WEATHER MODIFICATION:
SOME FACTS ABOUT SEEDING CLOUDS

Weather Modification Association

An international organization promoting research, development and application of weather modification

PO Box 26926, Fresno, California 93729-6926

Rain and hail cloud

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Lightning and rain

The Weather Modification Association

The Weather Modification Association (WMA) was organized in 1950 under the name "Weather Control Research Association" to develop a better understanding of weather modification among program sponsors, operators, and other scientists. The WMA now has approximately 200 members located on five continents.

Major activities of the WMA are:

* promotion of responsible application of weather modification technology;

* promotion of research and development in weather modification;

* serving as a clearinghouse and distributor of information on weather modification;

* producing and disseminating policy statements on all aspects of weather modification;

* publication of the Journal of Weather Modification;

* certification of members qualified to conduct weather modification projects; and

* encouraging international cooperation in weather modification activities.

General membership is open to any individual interested in any aspect of weather modification. Organizations interested in weather modification are invited to join as corporate members. Dues are assessed on a calendar-year basis. The classes of membership and the annual dues in 1996 were:

Corporate:	$200
Individual:	50
Student:	10

Applications for membership and additional information can be obtained from:

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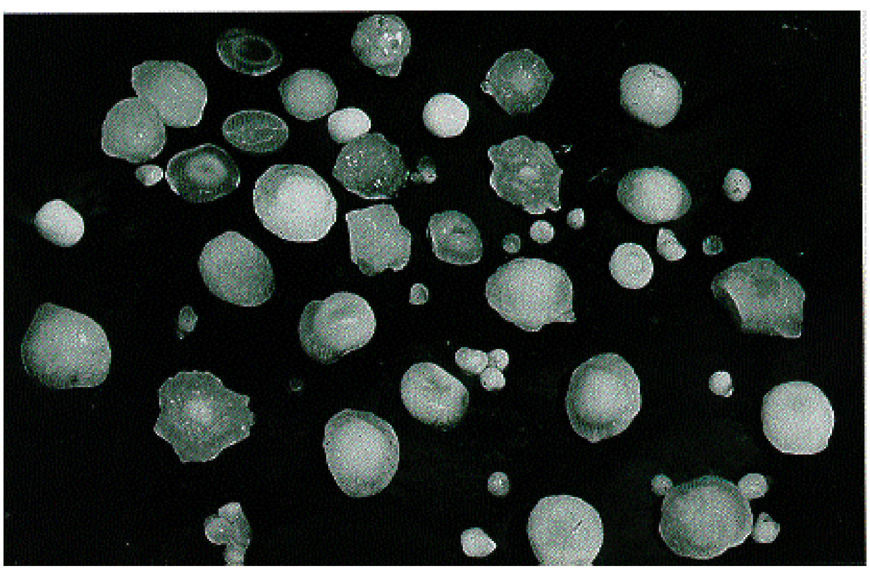
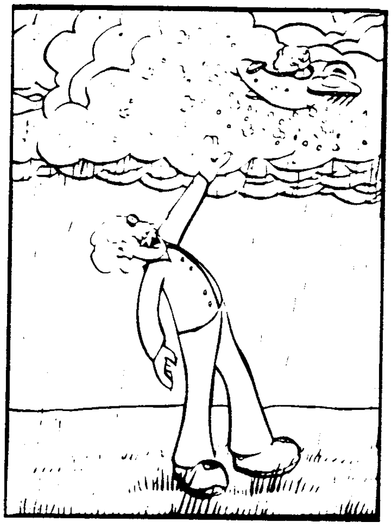
PO Box 26926
Fresno CA 93729-6926
U.S.A.

Fax & Phone: 209-434-3486
email: wxmod@ix.netcom.com



Hailstones

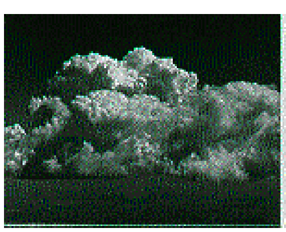
Foreword



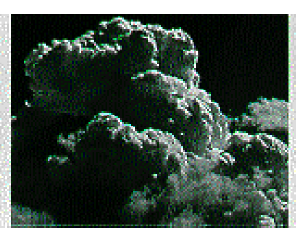
Nearly all modern attempts to modify the weather involve cloud seeding, which is the intentional treatment of individual clouds or cloud systems to achieve some desired effect. For a long time various materials have been known to affect the formation and growth of water droplets and ice crystals in clouds. Important discoveries in 1946 at the General Electric Research Laboratories in Schenectady, New York, led to practical methods for modifying large volumes of clouds at reasonable cost. Three key persons associated with those developments were Irving Langmuir, Vincent Schaefer, and Bernard Vonnegut.

Building upon those early discoveries and additional scientific experiments, atmospheric scientists continue to develop cloud seeding techniques which, when properly utilized, provide results of practical importance. Clouds have been seeded in attempts to modify fog, hail, wind, and lightning, but most projects have been intended to provide additional precipitation in the form of either rain or snow. According to information provided by member countries to the World Meteorological Organization, cloud seeding projects are now being conducted in over 40 countries.

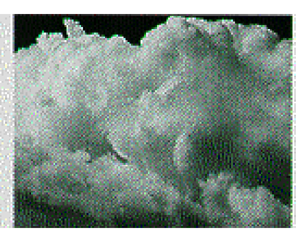
This brochure is intended to provide an educational overview of the physical basis for cloud seeding and a brief description of the most common applications.



Before seeding



During seeding



After seeding

Natural Cloud Processes

In addition to oxygen, nitrogen, and trace gases, the atmosphere contains variable amounts of water vapor. The amount of water vapor that can exist in a given volume increases as the temperature rises. The *relative humidity* is one measure of the concentration of water vapor; it is the percentage of the water vapor present relative to that which the air *could* hold. For example, if the air temperature near the ground is 25°C (77°F) and the concentration of water vapor is half of the maximum that could exist at that temperature, the relative humidity is 50%. If a volume of air as just described is cooled, say by lifting it to regions of lower pressure, the relative humidity will increase, even though the relative concentrations of water vapor and dry air remain the same. If it is cooled to 12°C (54°F), the relative humidity will reach 100%; the air is then said to be *saturated*. If further cooling takes place, the water vapor in excess of that required to maintain saturation will condense into cloud droplets.

Cloud droplets form around *cloud condensation nuclei*. Microscopic aerosol particles are always present in the atmosphere; those that are relatively large and hygroscopic are most apt to serve as cloud condensation nuclei. The atmosphere usually has an abundance of cloud condensation nuclei, so most clouds consist of small droplets in high concentrations. The droplets in a typical cloud are so small that it takes about a million of them to make one raindrop.

There are also aerosol particles in the atmosphere which cause cloud droplets to freeze or ice crystals to form directly from water vapor. These particles, which are called *ice nuclei*, are scarce, so many cloud droplets remain in the liquid state at temperatures below 0°C (32°F), which is the freezing point of bulk water. Such droplets are said to be *supercooled.* If part or all of a cloud is colder than 0°C (32°F), frozen particles (ice) may be present also, but generally in much lower concentrations than the supercooled droplets, which have been observed at temperatures as low as -40°C (-40°F).

Vast quantities of water in the form of water vapor, cloud droplets, and ice particles are constantly on the move in the earth's atmosphere. The atmospheric reservoir of water vapor is much larger than the amount of water which is visible as clouds. Furthermore, special conditions must be met before any of the cloud water can reach the surface of the earth as precipitation. Important factors controlling the initiation and amount of precipitation from a cloud are (1) cloud size, in both the vertical and horizontal dimensions, (2) cloud lifetime, and (3) sizes and concentrations of the droplets and ice particles that make up the cloud.

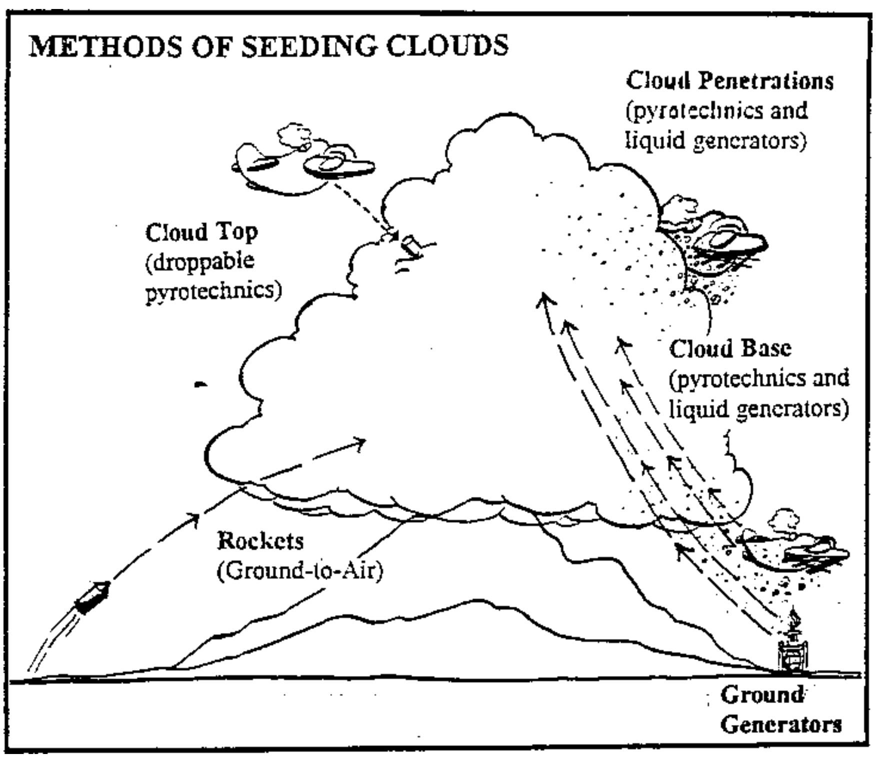
Precipitation forms in two distinct ways, which are sometimes called the "warm-cloud" and "cold-cloud" processes. The term "warm-cloud" was introduced after scientists noticed that rain often falls in the tropics from clouds existing entirely at temperatures above 0°C (32°F). Rain forms in these warm clouds as relatively large falling droplets overtake and coalesce with smaller droplets, which have lower fall speeds. Coalescence of liquid (supercooled) droplets also takes place at temperatures below 0°C (32°F). The term "warm-cloud" is therefore a little misleading, but it is widely used for convenience.

The cold-cloud precipitation process requires ice particles, so it occurs only where temperatures are below 0°C (32°F). Temperature generally decreases with height in the atmosphere, so even in the tropics the tops of clouds more than 5,000 m (16,000 ft) above sea level are colder than 0°C (32°F). Cold clouds, in the tropics or elsewhere, are often a mixture of large numbers of supercooled droplets and smaller numbers of ice particles, which may be single crystals or clumps of crystals. Ice crystals in a mixed cloud grow rapidly by deposition of water vapor, while the droplets evaporate to maintain a relative humidity near 100% and thereby feed the ice crystal growth. Typically, in 5 to 10 minutes the growing ice particles become big enough to have appreciable fall speeds. The falling particles then continue to grow by colliding with smaller ice particles and cloud droplets in their path. If they encounter temperatures above 0°C (32°F) closer to the earth's surface, they may melt completely and reach the ground as raindrops. Otherwise, they fall as snowflakes or hailstones.

The sizes, types, and concentrations of nuclei in the atmosphere are important in determining the efficiency by which a cloud system produces precipitation. For instance, large salt particles found over the oceans act as giant cloud condensation nuclei. They form large cloud droplets leading to a broad spectrum of droplet sizes, which speeds the onset of coalescence and initiates rainfall well within the lifetimes of many maritime clouds. On the other hand, the atmosphere over the continents usually contains more numerous but smaller condensation nuclei. Continental clouds tend to have higher concentrations of small, more uniformly-sized droplets. Therefore the warm-cloud (coalescence) process for initiating rainfall is inefficient in many continental clouds. To develop precipitation in such clouds requires activation of the cold-cloud process, which means that the clouds must extend above the 0°C (32°F) level, and then last long enough for the cold-cloud process to function. Furthermore, a scarcity of ice particles sometimes limits the efficiency of the cold-cloud process in continental clouds.

Cloud Seeding

Sometimes one can assist nature in the formation of precipitation by seeding clouds with appropriate types and numbers of nuclei at the proper times and places. Seeding with very large condensation nuclei, such as hygroscopic particles of common salt or urea capsules, can accelerate the warm-cloud process. Seeding with ice nuclei, such as silver iodide particles, or with very cold materials, such as dry ice pellets or liquid propane, can supply some clouds with additional ice particles and thus increase the efficiency of the cold-cloud process. The silver iodide is usually released from devices called liquid fuel generators, or pyrotechnic flares, which can produce as many as 1,000,000,000,000,000 particles from 1 gram of silver iodide. The nucleating ability of silver iodide increases as the temperature falls and varies with the type of device used. For many devices, the threshold temperature below which silver iodide is an effective ice nucleant is around -5°C (23°F).



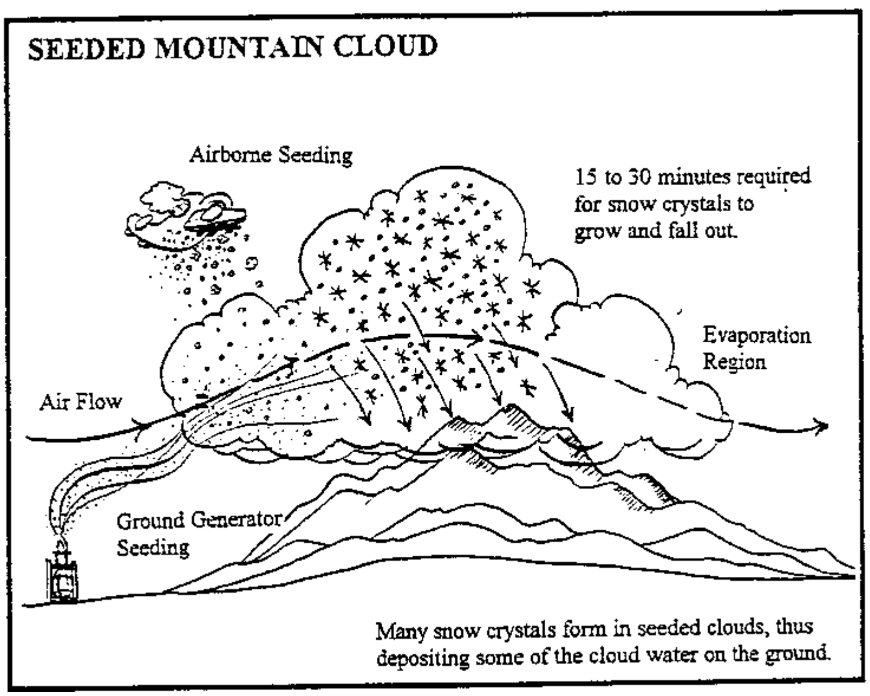
Seeding Winter Storm Clouds over Mountains

Clouds often form as moist air is lifted and cooled during its passage across mountain ranges. Clouds formed in this manner are called *orographic clouds*. In winter, many orographic clouds form as assemblages of super-cooled liquid droplets. Left to nature's devices, many of these clouds are inefficient precipitators, keeping more than 90% of their liquid moisture burden aloft until the droplets evaporate as the air descends and warms to the lee of the mountains.

The technology of seeding winter orographic clouds is fairly well developed and understood. Some of these clouds do not contain enough ice particles to efficiently convert their supercooled water into precipitation. By seeding such clouds with artificial ice-forming substances, their precipitation efficiency can be increased. Other winter orographic clouds contain abundant ice and adding artificial ice nuclei does not increase their precipitation efficiency. Seeding such clouds might actually reduce the amount of precipitation to less than they would produce otherwise. Although there is little evidence to support this idea, weather modification operators should be knowledgeable about the different types of clouds that occur over mountain ranges during the winter.

A variety of seeding agents have been applied to winter orographic clouds. Silver iodide, which can be released from either ground-based devices or from devices on airplanes, is by far the most widely used. Operators must consider the complexities of air flows over mountains in order to properly seed a designated target area.

Some projects designed to seed winter storm clouds over mountains in the western United States have operated continuously since 1950. Statistical studies of precipitation and streamflow data indicate that some winter orographic projects have increased seasonal target-area precipitation from 5 to 15%, with higher localized increases in some storms.



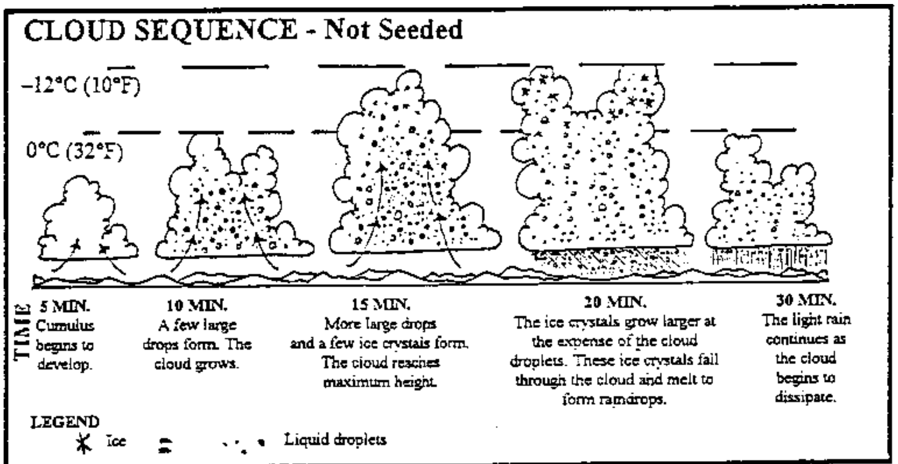
Seeding Cumuliform Clouds

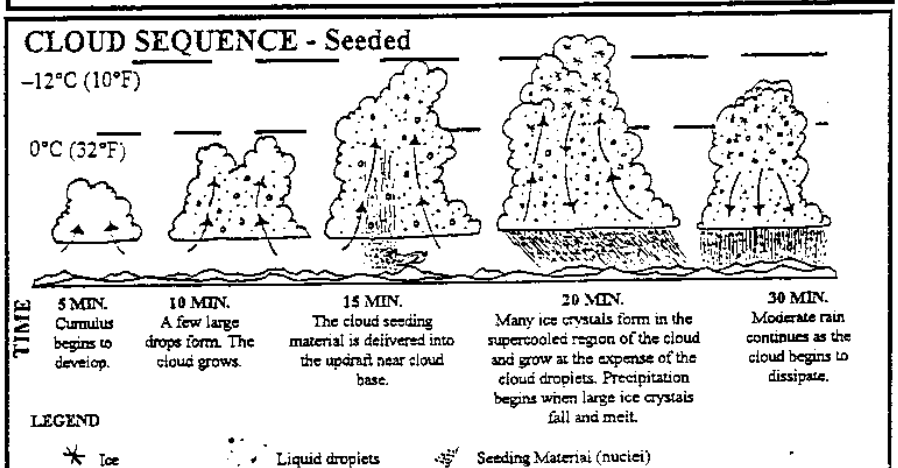
Cumulus clouds are important rain producers in the summertime over most of the world and are the main source of rainfall during all seasons in the tropics. These billowy giants form in updrafts in airmasses that are overturning due to instability. An airmass can be made unstable by the sun heating the ground below it or by the passage of an atmospheric disturbance, for example, a cold front.

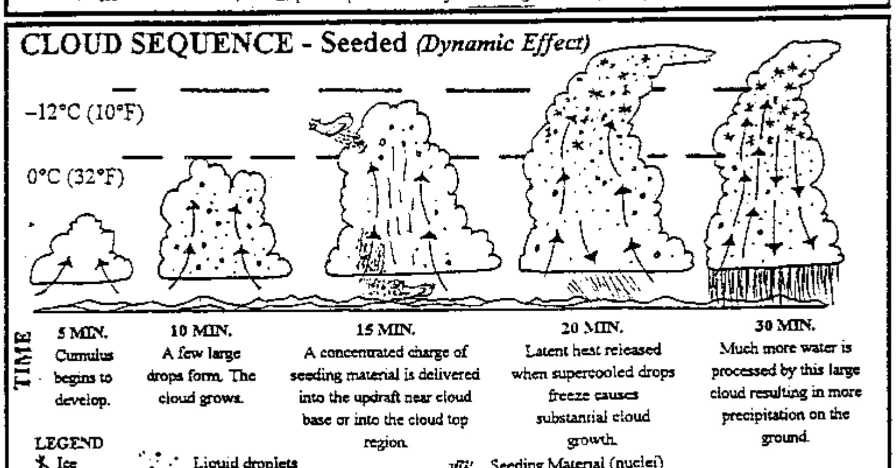
The modification of cumulus clouds is more complex than the seeding of winter orographic clouds. Cumulus clouds can be seeded with large condensation nuclei, but the amounts of material required are so large that this seeding method is seldom practical. Silver iodide and dry ice are used to stimulate rainfall when the cloud top temperature is below -5°C (23°F). The object of the seeding is to increase the number of ice particles in the supercooled portion of the cloud. When surrounded by supercooled droplets, the ice particles will grow rapidly and some may become large enough to fall to the ground. If an ice particle encounters temperatures above 0°C (32°F) during its fall, it may melt to a raindrop.

When conditions are right, cumulus clouds can be stimulated to grow larger and last longer. As noted above, the introduction of silver iodide or dry ice into the supercooled portion of a cloud causes some of the droplets to freeze. The freezing releases a large amount of heat, called the latent heat of fusion. The heat release makes the cloud more buoyant and may cause it to grow larger (taller and/or wider), thereby processing water at a higher rate, more efficiently, and for a longer period of time than without seeding. This type of seeding (for dynamic effects) is often done by aircraft dropping pyrotechnic flares containing silver iodide into the tops of promising cloud formations.

Hail forms in large cumulonimbus clouds with very strong updrafts extending well above the 0°C (32°F) level. Hailstones grow as supercooled cloud droplets and raindrops freeze around ice particles. Attempts to suppress hail usually involve introduction of fairly large quantities of silver iodide into specific parts of clouds that are hailing or are expected to produce hail. The additional ice nuclei result in higher ice particle concentrations that increase the competition for the available supercooled water within the clouds. As a result, the hailstones may not grow as large as they would if the clouds were left unseeded. If the hailstones are small enough, they have time to melt completely as they fall from the 0°C (32°F) level to the ground. Hailstorms have been seeded from aircraft and from the ground (including use of artillery and ground-to-air rockets). The great variability of hailfalls makes the evaluation of hail suppression projects difficult, but success in suppression of crop-damaging hail has been claimed by operators using all of the above methods for delivering the seeding agents.


CLOUD SEQUENCE - Not Seeded
-12°C (10°F)
0°C (32°F)
TIME
5 MIN. Cumulus begins to develop.
10 MIN. A few large drops form. The cloud grows.
15 MIN. More large drops and a few ice crystals form. The cloud reaches maximum height.
20 MIN. The ice crystals grow larger at the expense of the cloud droplets. These ice crystals fall through the cloud and melt to form raindrops.
30 MIN. The light rain continues as the cloud begins to dissipate.
LEGEND
Ice
Liquid droplets


CLOUD SEQUENCE - Seeded
-12°C (10°F)
0°C (32°F)
TIME
5 MIN. Cumulus begins to develop.
10 MIN. A few large drops form. The cloud grows.
15 MIN. The cloud seeding material is delivered into the updraft near cloud base.
20 MIN. Many ice crystals form in the supercooled region of the cloud and grow at the expense of the cloud droplets. Precipitation begins when large ice crystals fall and melt.
30 MIN. Moderate rain continues as the cloud begins to dissipate.
LEGEND
Ice
Liquid droplets
Seeding Material (nuclei)


CLOUD SEQUENCE - Seeded (Dynamic Effect)
-12°C (10°F)
0°C (32°F)
TIME
5 MIN. Cumulus begins to develop.
10 MIN. A few large drops form. The cloud grows.
15 MIN. A concentrated charge of seeding material is delivered into the updraft near cloud base or into the cloud top region.
20 MIN. Latent heat released when supercooled drops freeze causes substantial cloud growth.
30 MIN. Much more water is processed by this large cloud resulting in more precipitation on the ground.
LEGEND
Ice
Liquid droplets
Seeding Material (nuclei)

Fog Modification

Fog has been modified to improve operations at many airports. In particular, the airline industry has benefited from this weather modification technology and now employs operational systems at several major airports. The early emphasis was placed on dissipation of cold fog, which consists of supercooled water droplets at temperatures below 0°C (32°F). There has been some progress in the modification of warm fog, but there is still no inexpensive efficient technology for dispersing warm fog on an operational basis.

Seeding supercooled fog or a low stratus deck is an application of weather modification technology in which the effects are clearly demonstrated. Light aircraft are often dispatched to fly over the fog deck and drop dry ice pellets. The resulting ice crystals grow and fall as a light snow in 10 or 15 minutes. The release of the snow produces a temporary clearing, which can be targeted to affect an airport runway. Occasionally, the clearing may spread if it permits the sun to reach the ground and raise the local temperature.

Long rectangular holes cut through a stratus cloud using crushed dry ice at rate of about 1 kg/km. Such holes develop in less than an hour and become at least 2 km wide. Project Cirrus, 1974.

Photo courtesy Houghton Mifflin Company, from “Atmosphere“ Peterson Field Guide, Vincent J. Schaefer/John A. Day, authors.

WMA Capability Statement on Weather Modification

Adopted at 1984 Annual Meeting

Introduction

It has been established that weather can be modified by man under various circumstances. The problem is one of stating under what conditions predictable effects may be expected. The attainment of desirable weather modification effects depends upon several factors including: the prevailing weather regimes of a specific area, the design of a program to achieve a specified goal, the execution of the program, and the specification of a means of assessing the effects of the weather modification effort. Brief capability statements follow stating an assessment of the current state of weather modification technology for a variety of applications. A word of caution is necessary concering these statements. This caution deals with the concept of transferability of results. Differences in cloud microphysics, topography, seeding agent selection and dosage rates, and execution could alter these expectations.

Fog and Stratus Dispersal

The dispersal of shallow, cold (below freezing) fog or stratus cloud decks is an established operational technology. Dispensing ice phase seeding agents, such as dry ice or silver iodide, in these situations is effective in improving visibility. Clearings established in cloud decks embedded in strong wind fields fill in quickly unless seeding is done nearly continuously.

The dispersal of warm (above freezing) fog or stratus decks over areas as large as airport runways is feasible operationally through the provision of a significant heat source. The mixing of drier air by helicopter downwash can create localized clearings. Various hygroscopic substances have also been used to improve visibility in these situations, primarily by the military.

Winter Precipitation Augmentation

CONTINENTAL—Evaluation of both research and operational winter orographic cloud seeding programs indicate that 5-20% seasonal increases in precipitation can be achieved. Detailed analyses of research programs demonstrate that both positive and negative effects of seeding can occur over shorter time intervals such as individual storm events. Consequently, it is prudent to adopt seeding techniques and criteria, based upon meteorological conditions, designed to optimize the positive seeding effects during these short time intervals, thereby maximizing the seasonal increases in precipitation.

COASTAL—Evaluations of both research and operational wintertime programs conducted in more coastal environments with more limited topographic relief indicate the potential of 5% to as much as 30% increases in seasonal precipitation. Meteorological situations that appear to offer the most potential in these areas are convective in nature. It again appears prudent to adopt meteorologically based seeding guidelines for real time seeding decision making in order to maximize the increases in season precipitation.

Summer Precipitation Augmentation

The capability to augment summertime precipitation in an area-wide fashion is promising. Assessments from some operational and some research programs are encouraging, especially when a seeding mode is employed which allows selective seeding of individual clouds.

Evaluations of operationally conducted summer precipitation augmentation programs present a difficult problem due to their non-randomized nature and the normally high variability (temporal and spatial) present in summertime rainfall. Recognizing these evaluation limitations, the results of many of these evaluations have indicated a positive area-wide seeding effect in precipitation.

Results are mixed from research programs conducted on summertime cumulus clouds. Part of the resulting uncertainty is due to the variety or climatological and microphysical settings in which experimentation has been conducted. Another important factor is seeding mode. Those projects that employed a broadcast mode of dispersal of a glaciogenic seeding material have generally indicated no effect or even decreases in rainfall. Projects which relied upon injection of glaciogenic seeding material directly into clouds that met certain seeding criteria (based essentially upon the stage of development of the cloud) generally indicate positive seeding effects. These effects were normally observed on at least the seeded cloud's rainfall and oftentimes in area-wide rainfall.

Hail Suppression

Most of what is currently known about the status of hail suppression, either success or failure, has been acquired through study of surface hail data in a project area during seeding periods. Little has yet been shown through careful study of the physical behavior of the interior of storms from the suppression efforts. Therefore, the scientific linkages establishing hail suppression are not well established, although the assessment of surface hail differences are generally suggestive of successful suppression in the realm of 20-50% reduction. Execution of the operations is important. Timing and correct placement of seeding material are especially critical to successful suppression.

Government Involvement

Thirty-two states have enacted legislation dealing with weather modification. These state laws vary from simple reporting requirements to more extensive regulations which involve weather modification licenses, permits and the publication of notices of intent. Several states have developed statutes which permit the use of state funds for state/county cost sharing weather modification operations. The Weather Modification Association can supply the name and address of the agency in your state from which you can obtain copies of any regulatory procedures.

U.S. Government agencies which have been involved in weather modification research and/or operations include:

- U.S. Air Force
  Headquarters, Air Weather Service
  Scott Air Force Base
  Belleville, Illinois 62220

- National Oceanic and
  Atmospheric Administration
  Office of Oceanic and Atmospheric
  Research
  R/PDC/USWRP, Rm. 11554
  1315 East-West Highway
  Silver Spring, Maryland 20910
  Telephone: 301-713-0460

- U.S. Dept. of Interior
  Bureau of Reclamation
  P.O. Box 25007
  Denver, Colorado 80225

- National Science Foundation
  Division of Atmospheric Science
  4201 Wilson Boulevard
  Arlington, Virginia 22230

Inadvertant Weather Modification

Certification

One of the purposes of the Weather Modification Association is to encourage and promote the highest standards of conduct. In order to further this goal and to protect the public interest, the WMA has established a certification program for individuals qualified to manage and/or operate weather modification field programs of a research or operational nature.

Certification is based on character, knowledge and experience. All applicants must agree to accept and abide by the current WMA Code of Ethics and any Statement of Standards and Practices that the WMA has adopted at the time of application. Minimum requirements are:

Weather Modification Manager

CATEGORY A: Eight years (96 active months) experience in weather modification research and/or operations.

CATEGORY B: A Bachelor's Degree with at least 25 semester hours of meteorology plus five years (60 active months) experience in weather modification research and/or operations.

CATEGORY C: A Master's Degree or a Doctorate in Atmospheric Science and three years (36 active months) experience in weather modification research and/or operations.

In addition to the above requirements, the applicants must pass written and oral examinations to the satisfaction of the Certification Committee.

Weather Modification Operator

CATEGORY A: Twenty months actual "in the field" experience in weather modification research or operations.

CATEGORY B: A degree with at least 25 seemster hours of meteorology and eight months actual "in the field" experience in weather modification research or operations.

The field experience must be in a project designed to effect a change in the weather. It should involve significant exposure to how seeding decisions are made and how a project is managed.

The following lists show the managers and operators whose certifications are current in 1996.

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Attn: Mr. Al Ortega
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Sacramento, CA 95813

Southern Calif. Edison Co.
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Rosemead, CA 91770

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Answers to Questions Most Often Asked

Q. Does cloud seeding really work?

A. Yes! Fifty years of research and operations in 43 countries have demonstrated that properly designed programs operated by competent persons can dissipate supercooled fog, beneficially increase seasonal rainfall or snowfall, and decrease seasonal hail damage.

Q. Does seeding clouds to suppress hail reduce rainfall?

A. Seeding for hail suppression is intended to increase the number of precipitation particles, which tends to increase the efficiency with which the clouds convert cloud droplets into rain. The available evidence suggests that seeding for hail suppression, if anything, increases rather than reduces rainfall from the seeded clouds. Nothing indicates that seeding clouds to suppress hail actually breaks up the clouds.

Q. Is there a large amount of silver iodide or other seeding material in the precipitation which falls from seeded clouds?

A. No. The amounts are very small. The typical concentration of silver in rainwater or snow from a seeded cloud is less than 0.1 micrograms per litre (one part in 10,000,000,000).

Q. Is such a concentration harmful to people or the environment?

A. No. The silver concentration in rainwater from a seeded storm is well below the acceptable concentration of 50 micrograms per litre as set by the U. S. Public Health Service. Many regions have much higher concentrations of silver in the soil than are found in precipitation from seeded clouds. The concentration of iodine in iodized salt used on food is far above the concentration found in rainwater from a seeded storm. No significant environmental effects have been noted around operational projects, including projects of 30 to 40 years duration.

Q. What about downwind effects? Do you sometimes "rob Peter to pay Paul?"

A. No. The idea that rainfall increases in one area must be offset by decreases elsewhere is a misconception. Precipitation data from a number of cloud seeding projects have been examined in detail for evidence of "extra-area" effects. In some cases, there have been weak indications of increased precipitation at distances of 150 km (90 miles) or more downwind from the target areas. There are no significant indications of rainfall decreases downwind from any long term cloud seeding projects.

Q. If microscopic particles in the atmosphere have such a strong influence on Nature's ability to produce clouds and precipitation, don't all of the particles from homes, industry, automobiles, and even campfires in wilderness areas influence the weather?

A. Yes. Every particle in the atmosphere, regardless of how it originates, may influence the formation and growth of clouds, including their ability to produce precipitation and to modify the radiative properties of the atmosphere.

Q. In that case, does natural weather exist any more?

A. If "natural weather" means weather completely unaffected by human beings, there has been no such thing since human beings learned to use fire. However, impacts of human activities on weather and climate were much smaller before the Industrial Revolution than they are today.

Recent Weather Modification Activities in the United States

Number, Purpose, and Total Target Area of Weather Modification Activities by State for 1994

(Source: Golden, NOAA)

State	No. of Activities	Purpose	Target Area
California	15	Increase precipitation	15,934
Utah	3	Increase precipitation/Fog displ.	10,360
Kansas	1	Hail suppression*	12,000
North Dakota	2	Hail suppression*	9,203
Idaho	3	Increase precipitation	3,941
Nevada	3	Increase precipitation	4,923
Colorado	4	Increase precipitation	550
Texas	1	Increase precipitation	5,500
Wyoming	1	Increase precipitation	939
Washington	1	Cold fog dispersal	50
Oregon	1	Cold fog dispersal	10
Georgia	1	Cold fog dispersal	1
12 states	36	Total	63,592

* The purpose of the hail suppression projects was also to increase rainfall.

Note: Target areas for 3 activities overlapped state boundaries (2 for CA/NV; 1 for ID/WY).

Suggestions for Further Reading

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Water for the future

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