being led by the American Society of Civil Engineers and the Weather Modification Association. The ultimate goal is to identify regulations that have been implemented throughout the U.S. Water managers can then compare their statutes to the model code. Texans who are involved in drafting the modified code are Howard Taubenfeld, a professor of the Southern Methodist University Law School, and Conrad Keyes, an engineer with the U.S. Section of the International Boundary and Water Commission in El Paso.

The model code reaffirms that States have the right to increase precipitation by artificial cloud seeding. It also states that all moisture that is suspended in the atmosphere is public property. The code retains the right of individuals who feel they have been harmed by weather modification to sue groups that operate such projects. The code also sets forth a procedure for determining how to allocate the rights to increased amounts of water that may be made available from weather modification.

Nationally, managers and operators of weather modification programs can be certified through the Weather Modification Association. Requirements for certification include substantial experience, and a B.S. or M.S. degree in a closely related field.

## *Current and Future Activities*

Today, scientists are intensifying their efforts to gather data to confirm that cloud seeding works. Bruce Boe, a scientist with the North Dakota Atmospheric Resource Board, has developed and refined a technique that uses a tracer gas (sulfur hexafluoride), sensitive detectors, and a complex computer program to follow silver iodide through a cloud. Sulfur hexafluoride makes it easier to trace the flow of cloud seeding agents, because it can be detected in only a second (it takes airborne scientists a minute to trace silver iodide). Boe's research suggests that silver iodide often flows rapidly to cloud tops in a narrow ribbon. It then disperses and mixes with water vapor, before drifting back down through the cloud. The research provides information on which types of clouds need to be seeded to prevent hail damage. Researchers at the Desert Research Institute in Nevada are trying to determine how much rainfall can be attributed to weather modification. They are seeding clouds with a tracer (indium oxide) that can be detected in fallen snow.

This summer, Bomar is working with the Colorado River MWD and BuRec to document the development of super-cooled rain in growing cumulus clouds. The study is titled the Texas Experiment in Augmenting Rainfall through Cloud-Seeding, and is part of the cooperative State-Federal Atmospheric Modification Program, which is sponsored by the National Oceanic and Atmospheric Administration (NOAA). A T-28 cloud physics research plane will penetrate seeded and non-seeded clouds to document the effect of cloud seeding, and a twin-engine aircraft will be used to seed the tops of growing convective clouds. Ground-based Doppler and NEXRAD radar from the National Weather Service's Lubbock office will supplement data analyses. Information will be collected to better understand how rain water freezes in these cloud systems, and to quantify air temperatures and residence times. The objectives are to: 1) Provide more samples of suitable cloud formations, 2) Document the development of super cooled rain in growing cumulus clouds, 3) Gain information on the freezing of super cooled cloud and rain water, 4) Document cloud processes during the unloading stage, and 5) Gather data on the downdraft, merger and maturation of cumulonimbus clouds. The BuRec Skywater radar system in Big Spring will be used to make volume scans of treated clouds. Texas' recording rain gage network will be operated during the studies to measure rainfall distribution in the study area.

In 1995, Bomar plans to study how cumulus clouds are transformed to mature cumulonimbus clouds that are more likely to cause rain. The TNRCC plans to use dual polarizing radar, which will provide improved capabilities to trace the number of supercooled raindrops. Another goal is to gain information on cloud growth and the merger of small clouds into larger formations. Bomar stresses that research is still needed to penetrate seeded clouds and map out the exact process by which silver iodide helps clouds to produce more rainfall.

At Texas Tech University, Jerry Jurica and Colleen Leary have been working to develop a method to estimate the amount of rainfall that is stored in convective clouds. The studies focus on analyzing the reflectivity in digitized images of cloud formations. Areas with more reflectivity would show up as brighter images and indicate greater concentrations of moisture in key parts of a cloud.

William Woodley, a consultant from Colorado, and Daniel Rosenfeld of Hebrew University in Israel have been working with the TNRCC on weather modification projects throughout Texas. One of their efforts is to utilize a computer program to analyze radar images of clouds to prove that seeding warm-weather clouds produces rain. Woodley used ground-based and airborne radar to track seeded and non-seeded clouds. Because cloud formations that are more dense give off stronger radar echoes, they checked to see which formations were growing fatter. The software allows researchers to focus on a particular cloud and follow its progress. Woodley found that seeded clouds were twice as likely to merge with other clouds and produce rain than those that were not seeded.

## *Summary*

Weather modification projects have been carried out in some parts of Texas since the 1800s. Modern experiments to increase rainfall by cloud seeding have been conducted since the 1970s. Proponents of these projects believe that cloud seeding has increased rainfall, lake levels, and cotton yields in West Texas. Still, many policy makers and scientists are uncertain about the ability of weather modification projects to increase rainfall.

Despite the success of the Colorado River MWD program, there seems to be only mild support for such projects among many State and Federal agencies and local water management organizations. The BuRec recently announced that it was dropping out of cloud seeding programs, because that agency feels that it has been proven that weather modification works. Still, funds for weather modification studies are scarce and this has limited the number of scientists who are actively involved in the field. It needs to be noted that the TNRCC has strongly supported weather modification studies and the TWDB has funded these efforts.

There appear to be some promising developments on the horizon. Recently, limited federal funding has been made available for research into weather modification, as part of the NOAA Weather Research Program's strategic plan. A few scientists nationally are developing new methods and strategies to better understand, explain, and quantify the benefits of cloud seeding. This could increase public support for these efforts.

Unfortunately, until that happens, the public may not believe that weather modification is a tool that Texas should use to extend and better manage its waters.

## *For More Information*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