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The Current Status of

WEATHER MODIFICATION

A Summary--1964

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ABSTRACT

A brief history of weather modification experiments is presented. Literature and reports of later experiments and investigations are reviewed and discussed. The various cloud-seeding agents, how these are dispensed, and their actions on common cloud types are reported. Elementary cloud physics and the seedability of clouds are related to clouds occurring in Texas skies.

The history of proposed Federal legislature is partially described; some salient features of existing statutes in other states are analyzed; and the need for controlling experiments and protecting landowner and researcher alike is advanced. The challenges of future experiments and field tests are summarized and a needed experiment which could be conducted in Texas is described.

After perusing all available literature and considering the current state of development of the science of weather modification it is concluded: (1) especially selected and randomly-seeded isolated supercooled convective clouds occurring at scattered locations in Texas throughout the spring-summer-autumn months may respond favorably to produce rain in some cases when rain may not have occurred naturally and to initiate the occurrence of rain earlier in some cases when rain may have eventually fallen naturally at a later time or different location due to movement of the clouds while building up; (2) certain types of supercooled storm clouds incident to frontal or squall-line weather systems occurring during parts of autumn, during winter, and during parts of spring, when seeded in selected meteorological situations, may occasionally be made to release more rain as the system passes over seeded areas than would be released naturally as the system passes over unseeded areas; (3) weather modification experiments should be scientifically controlled, performed under the direction and supervision of a qualified meteorologist, accurate records should be kept, and reports on the experiments should be made through appropriate scientific media; (4) current knowledge of the science of weather and climate modification indicates that the correct meteorological conditions exist infrequently in Texas, and the orography of Texas is such that dependable or significant increases in precipitation cannot now be brought about by seeding Texas clouds; however, without conducting scientifically controlled laboratory and field experiments in Texas whenever possible, Texas may never realize a significant increase in precipitation resulting from weather modification. That is because each latitude, each geographical region, and each physiographic province produces its own characteristic cloud types that must be analyzed and on which experiments must be performed before it is ever known for certain if seeding these clouds will result in beneficial weather modification.

THE CURRENT STATUS OF WEATHER MODIFICATION: A SUMMARY--1964

INTRODUCTION

It is the purpose of this bulletin to summarize significant investigations and developments in the field of weather modification. Preparation of this report was directed toward a review of the numerous recent scientific investigations carried out by universities, colleges, and industries rather than actual experimentation by this Agency.

The principle of style used in the main text is not one that attempts to offer scientific proof of each statement--thus it enables the layman to keep in mental touch with developments as they unfold. One who has not been exposed extensively to the disciplines of atmospheric science should have little difficulty understanding what has transpired in the imagination-challenging attempt to alter, if not outright control, nature's capricious release of water stored in the atmosphere. For the scientific mind demanding proof, however, sufficient citation of original work is included.

A publication on the status of weather modification was necessary to supply current information to agencies and political subdivisons in Texas with responsibilities for water planning, administration, and distribution, and also to numerous individuals throughout Texas. The timing is appropriate because a number of authentic reports are now being published about the many experiments and field tests conducted over the past few years. These experiments were made attractive and possible by the release during the 1950's of National Science Foundation (NSF) and other federal and private funds in large enough amounts for the salaries, elaborate layout, and expensive equipment needed to enlist the aid and experience of learned scientific minds.

Earlier, funds, equipment, and personnel supplied by federal military departments, commercial cloud-seeding firms, and laboratories operated by industry and institutions of higher learning were the main sources of investigative reports on weather modification. Doubtlessly some thoroughly sound techniques were developed and keen scientific minds were employed in many commercial cloud-seeding operations. Equally doubtless, much of the fruit of these efforts may never have found its way into scientific annals. Some scientists, technical personnel, aircraft pilots, and others who were formerly employed by commercial cloud-seeding firms could, with the release of greater amounts of federal funds for grants and contracts, now turn to pure scientific exploration aimed solely at learning about the possibilities of weather modification without having to worry nearly so much about a cost-profit balance sheet. Thus, the scientific reports now being published may be based in part on the experience and work of some personnel formerly employed by industry who might have brought with them techniques and know-how developed initially by industry. The basic research represented by these reports have been sifted and studied for application to conditions in Texas that may provide a benefit to the people of this State. This publication then becomes one of applied research.

Experiment after experiment has demonstrated quite conclusively that almost every single seeding of the right type of cloud with the right type of seeding agent does modify the cloud to some extent--some change in the cloud takes place. Altering the internal structure of a cloud is one thing, but modifying the prevailing weather is quite another problem. Of course, man has been successfully modifying the weather or ameliorating its effects for some time now. For example, citrus crops all over the subtropical world are kept from freezing each year by lighting smudge pots to create a blanket of smoke aimed at preventing the escape of earth's heat by radiation, and man has been using umbrellas and lighting hearth fires for centuries.

Because of the great need for water during times of drought and the hope for relief from the threat of hail, wind, and flood damage, the farmer, the businessman, the banker, all are particularly susceptible to the promise of anyone who claims ability to make it rain or to control the weather. Since the first recording of history every major drought and prolonged period without rain has produced a new crop of rainmakers professing to have the knowledge or ability to influence nature's release of her waters from the sky. Many worked for fees while others worked only for glory. Most scientists formerly looked upon rainmaking claims with some degree of skepticism. At best they were quite conservative, and considered such activity as nothing more or less than unethical exploitation of man while weakened by the throes of misery. Enough coincidence with nature's release of rain prevailed, however, to compel desperate men in time of need again and again, drought after drought, to yield to the nebulous promises of rainmakers who could make no claim to scientific knowledge.

Many early scientific experiments with weather modification were doubtlessly not reported in the literature, but one of the earliest known explorations with dry ice was conducted in Holland by August W. Veraart in 1930. The cloud seeding techniques used were much akin to the methods employed in recent years with dry ice as the seeding agent. In our present era, scientific liaison with nature was again established when General Electric's scientist, Vincent J. Schaefer, seeded some clouds with pellets of dry ice dropped from a light airplane over western Massachusetts on November 16, 1946, and a few minutes later visually observed snow falling from the base of the clouds. The most recent scientific research in weather modification, for all practical purposes, began on that date.

While testifying on weather control before Senator Clinton P. Anderson's committee during the Joint Hearings of the 82d Congress, Professor Hans H. Neuberger (1951) of Pennsylvania State University recalled that he had worked as early as 1930 with Professor Albert Wigand at the University of Hamburg on scientific attempts at cloud seeding, which roughly coincided with Veraart's experiments. Since 1930 the science of weather modification has progressed to the awe-inspiring degree reported in 1963 by Meteorology Professor J. S. Malkus (1963) of The University of California, Los Angeles. Professor Malkus' paper contains such sophisticated, colorfully descriptive terms as "air flow over a flat heated island," "equivalent thermal mountain," cumulonimbus "hot towers," "cloud streets," and mentions hurricane modification, coating large surfaces with asphalt to increase the island effect in producing clouds, and cumulus clouds diluting and stunting themselves by entraining the dry air around them.

ACKNOWLEDGEMENTS

Regarding the subject of weather modification and climate control, reams have been written and scientific papers published by the score (see Figure 1). Therefore, it is virtually impossible to cite every authority and give credit for all past research and experiments performed in pursuit of an answer to the challenging question of whether man can really control or significantly alter the course of weather. The author gratefully acknowledges that almost every statement made in this publication represents the opinion or works of others. Particularly, acknowledgement for assistance, advice, and supply of scientific reports, basic research data, and background material is given to:

Dr. Louis J. Battan, professor of meteorology, Institute of Atmospheric Physics, University of Arizona, Tucson, Arizona

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Dr. Vance E. Moyer, professor of meteorology, Department of Oceanography and Meteorology, Texas A&M University, College Station, Texas

Mr. Robert W. Orton, state climatologist for Texas, U. S. Weather Bureau, Austin, Texas

Special thanks are given to Professor Vance E. Moyer of Texas A&M University for his criticism of the technical aspects of the original manuscript.

PERSONNEL

Preliminary plans for a publication summarizing developments and reporting upon the current status of weather modification are credited to Louis L. McDaniels, while heading the Hydrologic Section of the Surface Water Division.

This publication was prepared in Engineering Services, Texas Water Commission, by John T. Carr, Jr., in the Research Program under the general supervision of John J. Vandertulip, Chief Engineer; Manton A. Nations, Director of the Planning Division; and under the direct supervision of Louis L. McDaniels, Research Program Coordinator in the Planning Division. This publication is based on the works of all individuals and agencies, private and public, who have been engaged over the years in scientifically investigating and reporting on the fascinating and colorful subject of modifying the weather and climate to benefit mankind.

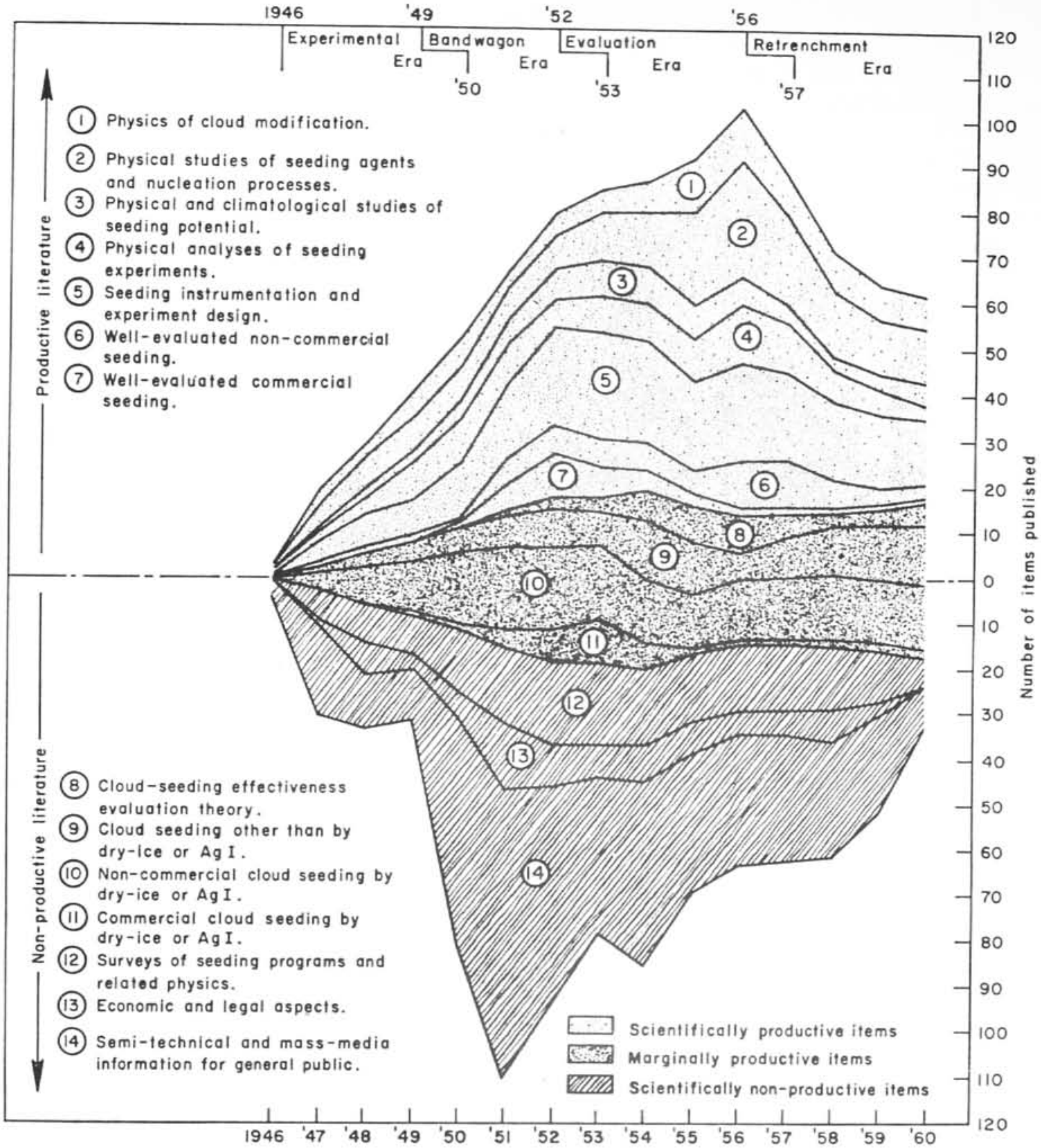


Figure 1

Anatomy of 15 Years' Literature on Weather Modification

After R. E. Huschke, 1963, A Brief History of Weather Modification Since 1946: Bulletin of the American Meteorological Society, v. 44, no. 7, July, p. 426.

NEED FOR WEATHER MODIFICATION

Prevention of Catastrophic Weather

Catastrophic weather has plagued mankind since before the first recording of history. Tales of suffering due to the adversities of weather are told in the Bible, in earliest writings, and in mythology, legend, and folklore. Today, one commonly finds in a newspaper or periodical headlined reports and pictures of disaster due to weather. It would be wondrous to report to the contrary, but nothing has developed in the science of weather modification to date to give rise to any real hope that large-scale disasters due to weather can be eliminated or controlled in the foreseeable future.

Hail

Some hope is held that future experiments may prove small-scale disaster due to hail damage can be alleviated before too many more years have passed (MacCready, 1960). Two types of hail-producing clouds have been experimented with:

1. The cold-base cumulus cloud (base with temperatures around or below freezing) found commonly over mountain ranges as in Trans-Pecos Texas; and,

2. The warm-base cumulus cloud (base with temperatures 39 to 59°F common over most of Texas during warm months.

Flood

Evidence has been offered to indicate that cloud seeding can produce a spreading and smoothing effect on rainfall patterns (Krick, 1951) over a wide area. Dr. Krick advanced the theory that this uniform distribution of rainfall over wide areas would be accompanied by a minimum of soil erosion, and may suppress hail and heavy-intensity rain within the seeded area. Suppression of heavy-intensity rain in a given area could also act to reduce some small-scale disasters due to flooding.

However, no literature reviewed offers any hope that rainfall will ever be so effectively controlled as to reduce flooding due to excessive precipitation in large drainage basins or over entire physiographic provinces.

Tornado

The tornado is one of the most devastating small-scale weather phenomena occurring in the world. The full-fledged tornado known so well to our mid-continent residents has been the recipient of much attention and study by the foremost meteorologists of our time. Mainly, the studies have been motivated by a desire to forecast tornado occurrences and movements. Little has been done toward preventing them; no significant advances in that direction can be pointed out.

Hurricane

The hurricane must properly be classified as a large-scale disastrous weather phenomenon of tropic-sea origin embodying most of the worst combinations of wind, rain, flood, and high tides; is frequently a spawner of offshore waterspouts as it approaches the coast; and breeds tornadoes when it moves inland to become extra tropical. Ability to control the trajectories of hurricanes and steer them harmlessly out to sea to die of forces caused by natural atmospheric conditions would probably be singularly the most important contribution the science of meteorology could make toward freeing mankind from the ravages of nature. Toward this end, Vincent J. Schaefer in March 1951, while testifying during the Joint Hearings, told of localized seeding of a hurricane off the Florida coast. Project Stormfury, joint U. S. Weather Bureau-Department of the Navy experiments designed to discover and test methods of modifying hurricanes, is now in progress. Other studies were begun by the U. S. Weather Bureau's National Hurricane Research Project (NHRP) in 1956. The first steps have been taken to ameliorate hurricane destruction.

Increase in Water Supply

Another great need for weather modification is the matter of increasing or relocating the Nation's (or world's) overall fresh water supply. Vast quantities of sea water and water vapor in the atmosphere exist, and are available to be artificially tapped as sources of fresh water to serve beneficially the needs of mankind. Additionally, great volumes of poor quality and mineralized or brackish-brine waters are stored inland seas or flow in rivers throughout the world.

Relief from Drought

Some day these sources may be artificially induced to give up vapors that can be converted to rain by some method of weather modification not yet explored. Imagine the potential for turning a crop disaster due to widespread drought into one of bountiful production by steering an artificially created cloud to where it is needed and then causing it to rain. Fantastic? Perhaps, but more down to earth along these same lines, serious scientists (Crawford and Linsley, 1962) have computed and published an estimate of the hydrologic results of rainfall augmentation by cloud seeding, using a 15 percent increase in the rainfall as a basis for their computations. Schleusener (1964) reports apparent significant increases in runoff due to cloud seeding in California's Kings River and Bishop Creek watersheds (see Figure 2).

Economic Advantages

The economic advantages that might be brought about by an increase in the usable water supply are many and varied. Increased water supplies could result in respectable boosts to an economy if pioneering research and laboratory and field experiments are continued and further tend to support reported suggestions that cloud seeding is a means of:

1. Supplying needed water to crops during critical growth periods to increase expected harvests;

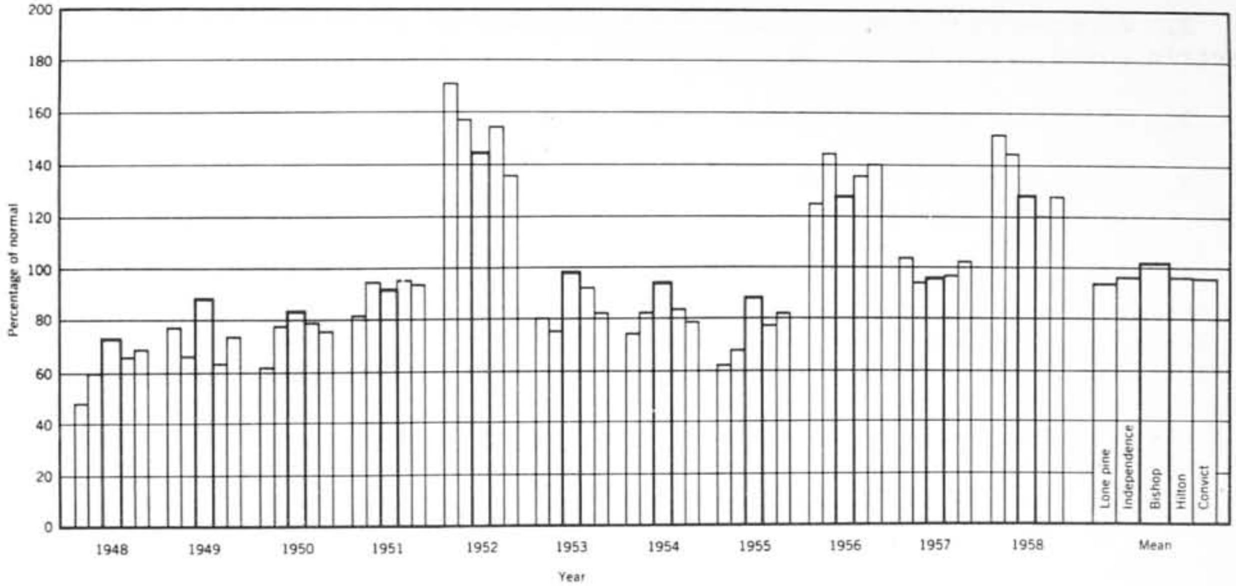


Figure 2

Natural Flow Comparisons for Bishop Creek and Adjacent Watersheds for the Period 1948-1958 (63)

After R. A. Schleusener, 1964, Weather Modification: Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, v. 90, no. HY1, pt. 1, January, p. 68-69.

The apparent increase in runoff from Bishop Creek (California) was approximately 5% using all the seeded years of record from 1948-1958, including those years in which seeding was done with silver-iodide. Using only those years in which seeding was done with dry-ice, the apparent increase was approximately 9%, which was the annual augmentation of flow on Bishop Creek estimated from an earlier study by Ferguson Hall and others.

A comparison of the percentage of normal runoff during the period of the operation is shown in the above Figure. The Figure shows that, during the period of operation, Bishop Creek yielded a higher mean percentage of normal runoff than adjacent watersheds.

2. Augmenting inflows to mountain reservoirs to allow for greater hydro-electric power productivity (see Figure 2);

3. Alleviating crop loss due to drought; and,

4. Helping to fill or maintain storage in reservoirs used for municipal, industrial, or irrigation purposes.

Vast tracts of untilled lands lie adjacent to irrigated lands in the arid regions of the world near the great mountain ranges. These unproductive lands are fertile and suitable for cultivation but lack sufficient water. Heavy clouds seem to take up semipermanent residence over the mountains, but rains seldom fall from them naturally. Many experiments now in progress and in the past have been conducted with these orographically formed convective clouds because of their frequency of occurrence and suitability for seeding (Battan, 1962). Much success has been experienced (Siliceo and others, 1962; Smith and others, 1962; MacCready, 1960). At least three electric power and light companies, Southern California Edison Company (Water Information Center, 1962), Snowy Mountains Hydro-Electric Authority of Australia, and Mexican Power and Light Company (Siliceo and others, 1963) have considered the idea of augmenting natural runoff into mountain reservoirs feasible enough for generating electricity to spend vast sums of money over the years experimenting with seeding mountain-formed convective clouds. Perhaps some day the natural rainfall from clouds in this category can be augmented sufficiently by seeding to increase dependably the water supply enough to permit expansion of the nearby areas now under irrigation. Consider the economic value of dependably increasing an expected low wheat yield of about 8 bushels per acre to 20 bushels per acre by causing rain to fall on the area at a critical time of wheat plant growth (Krick, 1951). Picture a city without a running stream nearby and with just enough ground-water resources to meet its municipal needs; think what it would mean economically to the city if enough surface water could be made available to attract needed industrial expansion by impounding quantities of rain-water runoff caused by modifying the clouds and increasing the precipitation.

Military Operations

The implication of weather modification for military operations is legion. Some suggestions seem clearly to be no more than fantasy--such as schemes to freeze, flood, or strike entire continents with drought by altering the natural courses of ocean currents and great masses of hot or cold air. Small to medium scale manipulation of the geophysical processes to favor or hinder military operations seem more within the realm of possibility at this time. Some serious experiments along these lines have been conducted, and varying degrees of success have been attained.

As a Weapon for Defense or Offense

Several experiments in cloud seeding have been successful in entirely dissipating or causing very large holes to form in decks of supercooled stratus clouds, including fog. A scant 20 years ago at the Battle of the Bulge in Europe during World War II, such a capability to dissipate fog or stratus clouds could have been a major factor as an offensive weapon in the hands of the Allies to "open up" the air above our fog-enshrouded operations and enable the Air Force to add its support in either advancing the Allied troops or deterring the movement of enemy troops. Weickmann (1963) calculated that 20 modern-day military transport aircraft and 20 tons of dry ice might clear a 12,000 square mile area of supercooled stratus clouds. Had this been done by either side during the Battle of the Bulge the course of history might have been changed.

A capability to cause rain to fall from the warm clouds that characteristically form over tropical islands could be a source for considerable harrassment of troops attempting to organize, dig-in, prepare gun emplacements, and so on. These warm clouds form as regularly over islands as the orographic cumulus clouds form over mountain ranges. Much experimentation has been done on both.

Peace-Time Uses

A peace-time need for weather modification that would be as applicable to civil use as to military use is the need to perfect that oft-demonstrated seeding technique used to open great holes in supercooled fog and low stratus clouds, which so often hinder take-off and landing operations at civil and military airports. Uses for weather modification involving the creation of clouds are not discussed here, because so far man has been unable to demonstrate an ability to cause the water vapor in the air to condense repeatedly and form a significant amount of clouds. Except in a few cases, man has demonstrated a capability only to modify already existing clouds that have been formed by nature's processes. Nevertheless, Dr. Henri Dessens[1] of France reported the creation of convective clouds with updrafts caused by large man-made fires, and sightings of cumulus clouds caused by the heat of large brush fires have been reported in Australia.

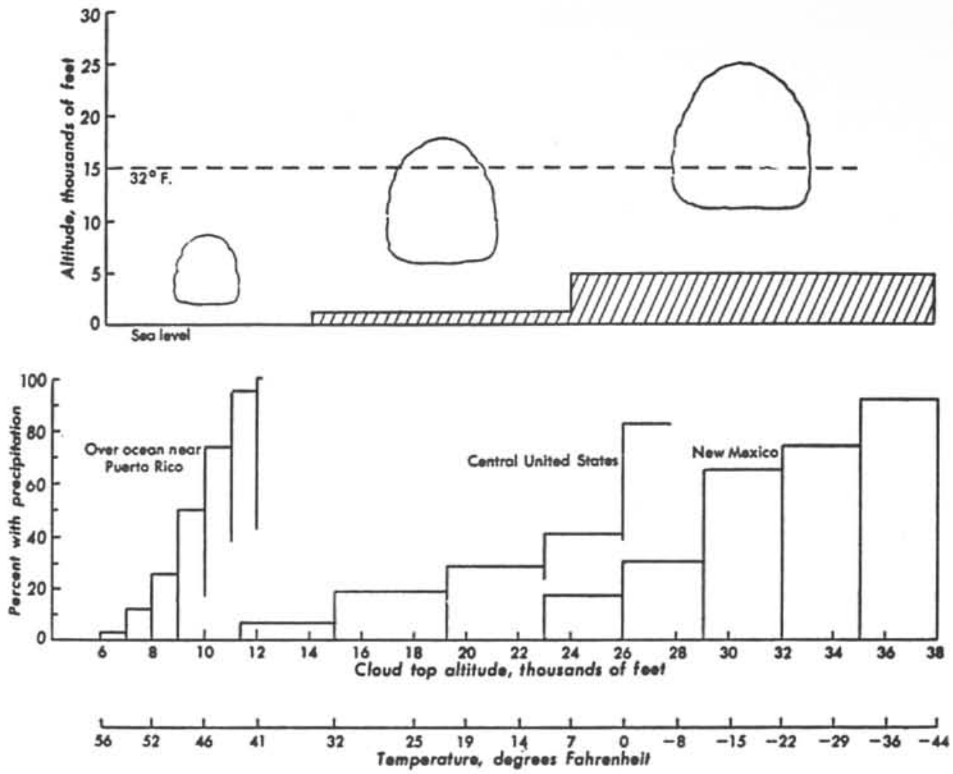
FUNDAMENTAL PRINCIPLES AT WORK

The Atmosphere About the Earth

Because the factors most favorable for successful attempts at artificial cloud modification vary with region, latitude, or altitude (Figure 3), and because these factors are so nearly the same as those most favorable for natural formation of clouds in the same region, this summary will be oriented toward artificial modification of existing natural clouds known to be endemic to Texas and the surrounding regions. The most common problem cloud in these regions is the warm cumulus cloud that forms over flat or rolling terrain on hot summer days, and which releases little or no precipitation. This common cloud has the most potential as a rain producer, and deserves the most attention.

The atmosphere about the earth is made up of gases and suspended minute solid particles that combine under natural conditions to produce clouds and hydrometeors of a wide variety of types and sizes dependent largely upon the thermo- and hydrodynamics of air, which force various degrees of contrast between moisture and temperature. As a general rule, the sharper the contrast between temperature and moisture the more violent will be the weather.

1/ Post presentation discussion with Dessens at Third Conference on Severe Local Storms, Urbana, Ill., November 1963.



Percentage of clouds producing radar (rain) echoes in terms of heights and temperatures at the cloud tops in three different geographical regions.

Figure 3

Rain Echoes in Clouds of Different Geographical Regions

After H. R. Byers, 1959, What Are We Doing About the Weather?, in Science and Resources--Prospects and Implications of Technological Advance: Johns Hopkins Press, Baltimore, p. 49.

Moisture in the Air

Invisible water vapor (gas) is the moisture in the air that must be ultimately converted to clouds by natural processes before man can stimulate rainfall. The amount of water the air can hold as invisible vapor is controlled mainly by the temperature of the air--the higher the air temperature the more water vapor the air can hold. When the air is cooled sufficiently (lifted) the moisture in the air is condensed out and becomes visible as clouds. Further cooling will cause the clouds to release their moisture in the form of hydrometeors. Not all warm air has a high water vapor content because after being warmed the air may not have had "absorption opportunity." For example, the warm air may not have passed over a large body of water where evaporation from the water into the warm air could have taken place. For this reason warm desert air is almost always dry air. When warm air enters Texas after passing over the Gulf of Mexico it is moisture-laden. When warm air enters Texas after passing over extensive land areas in Mexico and the Western United States it is dry, sometimes hot, and tends to absorb whatever moisture is already present in the air. Thus the Gulf of Mexico is the principal source of moisture in the lower levels of the atmosphere over Texas, although significant natural rains result from Pacific Ocean moisture under rarer circumstances.

Cloud Formation

Clouds are formed from the water vapor contained in the warm air by a cooling-condensation process. When the moist warm air is cooled sufficiently it will become saturated and visible clouds will form. Because the atmospheric pressure decreases with altitude above the earth, the air expands and is cooled as it goes aloft. Some of the most common ways air rises, is cooled, and clouds result are:

1. A stream of warm moist air flows up sloping terrain, a hill, or a mountain range;

2. A weather front wedges under warm air and forces it aloft;

3. Hot air, with its tendency to rise, goes aloft on hot summer days and forms air-mass type convective cumulus clouds;

4. Converging currents of air are forced upward; and,

5. Warm air rides up the slope of a stationary front.

Precipitation Theories

A popular theory about the natural precipitation-initiation process is the one advanced by the German, Wegener, in 1911, later adopted by a Swedish meteorologist Tor Bergeron in 1933, i.e., in order for any appreciable amount of rain to fall from a cloud, water in all its three forms--vapor, liquid, and solid--must co-exist in a cloud, at least a portion of which is supercooled. Such a cloud is known as a mixed cloud. Basically, the process is one where the solid particles (ice or snow crystals) grow at the expense of the liquid (cloud droplets) through the medium of deposition, or as meteorologists know it, sublimation (liquid to vapor to solid) until they are large enough to overcome upward motion and fall through the cloud and out beneath as snow. This occurs if the air between the cloud and the ground is below freezing, the solid particles melting and falling as rain if they fall through warmer temperatures (see Figure 4). As the ice or snow crystals fall they continue to grow larger by diffusion, and by collision and coalescense with other cloud droplets.

In Texas and other low-latitude areas of the world many clouds simply do not extend high enough to become mixed clouds, yet large amounts of rain frequently fall from these clouds. No part of them extends high enough (hence they are not cold enough) for ice or snow crystals to form naturally. Spontaeous freezing of supercooled cloud droplets to form ice or snow crystals has been proved time and again to occur at temperatures as low as minus 38 to 40°F both inside the laboratory and out in the field. Obviously, some process other than the mixed-cloud theory must account for the rain that falls from warm clouds.

The condensation-coalescence theory has received much attention, and is though by many to account for a large part of the precipitation falling from warm clouds (Moyer, 1956). Simply stated, the theory says that continued condensation of the water vapor to form an overabundance of warm cloud droplets will result in the individual droplets colliding with each other and growing by coalescence until they are large enough to overcome the updrafts of air within the cloud and then fall out as rain.

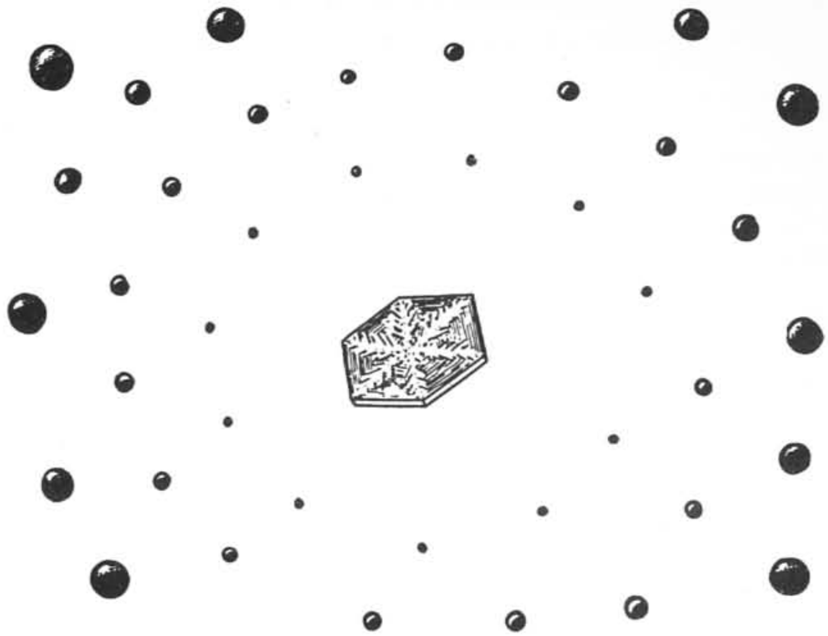
At the very slight supersaturations common to natural situations and at temperatures warmer than about minus 40°F, water vapor will not condense to form cloud droplets and will not sublime to make ice or snow crystals without the presence of some kind of solid nucleus on which to form. Natural condensation-nuclei are abundant in the earth's atmosphere and usually need not be supplied by artificial means. However, a stable cloud warmer than about minus 40°F, which is filled with cloud droplets all about the same size and physical makeup, may not rain no matter what its size. Something has to be done to upset its balance.

Possibility of Modifying Clouds

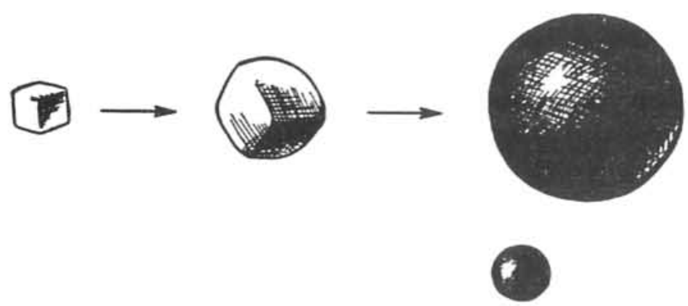
Either the temperature of a portion of the cloud must be reduced to less than minus 40°F so ice crystals will form spontaneously and grow at the expense of the water droplets (some of the drops must be made larger than others to begin the collision-coalescence process), or some other nucleus around which ice or snow crystals will form at temperatures warmer than about minus 40°F must be introduced into the cloud. This knowledge opened the possibility that if man could artificially supply what was missing he could modify the natural cloud. Artificial nucleation with freezing nuclei was one approach.

The Natural Freezing Nucleus

While natural nuclei around which water vapor will form to make cloud droplets are abundant in the lower atmosphere, the natural nuclei on which ice or snow crystals will form may be relatively rare and apparently temperamental for they will not allow ice crystals to form on them merely because the temperature is below freezing--they usually will not perform as freezing nuclei until the temperature is plus 5°F or colder. Table 1 shows some natural freezing nuclei. At temperatures warmer than plus 5°F but colder than plus 32°F, clouds usually contain only supercooled water droplets. If none of the water droplets



Ice crystal in the form of a hexagonal plate shown among undercooled droplets. Nearby droplets have evaporated partially and the vapor is being deposited on the crystal.



A "giant" nucleus composed of a substance such as sea salt (left) attracts a coating of water to it (center). As the particle reaches saturation in the cloud, it has grown to a small raindrop (right) which is large compared with the prevailing cloud droplets, one of which is shown immediately below it.

Figure 4
Ice-Crystal Growth Through Sublimation, and Hygrophilic Giant Sea-Salt Particle Growth

After H. R. Byers, 1959, What Are We Doing About the Weather?, in Science and Resources--Prospects and Implications of Technological Advance: Johns Hopkins Press, Baltimore, p. 40, 43.

Table 1.--Some natural freezing nuclei*

Substance	Crystal symmetry	Threshold temperature (°C)†
Ice crystal	Hexagonal	0
Covellite	do	− 5
Vaterite	do	− 7
Beta tridymite	do	− 7
Magnetite	Cubic	− 8
Anauxite	Monoclinic	− 9
Kaolinite	Triclinic	− 9
Illite	Monoclinic	− 9
Glacial debris	--	−10
Hematite	Hexagonal	−10
Brucite	do	−11
Gibbsite	Monoclinic	−11
Halloysite	do	−12
Volcanic ash	--	−13
Biotite	--	−14
Vermiculite	Monoclinic	−15
Phlogopite	--	−15
Nontronite	Monoclinic	−15

Of the 30 terrestrial dusts tested, 16, mainly silicate minerals of the clay and mica variety, were found to produce ice crystals to the extent of 1 crystal for every 10,000 dust particles, in a supercooled cloud at temperatures of −15°C, or higher, and of these, 7 were active above −10°C. These substances are all minor constituents of the earth's crust and it is significant that common materials such as sea sand were not effective. The most abundant of the active substances in the above table is kaolinite with a threshold temperature of −9°C.

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* Adapted from Mason, B. J., 1962, Clouds, rain & rainmaking: The Cambridge University Press, 145 p.

† Threshold temperature is that temperature where activity first begins. The nuclei are active at the threshold temperature and below.

are frozen into ice crystals there may be no vapor pressure gradients between them, and therefore none of them will grow at the expense of others by any sublimation process. If none grows larger than the others, none will fall out of the cloud as precipitation. The cloud will remain stable.

The Artificial Freezing Nucleus

To hurry, or begin, the cloud-particle growth process in supercooled clouds man has:

1. Artificially supplied foreign nuclei on which ice crystals will form at temperatures warmer than plus 5°F, thus creating a vapor pressure gradient between droplets and ice crystals (creating a mixed cloud) and enabling the ice crystals to grow at the expense of the water droplets; and

2. Introduced quantities of dry ice into the cloud that locally lowers the temperature enough to force spontaneous glaciation or ice crystal formation in a portion of the cloud (creating a mixed cloud), thus setting up a vapor pressure gradient between the frozen and liquid droplets enabling the frozen to grow at the expense of the liquid by the sublimation process.

Both processes carry the growth of the particles, ice or water, only to a few hundred microns in size (Battan, 1962). Thereafter the coalescence process is the only one that counts. It takes over and continues the particle growth to a size sufficient to overcome updrafts and fall from the cloud as precipitation.

WHY SEEDED CLOUDS UNDERGO CHANGE

Condensation Nuclei

Because we see clouds or fog nearly every day, it is obvious that if minute solid particles called condensation nuclei are necessary before condensation of the water vapor in the air will take place and form clouds, then it is equally obvious that there is no dearth of such nuclei in the atmosphere about the earth. The smallest of the nuclei are the most numerous. Three sizes are generally recognized: (1) the Aitken nuclei (minute), named after the 19th century scientist who proved that water vapor condenses on nuclei, smaller than about 0.4 micron in size; (2) large nuclei, 0.4 to 1 micron in size; and, (3) giant nuclei, 1 to about 10 microns in size. H. E. Landsberg computed that the numerous little Aitken nuclei have a range of concentration of 3,500 to 4 million per cm^3 of air around cities; 180 to about one-third million per cm^3 out in the country; and from about 2 to nearly 40,000 per cm^3 over oceans. Conversely, the giant nuclei must then be considered relatively scarce when one considers that cloud droplets occur within the range of 10 to 1,000 per cm^3.

Nuclei for Forming Water Droplets

All three nuclei sizes, Aitken, large, and giant, readily function as nuclei for forming liquid droplets, but due to their great numbers only a fraction of the ones available are ever used. Sampling indicates that overall there may be 10 to 100 times as many nuclei of all kinds available per cm^3 as there are cloud droplets per cm^3. When air becomes saturated because of cooling, the relative humidity is said to be 100 percent with respect to water. Further cooling would cause a state of supersaturation (greater than 100 percent relative humidity) in which event the water vapor is condensed out and forms droplets on the abundant nuclei.

Nuclei for Forming Ice Crystals

While there is no shortage of natural nuclei around which water droplets can form, there is a relative scarcity of natural freezing nuclei around which ice crystals will form, and their numbers vary to a large degree dependent in part upon temperature and altitude above the surface of the earth. Quantitative statements about relative numbers of freezing nuclei are without meaning unless a temperature is specified. With the same temperatures, the day-to-day variation in the numbers of freezing nuclei near the earth's surface is small, while the day-to-day variation in their numbers in upper air may be as much as a thousandfold or more (Advisory Committee on Weather Control, 1957).

Mixed-Cloud Condition

Water has the property that without freezing and forming ice it can withstand below-freezing temperatures in varying magnitudes dependent in part upon its chemical purity. Water that remains in liquid state at below-freezing temperatures is said to be supercooled. A cloud containing such water is said to be a supercooled cloud. Considering the uncooperative behavior of natural freezing nuclei and the contrary quality of supercooled clouds, one justifiably wonders how ice crystals ever form naturally in clouds. Spontaneous freezing and cloud glaciation does, however, occur naturally without the necessity for freezing nuclei whenever the supercooled cloud droplets of liquid water reach a temperature of between minus 38 and 40°F. Therefore, a continuously connected cloud whose base is at an altitude below the melting level and whose top extends vertically to an altitude where the air temperature is colder than minus 40°F will simultaneously contain water in all its three states: vapor, liquid, and solid--the mixed-cloud condition accepted by many cloud physicists as necessary before appreciable amounts of precipitation can be expected to fall from nontropical clouds.

Warm-Water Droplets

Warm-water droplets exist in all clouds having bases below the melting level. When both the base and top of the cloud are below the melting level the entire cloud is made up of warm-water droplets and is known as a warm cloud. This type of cloud with a vertical extent sufficient to cause rain occurs mainly in the tropics the year around and frequently occurs at higher latitudes during the warmer months of the year. It is a problem cloud for Texans. It is this cloud on which continued research is urgent and on which a seeding-technique breakthrough is necessary before Texans can expect beneficial increases in rainfall as a result of cloud seeding.

Supercooled Droplets

Both warm and supercooled droplets occur in a cloud that extends vertically from below to above the melting level. Many times, especially over mountains, an entire cloud is composed of supercooled water droplets. That is both the base and top of the cloud are above the melting level but the cloud does not contain ice crystals. It is this type of cloud when sufficiently deep (thick vertically) and active (dynamic forces acting upon it) that is particularly susceptible to seeding.

Ice Crystals

Ice crystals in a cloud can be thought of as tiny particles of snow. They occur naturally in a cloud at temperatures from plus 5 to about minus 40°F when a suitable nucleus, natural or artificially introduced, is available around which to form. Ice crystals will form naturally in any cloud at temperatures colder than about minus 40°F even if no freezing nuclei are present. The upper reaches of very tall clouds (cumulonimbus) and the entire contents of very high clouds (cirrus clouds--20 thousand feet and higher) are composed completely of ice crystals. Water vapor has an affinity for ice crystals, and water droplets in coexistence with ice crystals in the same cloud will evaporate permitting the ice crystals to grow.

Rain from Warm-Water Clouds

Although most heavy rain comes from mixed clouds in nontropical regions it is obvious that a mixed-cloud condition cannot account for a great percentage of the rain in the tropics, because month after month every cloud in the tropical sky may be entirely--base to top--below the melting level, yet large amounts of rain fall from them. Some process other than growth of ice crystals must account for the rainfall. The two processes receiving the most credit for causing precipitation from warm-water clouds are: (1) the coalescence-condensation process, and (2) the giant sea-salt particle (Nuclei) theory (Woodcock, 1956; Byers, 1959; Battan, 1962).

Giant Sea-Salt Particles

The salt particle is hygrophilic and water vapor will collect on it at relative humidities of less than 100 percent. Woodcock's investigation of giant sea-salt particle behavior as a condensation nucleus is explained by Battan (1962), and is clearly described and illustrated (see Figure 4) by Byers (1959). Although relatively few in number, the giant sea-salt particles absorb water so fast that as soon as saturation conditions (100 percent relative humidity) are reached in the cloud they grow into drops having a radius of 50 microns and more. Battan describes the average cloud droplet as having a radius of about 10 microns. Byers computed that 50-micron size droplets forming around a giant nucleus have a terminal velocity of fall of about 1 foot per second and that this gives them sufficient relative motion to collide and coalesce with the smaller cloud droplets and grow into small raindrops.

Condensation-Coalescence Process

Starting with some of the 50-micron or larger size warm-cloud droplets that were formed by condensation on giant sea-salt nuclei, now distributed among many millions of smaller cloud droplets formed on Aitken and large nuclei, one can readily understand that due to their greater mass and heavier weight the larger droplets will fall through the smaller ones colliding and sweeping a path as they pass. As the larger droplets collide with the smaller ones some, but not all, stick or coalesce (merge) and the large droplets grow larger. Battan suggests that after the large droplets reach a size of about 100 microns in diameter they can grow into raindrop size (1 millimeter in diameter) in a cumulus cloud by the collision-coalescence process within 15 to 20 minutes if the cloud is composed of many large droplets--somewhat slower in clouds composed of very small droplets. The evidence resulting from these and other studies leads to the conclusion that coalescence and continuing condensation account for most rainfall from warm clouds (Moyer and Cry, 1957). Without continued condensation of water vapor to replace the coalesced and precipitated cloud droplets, any cloud warm or cold will dissipate. Although not strictly true, one may better visualize what takes place in the condensation process if condensation of the water vapor in the air to form cloud droplets is thought of as a separation of the water out of the air by cooling and expansion. Invisible water vapor in the air once separated becomes the visible water a cloud represents.

Usual Texas Clouds, Warm and Supercooled

Mainly during only the warmest months, but occasionally in every month of the year, warm clouds of sufficient size to cause rain occur in Texas. Some precipitate and some don't. Why? Here is where the greatest need for research lies. Some scientists have discovered inland concentrations of the giant salt nuclei credited so widely with initiating the collision-coalescence process in warm clouds and some are proponents of the idea that electrical effects are very important in producing precipitation. Bernard Vonnegut and Charles B. Moore of Arthur D. Little, Inc. were in 1962 investigating the importance of these electrical effects. Some scientists suggest that electrical attraction may cause small droplets to coalesce and produce the larger droplets necessary to begin the precipitation process.

The warm layer-type (stratus) clouds that commonly occur all along and inland about 150 miles from the Texas coast occasionally produce some drizzle but for all practical purposes do not increase the overall rainfall because they are usually stable and do not extend to sufficient height (are not vertically thick enough) for the condensation-coalescence process to act long enough to produce large raindrops. However, these same warm layer-type clouds later in the day sometimes break up and reform as cumulus clouds because of insolation-produced air currents rising from below. When moisture and atmospheric stability conditions are right these heat-produced cumulus clouds can sometimes grow to awesome proportions in a matter of an hour or two. Such a cloud is known as a cumulonimbus and often produces heavy rains, hail, lightning, and thunder. These usually dissipate after nightfall over land because of decreasing insolation. Water exists in such a cloud in all three states--vapor, liquid (both warm and supercooled), and solid.

What Happens When Clouds Are Seeded

When clouds are seeded with artificial nuclei, dry ice, water, or solutions, the means utilized by the many seeding agents to accomplish the desired effect differs to varying degrees, but in the end if the attempt to produce significant amounts of precipitation succeeds, a collision-coalescence process is achieved within the cloud. It is the collision-coalescence act alone that is most accepted by scientists as the last and necessary droplet or crystal growth process to go through before rain or snow can result in the precipitation-producing chain of events that takes place in clouds whether we are talking about natural or induced precipitation.

Warm-Water Clouds

The collision-coalescence process has been induced from time to time in warm-water clouds (where the entire cloud, base to top, is below the melting level) by experimenters throughout the world for several years. Scientists in Asia and Africa and other parts of the world have variously reported success and failure in attempts to initiate the collision-coalescence process in warm clouds by introducing salt particles and/or salt solutions into warm clouds. Most such experiments have produced inconclusive results, but at least one, an important one, wherein quantities of just plain water were sprayed into tropical cumulus clouds near Puerto Rico by a research group from The University of Chicago (lead by Dr. Horace R. Byers) doubled the statistical probability of rainfall from these clouds. The idea of modifying warm clouds by introducing water into them was proposed by Dr. Irving Langmuir (1948) when he suggested that a chain-reaction coalescence process could be stimulated in warm clouds by the addition of water droplets 50 to 150 microns in size, but it remained until the period 1951-54 for Langmuir's suggestion to be tested under tightly controlled scientific-experiment conditions by Byers and other investigators and reported through scientific media (Battan, 1962). These tests led to the conclusion that seeding warm active cumulus clouds with water could result in rain. As indicated in Appendix A, warm layer clouds and small, inactive, warm cumuli often dissipate when seeded.

Supercooled Clouds

The internal structures of supercooled clouds, those containing liquid water droplets at below freezing temperatures, are almost invariably modified to some extent when artificial freezing nuclei or dry ice are introduced into them. The effects of the modification in many cases are not felt at the ground. It has been proved by scientists on numerous occasions, both in the laboratory and under actual field conditions, that the creation of ice crystals in clouds supercooled to temperatures below about 25°F will result in the growth of ice crystals at the expense of water droplets and the collision-coalescence process will be enhanced (see Figure 4).

Radar sets sensitive to certain wave lengths can detect the larger precipitation droplets in a cloud, but are insensitive to the smaller normal cloud droplets. On occasions shortly after seeding, supercooled clouds have been observed to give precipitation echoes on these radar sets, whereas before seeding no echoes were visible when the cloud was viewed in the radar scope. Identically appearing unseeded clouds in the vicinity viewed at the same time by the same radar scope showed no echoes during the test period. Battan and

Kassander (1962) listed as 1 result of 4 years testing of orographic convective clouds over Arizona in 1957-60 a finding that the cloud-census and radar studies suggest in some cases seeding may have led to the initiation of precipitation echoes. Again, as in the case of seeding warm clouds, seeding small, inactive, supercooled cumuli usually results in dissipation, or holes and valleys appearing in the cloud (Appendix A).

During the 12-month period ending March 31, 1964, Meteorology Research, Inc. (MRI) of Altadena, California, investigated the behavior of seeded orographic cumuli occurring in the mountainous regions near Flagstaff, Arizona. There report covering the period April 1, 1963 to March 31, 1964 MacCready and others (1964) deals primarily with these clouds that are quite similar to the Trans-Pecos Texas summertime thunderheads. The similarity of these Arizona clouds to the Texas clouds is such that the conclusions reached and recommendations made in the Flagstaff report may be of interest to anyone thinking of conducting cloud-seeding experiments on Trans-Pecos clouds.

One phase of the Flagstaff cumulus studies, which may be of special interest to cloud-seeding experimenters in Texas, concerns the growth of seeded cumulus clouds. In some cases the latent heat of fusion released in seeding supercooled clouds can significantly increase the ultimate height of the cloud. Under conditions specified in the report, the results imply that height increases of more than 5,000 feet due to seeding can be expected fairly often, and increases of more than 15,000 feet are sometimes possible. On the other hand, some individually seeded cumulus were observed to grow only slightly in height and collapse shortly after seeding. Woodley (1964) made some computations on cloud growth related to seeding, and noted that substantial height increases may result from seeding but that favorable conditions for such events occur only on a relatively small number of occasions.

Elliott and Hovind (1964), in their treatment of the question bearing on the prediction of orographic precipitation and the seeding of orographic clouds, find that approximately one-quarter of the orographically produced water content (condensate) of clouds falls as precipitation on the watersheds of two southern California orographic barriers (mountain ranges). These authors feel that the implications with respect to cloud seeding are clear; only the condensate that would otherwise move over the barrier and evaporate downwind can be tapped by artificially increasing the efficiency of the conversion of cloud water to precipitation (cloud seeding to produce rain).

CLOUD SEEDABILITY

Precipitation Initiation

Only the initiation of precipitation is discussed here. No attempt is made to explain the subsequent more complex stages of the precipitation process of getting the rain out of the cloud and onto the ground. The four cloud parameters concerned mainly in precipitation initiation are the updraft speed within the cloud, cloud base temperature, cloud depth, and size of activated nuclei near the base of the cloud. Using H. G. Houghton's (1951) computations, which put the initiation of precipitation through the ice phase in quantitative terms, C. J. Todd developed a precipitation initiation model based on work published by Dr. Irving Langmuir and others. The model and assumptions made in its development are described in detail by the Advisory Committee on Weather Control (1957).

The Precipitation Initiation Model

The precipitation initiation model developed by Todd and others supports many postulations about precipitation processes, and indicates additional areas for consideration--some of which are:

1. If the cloud base is cold, ice-crystal precipitation can occur earlier than warm-cloud rain, but if the cloud base is warm, the warm-cloud precipitation will occur before ice crystal precipitation;

2. There is a wide range of conditions under which ice-crystal precipitation will operate substantially ahead of warm-cloud rain;

3. The likelihood that the life of some clouds may be too short for warm-cloud processes to produce precipitation, but the cloud life may be long enough for ice-crystal processes to operate to produce precipitation, poses the possibility that if natural freezing nuclei concentrations are low, seeding may speed up initiation of ice-crystal precipitation;

4. In some cases, supplying nuclei will not produce easily detectable results; and,

5. Some indication can be obtained as to where and when a precipitation echo should appear in a cloud (some results have been compared with actual radar records).

Seedability Analysis and Use

Figure 5 (Advisory Committee on Weather Control, 1957) is a precipitation schematic to be applied to clouds having a 200-feet per minute updraft. It will accommodate a wide range of cloud-base and cloud-top temperatures for such clouds. It was made up from charts accompanying the Todd Model and is for use in making a seedability analysis. A family of precipitation schematics can be made up from the model if one is interested in seedability analyses of clouds having updrafts at rates other than 200-feet per minute. When applied to a cloud that fits the precipitation schematic in Figure 5, the six areas lettered A through F indicate the following:

1. Area A--no precipitation will occur, because cloud-base temperatures are too cold for warm-cloud precipitation and cloud-top temperatures are too warm for ice-crystal processes;

2. Area B--only warm-cloud precipitation due to condensation-coalescence processes can occur;

3. Area C--seeded ice-crystal precipitation may occur, and if it does occur it will clearly represent a local precipitation increase, because no other opportunity for precipitation development exists;

4. Area D--both seeded ice-crystal and warm-cloud precipitation can occur, with the seeding serving to convert more precipitable moisture even though warm-cloud processes are already productive;

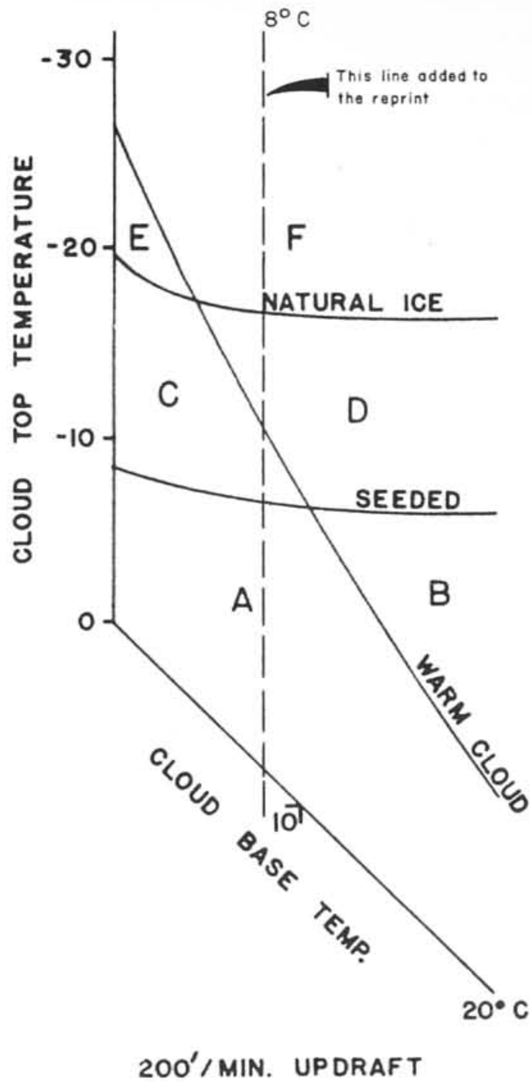


Figure 5

Precipitation Schematic

Adapted from Advisory Committee on Weather Control, 1957, Santa Barbara Radar Evaluation and Other Special Studies: Final Report of the Advisory Committee on Weather Control, v. II, p. 193.

A region--no precipitation expected to develop; B region--the condensation-coalescence process expected to develop precipitation; C region--only precipitation formed by the artificial production of ice-crystals may develop; D region--both warm-cloud and seeding processes can contribute to precipitation; E region--there are enough naturally-produced ice-crystals to produce precipitation; F region--both natural ice-crystal and warm-cloud processes contribute to precipitation.

5. Area E--natural ice-crystal precipitation should occur because a sufficient number of ice-crystal nuclei to cause precipitation should be present; and,

6. Area F--conditions are conducive to initiation of both natural ice-crystal and warm-cloud precipitation.

To take a look at what the precipitation schematic is designed to tell about a cloud having a cloud-base temperature of 8°C (46°F), interpolate along "cloud base temperature" line to 8°C, and strike a vertical line upward from the 8°C point (see broken vertical line on Figure 5); then read temperature values off the "cloud top temperature" scale opposite where the struck line passes through the "warm cloud," "seeded," and "natural ice" lines. What this says is:

1. Reading opposite where the struck line passes through the "seeded" line--no precipitation can occur from a fitted cloud whose base is 8°C and whose top is warmer than about minus 6°C (19°F), whether seeded or not;

2. Reading opposite where the struck line passes through the "warm cloud" line--seeding can be expected to initiate precipitation in the minus 6 to minus 11°C portion of a fitted cloud whose base is 8°C and whose top is about minus 11°C (12°F); and,

3. Reading opposite where the struck line passes through the "natural ice" line--seeding can be expected to augment precipitation already initiated by natural warm-cloud processes in the minus 11 to minus 17°C portion of a fitted cloud whose base is 8°C and whose top is about minus 18°C (0°F), because both the natural warm-cloud and ice-crystal processes are acting to initiate precipitation.

Seedable Clouds

Not every cloud seen in the sky is seedable in the sense that results after seeding will be easily detectable. The major features of warm, supercooled, and mixed clouds were discussed earlier and will not be reviewed; however, it is of importance to call attention to Figure 5, areas C and D, in order to point out that all the temperatures therein are below freezing. This means that cloud droplets within these areas are supercooled, and the ice-crystal process is expected to start when the cloud is seeded with ice-crystal producing nuclei, resulting in a mixed-cloud condition and enhancing the condensation-collision-coalescence precipitation process. If giant nuclei are present, or if the cloud is seeded with hygrophilic nuclei or sprayed with water, the results would be to lower the line labelled "warm cloud," thus allowing for precipitation falling from clouds with warmer tops, clouds with less vertical development.

Liquid water content ranging from 1 to 10 grams per cubic meter was taken into account when developing the precipitation initiation model discussed earlier. Liquid water content of a cloud certainly is important in any seedability analysis. It is a function of temperature, and was taken into account in the precipitation schematic (Figure 5) when determining the configuration of the "cloud base temperature" line, which will accommodate clouds with bases as warm as 68°F. Interpreting Figure 5, a cloud having a base as warm as 68°F would not rain for any reason now known unless its top was colder than about 50°F.

Cumulus

More seeding experiments have been performed on cumulus clouds than on any other type because: air-mass type cumuli are isolated or occur in families, greatly facilitating visual and statistical evaluation of the effects of seeding; they develop to a vertical extent covering an extremely wide range of temperatures from base to top (plus 60°F to minus 40° or 50°F is not at all uncommon) affording a wide range of experimental seedability with respect to updraft speeds and liquid moisture content; cumulus clouds occur also in fronts, squall lines, hurricanes, and in areas of atmospheric instability; and, except for the small fair-weather cumulus they are almost always active.

Orographic

Of all cumulus-type clouds the convective orographic cumuli are the most seedable, and have been the recipients of the most experimentation (Battan and Kassander, 1962; MacCready, 1960; Smith, T. B., 1962). This is in large measure a result of their characteristic of forming at nearly the same time and in nearly the same place from day to day in a given season. An experiment can be tried on one today, and a new or the same experiment can be tried again on another one almost like it tomorrow at about the same time and place. This predictable and dependable characteristic of convective orographic cumulus clouds is one reason why Dr. Paul B. MacCready and his associates in Meteorology Research, Inc. chose the site of the San Francisco Peaks north of Flagstaff, Arizona to set up their outdoor cloud laboratory in 1956 while working on Project Skyfire. These peaks are relatively isolated, and most cumuli near them have been caused by the peaks themselves. Meteorology Research, Inc. moved laboratory equipment (radar sets, whole-sky camera equipment, balloon tethers, dry-ice crushers, especially instrumented and equipped aircraft, and so on) to the field and established an outdoor cloud laboratory, because it was felt that the complexities and interrelationships involved in cloud physics could not be put in proper perspective or duplicated in the confines of an indoor laboratory. This outdoor cloud laboratory has been in almost constant operation, working on a variety of weather modification and cloud physics contracts and projects, since the Project Skyfire activities began (MacCready and others, 1963).

The Arizona orography and the large-scale atmospheric circulation patterns affecting Arizona apparently are conducive to comprehensive and long-range weather modification experiments and cloud physics studies, for Dr. Louis J. Battan and his associates with the University of Arizona's Institute of Atmospheric Physics have conducted such activities in the vicinity of the Santa Catalina Mountains northeast of Tucson, with National Science Foundation support and U. S. Weather Bureau and U. S. Forest Service assistance, since at least 1957. Correspondence and conversations with Dr. Battan and study of literature authored by him and his associate, Dr. A. R. Kassander, Jr., have contributed immensely to whatever claim to scientific knowledge dissemination this bulletin can make.

Frontal

Cumuli accompanying fronts, squall lines, hurricanes, and other systems that move are frequently the most violent, spawning tornadoes, hail, high winds, and other catastrophic weather phenomena. Being transitory in nature, when such cumulus clouds are seeded they must be followed in aircraft, or their paths (trails) after seeding must be closely examined if any worthwhile statistical evaluation of the results of seeding is to be made. Too, the problem of judging whether or not the seeding was effective and to what degree it was effective over and above what would naturally have happened is more complex with clouds that move--encountering new and different atmospheric forces as they go along.

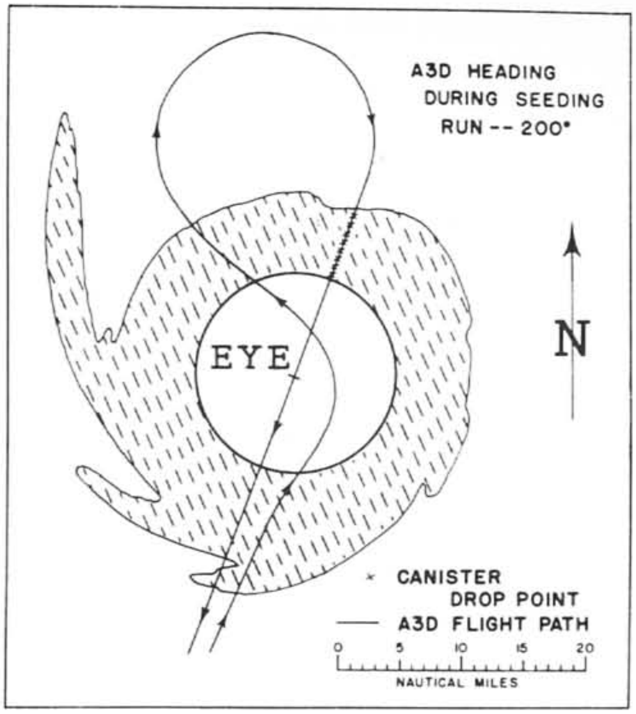
Hope about the problem of determining what would have occurred naturally without seeding these passing weather systems is expressed in a July 1962 statement by the American Meteorological Society presented in Appendix B. This statement acknowledges that the physical laws governing atmospheric motions can be cast in mathematical form suitable for processing on high speed electronic computers to predict the future state of the atmosphere--giving promise that it will some day become possible to predict with accuracy the short and long-term effects of artificial interference with normal atmospheric processes.

Nevertheless, it has long been recognized that transitory cumulus clouds must receive their share of investigation if we ever expect to modify the weather beneficially. They have not been neglected, although statements about the results of seeding them have understandably been less positive. In addition to the hurricane projects and experiments mentioned earlier, Dr. J. S. Malkus (1963) tells of massive seeding experiments carried out on Hurricane Esther in 1961 (see Figure 6). The program of the 225th National Meeting of the American Meteorological Society, held at Los Angeles January 29-31, 1964, abstracts a proposed paper co-authored by R. H. Simpson, J. S. Malkus, and M. A. Eaton concerning the joint Weather Bureau and Navy Project Stormfury seeding of 1963's Hurricane Beulah with approximately 800 pounds of silver iodide on each of the two days, August 23 and 24, 1963, affording plenty of evidence that investigation of transitory weather systems is not at a standstill. They are seedable and they are being seeded, but the results are still inconclusive.

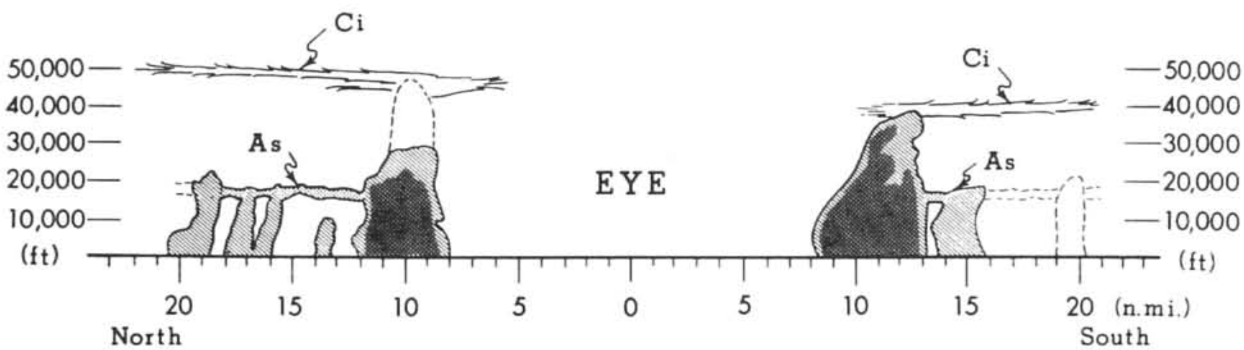
Air Mass

The so-called air-mass convective cumulus cloud is the cloud occurring at scattered locations within a mass of quasi-stationary air that covers a vast several-state area, usually in the summer and usually on a hot afternoon. It builds to various heights depending mainly on stability of the air mass, availability of moisture in the air (relative humidity, generally), and the heat-produced updraft speed. This is the oft-times violent cumulonimbus cloud discussed earlier. Battan (1962) uses the descriptive term "penetrative convection" (suggestion of the term credited to Frank H. Ludlam of England) to analogize a small volume of air penetrating vertically through a larger volume of more stable air. The small volume of air forms the cumulonimbus cloud if conditions are right, and can cause the cumulonimbus to reach heights in excess of 60,000 feet with updrafts exceeding 4,000 feet per minute.

Air-mass cumuli have been the subject of much experimentation both in the United States and abroad. These clouds are perhaps the best suited of the lot for statistical evaluation of the effects of seeding because where one is found



Flight pattern followed
by the A3D on Sept. 16, 1961.



Cross section radar composite of Hurricane Esther, 1945 GMT,
Sept. 16, 1961. (DC-6 aircraft, RDR-1, 3-cm. radar)

Figure 6

Hurricane Esther, 1961

After R. H. Simpson, M. R. Ahrens, and R. D. Decker, 1962, A Cloud Seeding Experiment in Hurricane Esther, 1961: U. S. Department of Commerce, National Hurricane Research Project, Rept. No. 60, p. 16, 19.

another is probably nearby. One can be seeded and the results can be compared on the spot with the nearby one that was not seeded. The results of seeding can be stated directly with a higher degree of confidence because of the knowledge that two similar clouds in the same mass of air at the same time and presumably under the same dynamic influences, one seeded and one not, behaved differently. Both the experimenter and the reviewer have fewer doubts what happened.

One current operation involving silver iodide seeding of summertime cumulus clouds is the NSF grant Project Whitetop, described in a report prepared by Braham (1963a). Dr. Braham's report suggests that initial precipitation formation in these clouds is dominated by all-liquid warm-rain processes, and while snow pellets frequently are found in such clouds, they are usually preceded by the development of large liquid drops. Observations tending to support the suggestion in Braham's report were made by Battan (1962). If proved, this may be cause for reexamination of the classic Bergeron mixed-cloud theory and the part ice crystals play in the cloud-particle growth process.

E. J. Smith and his associates of the Commonwealth Scientific and Industrial Research Organization (CSIRO), Sydney, Australia, post a long record of seeding experiments with air-mass and other types of convective cumuli in the Snowy Mountain region of southeastern Australia dating from at least 1955. Henri Dessens of France has reported the formation of precipitation-potential cumulus clouds in France by large controlled fires, and the Australian group has reported on seeding of cumulus clouds forming above large brush fires.

Stratus Clouds

A thick bank of supercooled stratus clouds was the first to be seeded in recent modern times (Schaefer's work referred to on page 4). The quick apparent reaction of these clouds to Schaefer's dry-ice seeding (the falling of snow a few minutes later) is credited by some with starting the frenzy of weather modification attempts immediately undertaken by researchers, ranchers, commercial interests, laymen, and the outright uninformed, which reached maximum activity some 10 years later in 1956 (see Figure 1). Some sorts of stratus-type clouds occur under different conditions at different elevations all the way from the surface to as high above the earth as clouds are known to exist. Common advection fog is a type of stratus cloud, for when it lifts to where its base can be called a hundred feet above the surface, fog is then identified as stratus clouds in weather observation records kept the world over. Or a deck of what is called stratus clouds while over the plains becomes known as fog when the "cloud" touches the ground on the slope of a hill or mountain. To further identify stratus clouds the combining prefixes alto-, nimbo-, and cirro- are placed before stratus-type clouds, depending upon the altitudes or conditions of occurrences. Modification attempts have been tried on them all. The various types of stratus clouds behave differently when seeded, or behave not at all--as has been the case with cirro-stratus clouds because they are already glaciated (are themselves composed of ice crystals).

Thick Stratocumulus Clouds

Thick (vertically deep) supercooled stratus clouds, such as nimbo-stratus, stratocumulus, and alto-stratus, when seeded with dry ice or ice-crystal producing nuclei have generally produced easily detectable results. Observers have often seen the tops turn dark and snow fall from beneath, melting and reaching the ground as rain when the air between the cloud base and the ground was more than 32°F, and as snow if the temperature between the cloud base and the surface was everywhere below freezing. Troughs or valleys have on occasions been observed to form in this type cloud when seeded. Thick stratus cloud occurrence in Texas is usually associated with transitory weather systems as opposed to the occurrence of cumulus-type clouds over mountains or in masses of quasi-stationary air.

The seeded stratocumulus and nimbostratus clouds associated with moving frontal systems are those that may with continued research be coaxed to release more rain as they sweep across Texas during their favored seasons. Often the rainy season is not the growing season, but the ability to impound increased rainfall in the rainy season and release the water from full reservoirs when needed for irrigation during the growing season would give a tremendous economic boost to the agriculture industry. Perhaps some day the weather can be controlled to such an extent; however, for the present and during the immediate future Texans must continue to live with and plan for the same kind of cyclic weather patterns that have historically played their parts in the outcome of agricultural endeavors in the past.

Thin, Low Stratus Clouds

Thin low stratus clouds and fog usually are thought of in a hazardous light rather than as being potential precipitation producers. These are thin clouds, not usually under any marked dynamic influence, that are associated with a stable atmosphere as opposed to the turbulent, unstable atmospheric conditions commonly associated with nimbostratus, strato-cumulus, and cumulus-type clouds--the heavy precipitation producers. Efforts toward modification of these clouds are often directed toward their dissipation wholly or in part as a means of increasing visibility and improving airdrome-terminal operating conditions. Many airdromes in Texas, both military and civil, are compelled to curtail or halt take-off and landing operations many hours each year because of adverse low stratus and fog conditions. Control of these adverse conditions has obvious advantages.

Modification experiments have been tried on both warm and supercooled stratus clouds and fog with varying degrees of success. Supercooled clouds of this nature are most often seeded with dry ice or silver iodide, and recently with phloroglucinol. Warm fog and stratus clouds have been seeded most often with hygrophilic particles, solutions, or water. When fog and stratus clouds respond to seeding the usual result is that the formation of troughs or holes in them is accompanied by very light precipitation.

On December 26, 1963 at Salt Lake City, Utah, a commercial cloud seeding firm based in Salt Lake City seeded a supercooled bank of fog with crushed dry ice, and caused dissipation of the fog to begin within 10 minutes. Within 20 minutes the sun became visible through a high cloud deck and an open slot in the fog 5 to 6 miles long appeared over the airport. Air traffic was resumed. The fog had been effectively cleared for a 4-hour period. Fog dispersal operations using dry ice seeding on supercooled fog was used five more times at Salt Lake City in December 1963 and January 1964 with excellent results (Ramsey, 1964).

Need for Evaluation of Results

As with any other science, evaluation of the apparent results of all weather modification experiments must be made by experts in the field if the true results are ever to be known and disseminated through recognized and accepted scientific media. Not only is useless duplication of effort minimized in this way (resulting in a savings of money and time), but an orderly, progressive program of experiments can be encouraged and designed in a manner best calculated to achieve the desired end in the shortest period of time. Science, and ultimately the people of Texas, would stand to gain only if all persons and organizations properly plan seeding operations to obtain necessary data and provide records of the experiment to qualified scientists for evaluation and dissemination.

Methods of Evaluating Cloud-Seeding Effects

Numerous methods of determining the effects of cloud seeding have been used with experimenters expressing varying degrees of confidence in the results. But to date it appears that no positive means of knowing the long-range beneficial effects of weather modification attempts, such as overall increases in the yearly average number of inches of precipitation over a large area of the earth, have been proved. However, the immediate or short-range results of many such experiments have been conclusively proved time and again. Precipitation has many times been observed falling from seeded clouds, troughs or holes have developed in seeded clouds, and seeded clouds have been observed to dissipate.

Discerning an artificially induced 10 to 20 percent increase in the average annual rainfall over a large area is extremely difficult when one stops to consider that natural variations are sometimes as much as 50 percent or more in arid regions. It is not at all uncommon when a Texas city with average annual rainfall of about 32 inches experiences a 20- to 25-inch year (off 37 and 22 percent, respectively). The ability of forecasters to predict weather with increasing accuracy aided by high-speed electronic computers gives rise to hope that the future will see a means developed whereby meteorologists may be able with a high degree of certainty to determine the effects of cloud seeding. With current knowledge, to statistically prove the effects of cloud seeding one must be prepared to embark on a weather modification program extending over many years. The ensuing paragraphs are devoted to a discussion of some of the evaluation methods presently in common use.

Pairs of Days--Random Pick Statistical Evaluation Method

This method of statistically evaluating cloud-seeding effects is suitable for use in conjunction with a nonparametric statistical test such as the sign-rank statistical test (Wallis and Roberts, 1956) and involves seeding clouds on only one randomly picked day from a pair of days, both determined to be favorable for cloud-seeding operations. The system increases the likelihood of day-to-day correlations and guarantees that there will be an equal number of seeded and not-seeded days during the cloud-seeding season (Battan and Kassander, 1962). Using the sign-rank test and data accumulated by Battan in Arizona during 4 years of pairs-of-days randomized cloud-seeding experiments (1957-60) it was calculated that about 64 years of seeding on a basis of 17 pairs per year would be required to determine if the difference in mean rainfall on seeded and not-seeded days is statistically significant. The required length of time diminishes, however, with decrease in aridity of the test area.

Target-Control Method

The target-control method of evaluating the results of cloud seeding is thought by many to be the best evaluation method in common use. The method simply involves establishing criteria for seeding and, when conditions are suitable, selecting one of two or more clouds in the same general area that are as nearly alike as possible. One (the target) is seeded but not the other (the control) and what happens to the seeded cloud is observed and compared with the behavior of the unseeded cloud. The behavior of the unseeded cloud is postulated to be natural, and that of the seeded one is assumed to be artificially induced. Some in favor of this method reason that the results are more realistic, especially if both the seeded and unseeded clouds can be observed from one vantage point, because both clouds are caused by the same dynamic forces that characterize the mass of air in which they form. Opponents to the method sometimes argue that if the two clouds are very close one can never be quite sure that some effects of the seeding are not reflected in the unseeded cloud, and if the two clouds are far enough apart for one to feel more confident on this point, they are not close enough to be always of the same population.

Radar Method

The use of radar may constitute the entire method of observing the results of cloud modification experiments as is sometimes the case when evaluating seeding effects on hurricanes; or, radar may be used in conjunction with other evaluation methods. Radar has the characteristic that echoes of objects in the path of its directed scanning beam are returned to the radar set and shown on the face of a large, flat, cathode-ray tube (oscilloscope) thereby becoming visible in miniature to one wishing to view from afar the direction, distance, and altitude of matter that is of sufficient density to be shown. If the matter (the cloud) is moving, developing, or spreading out, its speed and direction of movement can be calculated. Various types of radar sets are capable of showing matter of various densities. For example, a given type of radar set may be incapable of showing clouds because of the small diameters of the tiny cloud droplets, but the same set is capable of showing precipitation or hail echoes due to larger particle sizes. Therein lies the value of radar in detecting and keeping under surveillance the initiation of precipitation in a seeded cloud. When evaluating seeding effects by the target-control method, radar is especially valuable if both the target cloud and the control cloud can be covered with one sweep of the radar beam. The time of initiation of precipitation in the seeded (target) cloud can be noted, and the subsequent time that precipitation is initiated by nature, if at all, in the unseeded (control) cloud can also be noted--affording investigators a higher level of confidence in evaluating the results of the seeding operations.

Visual and Photographic Methods

It is often said that anything that can be seen can be photographed. With that axiom in mind, in addition to evaluating the reported visual effects of weather modification experiments as seen through the eyes of observers, scientists have with increasing frequency begun to utilize the eyes of cameras of all sorts, some clock-equipped to record these visual effects for posterity and subsequent analyses. Both ground-located and airborne cameras have been used in in a variety of ways, including these:

1. Pairs of ground-located cameras used so the pictures can be studied stereoscopically;

2. Ground-located cameras equipped to photograph the whole sky, time, temperature, and wind velocity all at the same time;

3. Time-lapse cameras used alone or affixed to radar scopes to record step-by-step cloud development;

4. Airborne cameras, both still and motion picture; and,

5. Still cameras affixed to microscopes for future study of pictures made of minute cloud droplets, ice crystals, and so on.

Ice-Crystal Detection

The presence of ice crystals in seeded supercooled clouds at temperatures warmer than about 14°F is generally considered evidence that the ice crystals have been artificially produced, especially if cloud-droplet samples taken from the same cloud at about the same altitude just prior to seeding failed to disclose the presence of ice crystals. The act of causing ice crystals to form artificially in a cloud is within itself evidence that the cloud has been modified at least to that extent. Clearly, detection of such ice crystals is highly desirable in determining the effectiveness of artificially introduced ice-crystal producing nuclei. Their numbers, the temperatures at which they occur, and the time lag to first occurrence of ice crystals in the cloud after seeding are extremely important data to scientists striving to improve supercooled-cloud seeding techniques, or when searching for better cloud-seeding agents (see Figure 3 in Appendix C).

The rudiments of three of the various techniques used for detecting and evaluating ice crystals are described next:

1. The continuous droplet collectors affixed to aircraft used by Meteorology Research, Inc. (during 1962 and 1963 while working near Flagstaff, Arizona) functioned by admitting cloud particles through a slit, which left replicas of cloud-droplet and ice-crystal impingement impressions on moving plastic film to be viewed later in the laboratory;

2. Coated slide-type cloud samplers, thought by many to be the most reliable (slides of a known size coated with oily substances), function by being exposed to a cloud for a specific period of time as an aircraft flies through at a known speed. Impingement impressions are then immediately evaluated with the aid of a microscope or photographed for laboratory examination later; and,

3. On occasions of suspected low concentration of ice crystals or when searching for a quick indication of the existence of ice crystals in a cloud,

often a black object, including the black-gloved hand of someone aboard, is thrust outside the aircraft. The shiny white ice crystals are visible against the black background as they strike.

SCIENTIFIC EXPERIMENTS IN CLOUD SEEDING

Dry-Ice Experiments

The earliest recognized cloud-seeding experiments in which dry ice was used as a seeding agent were conducted by Veraart and Wigand in 1930 and by Schaefer in 1946. Since then dry ice has been proved time and again to be about the quickest acting and most effective ice-crystal producing cloud-seeding agent ever tested. The spectacular changes that a cloud under goes when seeded with dry ice are so rapidly apparent that areas of some clouds seeded with the less effective slower acting agent phloroglucinol (PHL) were also seeded at the same time with dry ice to mark a particular spot--so the PHL seeding could be visually located when the seeding aircraft returned (Braham, 1963b).

Current thinking leaves no doubt about the process by which dry ice forms ice crystals in supercooled clouds. That is, dry ice lowers the temperature in the vicinity to the sublimation level where the solid ice crystals can form directly from water vapor without going through a liquid stage. Battan (1962) computed that a dry-ice pellet 1 centimeter in diameter will produce about 10^{11} nuclei at 14°F before it completely evaporates, but he explained that these figures will vary with the moisture content of the air. Effective though dry ice is as a cloud-seeding agent, its use has the inherent and expensive drawback of requiring an aircraft and pilot for dispensing the crushed dry-ice pellets into the cloud.

Experiments with Other Seeding Agents

The search for cloud-seeding agents might have ended with the discovery that dry ice would, indeed, dependably modify supercooled clouds if a practical means of introducing dry ice into clouds from ground-based equipment could be developed. What was needed was a dependable and highly efficient seeding agent that was inexpensive to buy, did not require highly skilled personnel to operate modestly priced dispensing equipment, and could be dispensed from the ground out of stationary or mobile apparatus in all kinds of weather. Rain-potential clouds and poor flying weather go hand-in-hand. Therefore, it seemed that if only dry ice were suitable for cloud seeding, a great number of seedable clouds would go by without an attempt being made to tap their rain potential. Faced with these facts scientists began searching for a seeding agent to match the needs as closely as possible. Almost every cloud-seeding agent with potential was tried, and new ones are being discovered and tested all along (see Figure 3 in Appendix C). A representative group of the various cloud-seeding agents are subsequently described in rudimentary fashion.

Silver Iodide

The search for a more practical cloud-seeding agent led to the discovery by Vonnegut (1947) of the silver iodide method of supplying ice-crystal nuclei to clouds. It was found by Vonnegut and others that, when heated, silver iodide would vaporize and, upon cooling, small solid particles of about 0.01 to 0.1 micron in size were formed. After some years of doubt as to just how silver iodide works to produce ice crystals in supercooled clouds, scientists now offer evidence that a film of water about 5 molecules thick first forms on the crystalline faces of the silver iodide particles and freezes; thereafter, growth of the particles is by sublimation, collision, and coalescence.

Silver iodide could be heated at the surface and released into the air as smoke (see Figure 7) in locations thought to be right for seeding clouds; or, silver iodide smoke generators could be carried aloft in or affixed to aircraft for direct release beneath or in a portion of the cloud thought most likely to respond to seeding. The silver iodide smoke generators were relatively inexpensive, and most other criteria for a good cloud-seeding agent were met. There remained, however, two main objections to its being branded the ultimate in cloud-seeding agents: (1) silver iodide was not effective as a nucleating agent for clouds warmer than about 23°F, and (2) its decay rate (effectiveness loss rate) was about one exponential power for each hour of exposure to sunlight (Battan, 1962) while traveling from ground-based generators to clouds selected for seeding. The latter drawback considerably increased the odds against successfully initiating precipitation with ground-based silver iodide generators, because it many cases the particles of silver iodide must travel upward at an unknown rate of ascent to altitudes between 17,000 and 20,000 feet before arriving at the 23°F level where they can begin to be effective. Burley and Herrin (1962) have recently worked with silver iodide additives with indications of substantial reduction in decay rates.

Weickmann (1963) roughly estimates the changes of successfully making rain artificially by supplying freezing nuclei to supercooled continuous-precipitation producing clouds in this way: only 1 in 10 rain events is seedable; only 1 in 10 of the preceding will be in that certain right location; only 1 in 10 of the preceding will occur at that certain right time; and, only on 1 in 10 will the seeding material act as it is supposed to. The combined probabilities result in a 1:10,000 chance of making rain artificially from continuous-precipitation producing clouds.

Chlorosulphonic Acid and Sulphur Trioxide Mixture (FS)

Weickmann has worked out a technique for releasing a mixture of 55 percent SO_3 and 45 percent $ClSO_3H$ (FS) resulting in a smoke consisting mainly of a great number of tiny droplets of H_2SO_4 (sulphuric acid), which do not require foreign nuclei because of homogeneous nucleation. Reaction to use of this material is hygrophilic, and 110 gallons will absorb enough water to evaporate a cube 205 meters on a side from a cloud with water content of 0.1 grams per cubic meter. Professor A. Goetz, California Institute of Technology, Pasadena, California, by penetrating the large haze cloud remaining 15 to 20 minutes after seeding with this mixture, supplied data that permitted the computation that seeding with 0.5 gallons per minute would increase the concentration of condensation nuclei in shower clouds to 250 per cc per km^3. It has been computed by Weickmann that a droplet concentration of 200 per cc would effectively decrease the efficiency of the coalescence process.

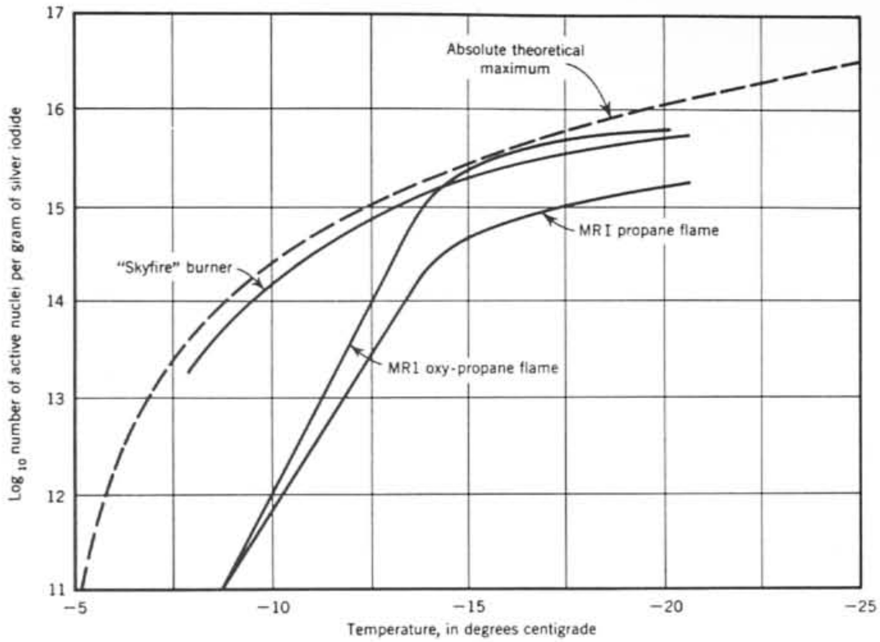


Figure 7

Activity Curves for Experimental Silver Iodide Generators

After R. A. Schleusener, 1964, Weather Modification: Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, v. 90, no. HY1, pt. 1, January, p. 62.

Carbon Black

Experiments with carbon as the seeding agent are generally directed toward decreasing the albedo, or for absorption of radiant energy, upsetting the atmospheric radiation budget to dissipate clouds. Russian scientists are reported to have successfully sprinkled snow surfaces with carbon. Korb and Moller (1962) found that clouds composed of pure water droplets mixed with pure soot particles have the best sunlight absorption characteristics.

Water

The sudden release or spraying of hundreds of gallons of water into warm clouds was demonstrated by University of Chicago scientists and by an Australian group to be effective in initiating rain. In the test performed on tropical cumuli near Puerto Rico, the Chicago group observed nearly twice as many rain echoes (by radar) in clouds seeded with water as were visible in clouds not seeded; furthermore, the echoes in the water-seeded clouds developed in about half the time required for the echoes to develop in similar unseeded clouds nearby (Battan, 1962).

Phloroglucinol

Phloroglucinol [$C_6H_3(OH)_3$], abbreviated PHL in this publication, is an ice-crystal nuclei producing organic substance that was laboratory tested by G. Langer and J. Rosinski at Armour Research Foundation in Chicago and reported on in 1962. It was found that PHL repeatedly caused rapid nucleation in a laboratory cold box at 26 to 28°F, compared with about 23°F for silver iodide. If producing ice crystals in super-cooled water at temperatures just below freezing (23°F) was indeed a major requirement for artificially making precipitation, then surely the key to success had been found if PHL would perform in the field as it had in the laboratory.

PHL was subjected to field tests in December 1962 and January 1963 by a team of investigators headed by Dr. Roscoe R. Braham, Jr. of the University of Chicago, Department of Geophysical Sciences, then working under a national Science Foundation grant on Project Whitetop. The field facilities of Project Whitetop, including the instrumented aircraft, were utilized in the tests.

The four PHL preparations used in the twelve PHL seedings were:

1. Dry powder as received from the manufacturer;

2. Dry powder ball-milled and mixed with Cabosil;

3. The original dry powder dissolved in alcohol--both methanol and isopropynol; and,

4. Water slurry of the original dry powder.

Releases were made directly into the airstream and in most cases in the upper 100 feet of the cloud. The alcohol solutions gave the best results. Based on these field experiments Braham (1963b) concludes that under favorable conditions PHL will induce ice crystals in undercooled (supercooled) clouds, but PHL is not nearly as effective as dry ice for this purpose. The field experiments appeared to stand in marked contrast with the laboratory findings of Langer and Rosinski principally in that PHL materials nucleated rapidly in the laboratory cold box at 26 to 28°F, while the first visual indications of nucleation in the field occurred 12 minutes after seeding with the unmilled dry powder--20 to 40 minutes after seeding with alcohol solutions.

Metaldehyde

Metaldehyde $(CH_3CHO)_4$, abbreviated MET in this publication, like PHL, is an ice-crystal nuclei producing organic substance uncovered in the search for a cheaper, practical, or more effective nucleating agent to substitute for dry ice and silver iodide. Laboratory testing of MET was reported on in August 1963 by N. Fukuta while on leave from the Chemistry Department, Nagoya University, Japan, then on fellowship with the Commonwealth Scientific and Industrial Research Organization (CSIRO), Sydney, Australia.

Fukuta proposed that MET be seriously considered for use in cloud-seeding operations because of its economy and efficiency at temperatures where natural ice-crystal nuclei are rare. Laboratory tests indicate that a large percentage of prepared crushed MET crystals nucleated ice at 28°F compared with 25°F for ground silver iodide using the same method; and, to offset the known decaying characteristics of silver iodide when exposed to sunlight, it was observed that ground particles of MET placed on a tray in sunlight for 2 hours at 28°F showed no significant change in ability to nucleate, and that as long as the nuclei were kept under 91°F for less than 2 hours the activity of MET at 28°F remained unchanged.

Dispensing Techniques and Equipment

Some techniques for dispensing cloud-seeding agents are born of necessity such as the techniques used with dry ice. There simply is no tested method for dispensing dry ice that does not require an aircraft and personnel to drop the crushed material into clouds from aloft. Because the life of dry ice is temperature dependent, it must be kept in an insulated container to prevent its evaporation before use. Dry ice is usually crushed into cubes ranging in size downward from about half an inch, because if much larger cubes are used they will fall completely through many stratus-type clouds before contributing all of their cooling effects.

Airborne Techniques

Necessity also requires the same type equipment, such as aircraft, personnel, and containers in which to carry the seeding material, be used for seeding clouds with water and solutions as is required for dry ice. Water and solutions are sprayed or dumped directly into clouds, metered in whatever amounts and over whatever flight tracks the particular experiment requires. However, with silver iodide choice, not necessity, motivates the experimenter to dispense the material via airborne equipment. Many believe it to be essential to use airborne methods to hand place silver iodide in or under clouds where it is calculated to do the most good, minimizing the known decay characteristics and at the same time insuring that "live" silver iodide crystals have a most favorable below-freezing temperature environment for nucleation and ice-crystal formation. Others like Wickmann (1963) have suggested that freezing nuclei be introduced at the base of clouds with the intent that they be used as condensation nuclei around which liquid droplets would be formed to be carried aloft in cloud updrafts, setting the stage for more of the larger droplets to freeze after being carried aloft through the freezing level. Weickmann reasoned that the then larger soft hail particles could more efficiently sweep out the water content of the cloud due to their greater fall velocity. He postulated that introducing freezing nuclei into the supercooled part of the cloud serves only to increase the number of useless small ice crystals at a level where the trigger particles for precipitation should already be the size of drizzle droplets--large enough to begin the collision-coalescence process.

Aircraft have been used, also, for spreading carbon black to cause decreases in natural albedo and imbalances in the atmospheric radiation budget.

Silver Iodide Generators

Ground-based cloud-seeding equipment has been employed mainly to dispense silver iodide crystals, although comparatively unsuccessful and inconclusive tests have been conducted in the United States and abroad using ground-based equipment with various dusts, salt particles, and so on. Silver iodide, when heated sufficiently and dissolved in a solution of potassium or sodium iodide and acetone, will vaporize forming very fine smoke-like particles that under favorable conditions can be carried aloft into clouds by turbulent diffusion (Byers, 1959). Several methods of vaporizing silver iodide have been developed and used successfully (see Figure 7). The piece of equipment that does the work is commonly termed a generator. Not all silver iodide generators are designed to be ground-based. When experimenters wish to dispense silver iodide particles directly into, underneath, or upwind from clouds marked for seeding, aircraft equipment with special silver iodide generators can be used.

Airborne Silver Iodide Generators

U. S. Forest Service (USFS) silver iodide generators (Advisory Committee On Weather Control, 1957, p. 148) were mounted on each side of the wing of an aircraft used by Meteorology Research, Inc. in recent Arizona experiments conducted under a Department of Defense, U. S. Army contract. Each generator consumed about 4 gallons of silver iodide solution per hour. It burns a solution of silver iodide in acetone, ignited by a spark plug in the burning compartment, and burns as long as solution is fed to the compartment. While burning, 6 to 12 inch flames shoot out of the rear of the burner vaporizing the silver iodide, which later condenses and forms the high number of silver iodide crystals necessary for successful cloud modification.

In other recent Arizona experiments, the Institute of Atmospheric Physics group used an airborne generator manufactured by CSIRO in Australia, which burned a silver iodide and acetone solution. The University of Chicago group working on Project Whitetop used three seeder airplanes burning a solution of 10 percent silver iodide (by weight) complexed with sodium iodide in acetone. An earlier airborne generator mounted in a USFS aircraft burned sash cord impregnated with silver iodide in an oxypropane flame to produce silver iodide nuclei. Another early, very simple and inexpensive technique that was at that time quite satisfactory involved impregnating chunks of charcoal with silver iodide, igniting them, and dropping them from a moving aircraft to leave a trail of silver iodide smoke as they fell.

Pyrotechnic silver iodide generators were used to seed Hurricane Beulah (Simpson and Malkus, 1963) on the 23rd and 24th of August 1963 during Project Stormfury, a joint program of the U. S. Weather Bureau and the U. S. Navy. These generators were developed by Pierre St. Amand of the Naval Ordnance Testing Station, China Lake, California, and were dropped from 35,000 feet along a radial path extending from 15 to 35 miles from the storm center. A vertical sheet of silver iodide 20,000 feet in depth ostensibly was proved by the pyrotechnic generators, to be swept around by the strong winds.

Ground-Based Silver Iodide Generators

Ground-based, like airborne, silver iodide generators burn silver iodide dissolved in a solution of potassium or sodium iodide and acetone. The technique of charcoal impregnated with silver iodide was used in the combustion chambers of early ground-based generators fed from a hopper. The silver iodide smoke thus produced was forced out by a stream of air from a blower. From that simple early process, through experiments with fireworks and railroad flares and through the silver iodide impregnated cords burned with propane, emerged the popular Hypodermic Type Acetone Burning Silver Iodide Generator (Advisory Committee on Weather Control, 1957, p. 148) in common use today. The silver iodide and acetone solution is released through a hypodermic needle into a jet of propane. The mixture is burned in a flame-holder, and will operate 8 hours on 1 filling.

Use of Rockets

Ground-based rockets are being used as a vehicle for transporting both seeding materials and explosives aloft for cloud modification with a view to increasing rainfall, suppressing hail, and ameliorating the devastating effects of hail. Regarding the latter, Battan (1962) describes the rockets used by farmers in northern Italy and reports on the remarks of Ottavio Vittori, an Italian scientist, regarding the use of these rockets. The rockets are loaded with nearly 2 pounds of gunpowder, and are capable of reaching nearly 5,000 feet altitude. When questioned, farmers using them (during the 1959 hail season more than 100,000 were used) reported that minutes after firing them hailstones in the vicinity of the rocket stand were mushy instead of hard. Vittori's ideas about what happens to make hailstones mushy, rendering them less harmful to growing trees and other plants, have been questioned by some scientists. He speculated that explosion of the rocket heads might produce a pressure wave in hail clouds capable of causing many cracks in the ice (hard hailstones). Perhaps not, but 100,000 rockets fired in one hail season represents a lot of user confidence. Because of the importance of the matter, the investigation continues.

Great numbers of rockets bearing cloud-seeding agents are used each year by farmers in other parts of the world. Do-it-yourself cloud seeders in southwest Africa (Water Information Center, Inc., 1963) reportedly bought over 8,000 cloud-seeding rockets at $15.40 each for firing into clouds passing over farm lands.

During the American Meteorological Society's Third Conference on Severe Local Storms at The University of Illinois in November 1963, Dr. Hans G. Muller (director of the Institute of Atmospheric Physics, Aviation Research Institute Munich) delivered a paper and showed slides on hail suppression experiments in the Rosenheim district of Bavaria. Stationary and mobile ground-based rockets loaded with cloud-seeding agents were fired into heavy cumulus clouds in the hail path along the northern slope of the Alps. Dr. Muller reported to the author that the hail suppression experiments have been moderately successful to date, and experimentation will continue.

Hail Suppression

Without belaboring the point of how the following facts were developed, opinions formed, and conclusions reached, suffice it to say the consensus of the most experienced and learned investigators in the field of hail suppression indicates:

1. The longer lived the hail-producing clouds, the better the chance hailstones will grow to damaging size; therefore any successful effort to shorten the life of these clouds will result in decreasing their hail-damage potential.

2. The collision-coalescence process is very important in developing the hail potential in convective clouds.

3. The collision-coalescence process is hindered by overseeding.

4. If supercooled water droplets in a hail-potential cloud could be eliminated completely no hail would form.

5. Hail-suppression field experiments conducted to date have produced inconclusive results.

The droplet concentration and the ice-crystal concentration required to decrease effectively the efficiency of the coalescence process in convective clouds has been calculated by Weickmann (1963) to be 200 per cc and 1 per cc, respectively. Considering a stationary hailstorm and moist layer 2 km thick, the storm will entrain air from a radius of about 50 km. It was computed that the flux of air through a storm in 1 hour and 30 minutes was 27,000 km^3. Reducing this amount of air to cm^3 and considering other known parameters, one can calculate the tremendous amount of seeding material required to inhibit coalescence (and ultimately the growth of hailstones) if 1 ice crystal per cc is to be artificially produced. Using Weickmann's tables for hailstorms, to produce an ice-crystal concentration of 1,000 per liter at 14°F, 14.7 kilograms of silver iodide or 1,650 kilograms of dry ice would have to be dispensed per minute.

Battan (1962) made calculations using dimensions and figures that usually can be expected to apply to a reasonably representative hailstorm about 2 miles in diameter. His figures indicate that when applying a given set of reasonable conditions to this cloud, silver iodide would have to be dispensed at a rate of 440 pounds every 10 minutes to be effective, supplying 1 nucleus for each drop. Silver iodide costs about $12 per pound; adding other costs--seeding equipment, personnel, and so on--would at least double the expenses. A 1-hour seeding attempt for hail suppression would cost at least $60,000.

Although no one is known to have yet seeded a potential hailstorm with such massive quantities of silver iodide, $60,000 an hour may not be too high a price to pay for testing the theories Battan's and Weickmann's figures represent and to learn more about hailstorms. If these massive overseeding schemes are proved workable, there may be some situations in which the operational expenditure is economically feasible: For instance, a 1-hour hailstorm can ruin a million dollar Trans-Pecos or High Plains cotton crop, and some believe hailstorms to be the reason for the decline in tomato growing in east Texas, while wheat crops take an annual hail beating throughout the High Plains.

LEGAL ASPECTS--THE NEED FOR REGULATING EXPERIMENTS

Unregulated or uncontrolled and haphazard experiments in weather modification or tampering with nature in any way leads inevitably to criticism, censure, lawsuits, or reprisals. Laymen are always worried about upsetting the balance of nature, or perhaps more realistically, being deprived of their just shares of whatever nature has to offer. To the serious investigator who might better understand the imbalances in nature, the real tragedy of unregulated experimentation lies in either hampering important scientific experiments of far-reaching economic importance, on the other hand, or an outstandingly significant breakthrough might be stumbled upon but not recognized by an undisciplined experimenter.

Less apprehension about being deprived of rightful natural rain might be expressed by the public if the facts uncovered by meteorologists and other scientists were understood:

1. The amount of precipitation is limited by the large-scale horizontal transport of water vapor into the area (Houghton, 1951).

2. Scientists agree that frontal systems as such do not ordinarily bring moisture into the area--the moisture is either not already there as a result of (1) above, in which case the front is sometimes termed a "dry" front, or the moisture is already there as a result of (1) above, in which case precipitation occurs along the front as it "lifts" the moist resident air and the front may be termed "wet."

3. At any point as a storm passes through, there is probably not more than half of 1 percent of the total amount of water in the air as a result of (1) above that is ever precipitated.

4. Because artificially introduced freezing nuclei operate best in a segment of the cloud where the temperature is too warm to be affected by the majority or natural freezing nuclei (Appendix C, Figure 3), it is postulated that any downwind area would not have naturally received the precipitation removed from that segment of the cloud by any upwind artificial freezing nuclei seeding operations.

On the other side of the coin, the effects of seeding clouds with freezing nuclei (other than dry ice, which falls and evaporates) may extend downwind from the seeding operation, and may act to cause artificially some downwind clouds to precipitate when they would not have precipitated naturally or cause some to precipitate earlier than they would have precipitated naturally. In a National Science Foundation Report (1962), a RAND Corporation study group stated, "Any attempted modification of the weather, consisting as it does with atmospheric interactions, may produce an unsuspected, uncontrollable, irreversible, or deleterious effect on the environment. But such a result is only a remote possibility because of the atmosphere's ability to damp out abnormal perturbations that are out of phase with its natural modes of oscillation." Armed with the knowledge of this possibility, though remote, experimenters are hesitant to conduct field investigations in weather modification unless they know that they are "on the side of the law," and land and property owners have a right to redress should they suffer damages resulting from weather modification operations. Some sort of legal protection for both property owner and researcher seems necessary.

Federal Regulation of Weather Modification Experiments

Federal weather modification laws were proposed during, indeed may have been the main purpose of, the Joint Hearings conducted in March and April 1951. Other proposals for federal regulation of weather modification have been made perennially. On October 3, 1963, H. R. 8708 was introduced in The House of Representatives (Appendix G). The bill proposes to prohibit dropping or ejecting any matter from an aircraft in flight in air commerce over any state for the purpose of affecting the weather, unless the consent has been obtained from the occupants of all lands underlying the place where such matter is ejected or dropped and the trajectory followed by such matter after being ejected or dropped. The bill was referred to the Committee on Interstate and Foreign Commerce. The report of the committee on Cloud Physics, American Meteorological Society, indicated the committee members considered H. R. 8708 (see Appendix G) not to be in the interest of the welfare of the United States because it would prevent the use of aircraft to dissipate fog and stratus over airports, and it would serve to inhibit the actions of scientists in their efforts to develop useful weather modification techniques and prevent them from carrying out essential cloud physics research. Additionally, cloud seeding from ground generators results in spreading materials over large areas in a manner similar to that resulting from seeding materials dispensed from aircraft. They reason that it is inconsistent to permit one type of seeding and not the other. The bill is now pending before the committee on Interstate and Foreign Commerce.

Many close to the subject feel today as does Edward A. Morris, an attorney and president of the Weather Control Research Association, Sacramento, California, who says (personal communication),

> "Over the past few years I have given a great deal of study to the science of cloud seeding. Also, as an attorney, I have studied the problems of legislation concerning this activity. My personal conclusion is that this is a field which should properly be dealt with on the Federal level rather than to have fifty states drafting a different set of laws. The very nature of cloud seeding is that it is not always easy to prevent the effects of seeding from crossing state lines. I believe that at the present time both the Department of Commerce and the National Science Foundation are giving some consideration to this very matter, and for that reason I am sending them a copy of this letter."

Mr. Morris' remarks in the same letter concerning state legislation on weather modification are enumerated later.

The consequences of experimenting in weather modification may be lessened somewhat by the control over operations of this nature indirectly exercised by the federal government in the system employed to approve requests for grants and award contracts in the field of weather modification. If a grant of funds is made, by the National Science Foundation for instance, or if a contract is awarded, possibly by a Department of Defense agency, it appears certain that a comprehensive project plan and statement of objectives would be a National Science Foundation requirement of any research organization requesting a grant, or same would be furnished to the Department of Defense if a contract was being awarded by them. It seems reasonable to assume federal funds would not be released to back any research effort tainted by unresolved questions of legality, rights, or liability. Because the National Science Foundation and agencies of the Department of Defense are the main sources of grants and contracts approved for comprehensive weather modification projects not being conducted by the agencies themselves (see Table 3), withholding their funds in questionable cases is in effect a measure of control that is undoubtedly real and serves to decrease the vulnerability of those conducting the experiments. There also may be some hesitancy on the part of the general public with respect to operations sanctioned by the federal government to hold participating individuals responsible. Most feel that the federal government employs the best scientists and uses the best equipment when funding and conducting valuable experiments that may have far-reaching economic benefits to the Nation.

One example of the method used by the federal government to excercise a measure of control over weather modification experiments, even though no specific legislation authorizes direct control, is contained in a November 1964 news release by the U. S. Department of the Interior. Appendix H is a copy of the text of the news release. In this news release it is announced that the U. S. Bureau of Reclamation has awarded three major contracts totaling $568,729 to expand its research and investigations into the potentialities of atmospheric water resources. These contracts were awarded to the Institute of Atmospheric Sciences at the South Dakota School of Mines and Technology, the University of Wyoming's Natural Resources Research Institute, and E. Bollay Associates, Inc., which will have its headquarters in Colorado.

Weather Modification Laws in Other States

Statute books on file at the Law School Library of The University of Texas were examined to determine which states currently have a weather modification or similar law. In most cases perusal of the statutes failed to disclose the exact degree and method of control exercised by the various agencies over weather modification operations. Rather, it was left up to the agencies to prescribe regulations, draft and issue permit and license forms, and approve the qualifications of licensees. To clarify these procedural questions, the Texas Water Commission has requested each weather modification agency in the several affected states to supply samples of application and permit forms, copies of procedures for administering the act, and any other pertinent data. This information will be kept on file at the Texas Water Commission and available for review in its offices. For an abbreviated analysis of weather modification laws in other states see Table 2.

Table 2.--Features of weather modification laws in other states

State	Statute	Requirements*	Remarks
Arizona	SB 46, 20th Legislature	L, O, P, Q, R	
California	Ch. 4, Div. 1, Water Code	L, N, P, Q, R	Reasonable evidence of financial responsibility required.
Idaho	22-3201-2, 1957 Code	R	Registration required.
Louisiana	Act No. 350, 1956	F, L, Q, R	
Massachusetts	Ch. 6, Sect. 72, General Laws	C, N, P, R	
Nevada	Ch. 332 8c 349, Nevada Compiled Laws	F, L, N, P, Q, R	Federal, State, Counties contribute or appropriate monies for a research program.
Oregon	Ch. 558, ORS	F, L, N, P, Q, R	
South Dakota	Ch. 449, 1957 Session Laws	F, L, P, Q, R	Sovereign right to moisture above State is declared. State funds appriated for research.
Utah	Ch. 129, Session Laws of 1953	P, R	Advance notice to Univ. of Utah required.
Wisconsin	Ch. 195.40, Public Service Commission	P, R	Registration required.

* Requirements column:

C - Certificate issued allowing operations.
F - Financial responsibility of operator required.
L - License required to conduct operations.
N - Public notice required before conducting operations.
O - Home-use by landowners authorized.
P - Penalty provided for conducting operations outside the law.
Q - Licensee qualifications taken into account.
R - Reports required on operations.

Table 3.--Federal-funded weather modification programs in Fiscal Year 1962*

Reporting agency	Number of projects	Amount
Agriculture	1	$ 119,000
Commerce	4	224,500
Army	4	375,561
Navy	3	370,000
Air Force	12	395,000
Advanced Research Projects Agency	12	1,605,000
Federal Aviation Agency	1	37,300
Interior	5	100,000
National Science Foundation	15	1,342,900
All Government Total	57	$4,569,261

* After National Science Foundation, 1962, p. 80-84.

Weather Modification Laws in Texas

Progress in weather modification operations is definitely not at a standstill in the United States (Table 3 and Figure 8), or in the remainder of the world for that matter, but is checked in Texas partly by the lack of established clear-cut legal precedent in weather modification cases in other states, partly by the lack of vast areas with suitable topography for orographic convective cloud seeding, and partly by the absence of federal or State regulations designed to both protect the landowners rights and to free the researchers from apprehension. It may be true that one crop loss could cripple a landowner, but one large liability settlement could also put a researcher out of business. Neither landowner nor researcher appears willing to risk the possible consequences for their actions in conducting programs aimed at attempting to modify the weather in Texas.

WHAT NOW?

Climate Control

Any successful control or significant alteration of the climate over vast areas of the earth would require harnessing entire ocean currents, melting large ice caps, upsetting the radiation budget balance, or in some way controlling the horizontal wind circulation patterns over millions of square miles. Perhaps more than any other single climate-influencing consideration, the Gulf of Mexico's wind-circulation pattern does the most toward governing the climate of Texas. Such undertakings would most certainly require international effort and agreement, because what seems to benefit one large area may be harmful to another.

The National Science Foundation's Fourth Annual Report on weather modification has this to say (1962, p. 8):

> "Engrossed in the immediate hope of controlling his weather, man must not neglect to find an approach to the modification of climate. In approaching climate modification he must start by admitting his ignorance of the causes of climatic change, whether brought about by natural means, by man's deliberate intervention, or inadvertently by human activity.
>
> "First, man is constantly faced with the possibility that a rather delicate climatic balance may be upset by events occurring naturally over a large area. For example, it is possible that a snowmelt season in Canada will be late and that some snow cover will remain when winter returns. If not offset in some way, a permanent Canadian snow cover may gradually build up, producing any number of major climatic changes. It is obvious that neither the knowledge nor the understanding is yet available to counteract such a potential catastrophe.
>
> "Second, although the desire to modify the climate exists, there has been no large-scale deliberate attempt,

and until meteorologists know much more (and understand what they know) about the results of deliberate interference, no such attempt can be said to be either safe or successful.

"Third, man must consider and try to understand the effects of inadvertent artificial modification. Today it is very difficult to separate that which is natural climatic modification from that which may be inadvertent artificial modification. We know, however, that as population increases, bodies of water are diverted, destroyed, or created; ground covers are changed over relatively wide areas; and the atmosphere is polluted at all levels by industrial effluents, by rocket exhausts, and by the activity involved in living in a highly technological society. We suspect that such events affect the weather or climate or both. But we cannot, either qualitatively or quantitatively, define these effects, or say whether they benefit man.

"The explanations of climatic variation that can currently be offered are, we conclude, characterized by a seriously incomplete understanding stemming from the current lack of knowledge of how the atmosphere interacts within itself and its boundaries."

Weather Modification

All that has been done with this young science is an outgrowth from Veraart's and Wigand's experiments with dry ice a mere 30-odd years ago. Tremendous progress has been made toward finding the key to successful weather modification--considering that a great depression, two major "hot" wars, and one "cold" war have retarded investigative efforts from time to time. However, work continues on all fronts:

1. The United States and at least 16 foreign countries are engaged in weather modification experiments;

2. Within the United States, at least 15 universities and institutions of higher learning are currently engaged in weather modification activities;

3. Some states have appropriated sums of money for currently active weather modification research programs conducted solely by themselves, in conjunction with local governments, institutions of higher learning, the federal government, or by contract with private commercial or research firms--supported with private funds and funds from local, state, or federal sources including NSF grants;

4. Commercial weather modification firms continue to be supported by the public; and,

5. That important consideration, the private individual either alone or in cooperative groups, continues to fire up his personal or leased "generator" or he sets off another rocket whenever likely-looking clouds drift by.

Senator Frank E. Moss of Utah, chairman of the Senate Subcommittee on Irrigation and Reclamation, has announced (National Reclamation Association,

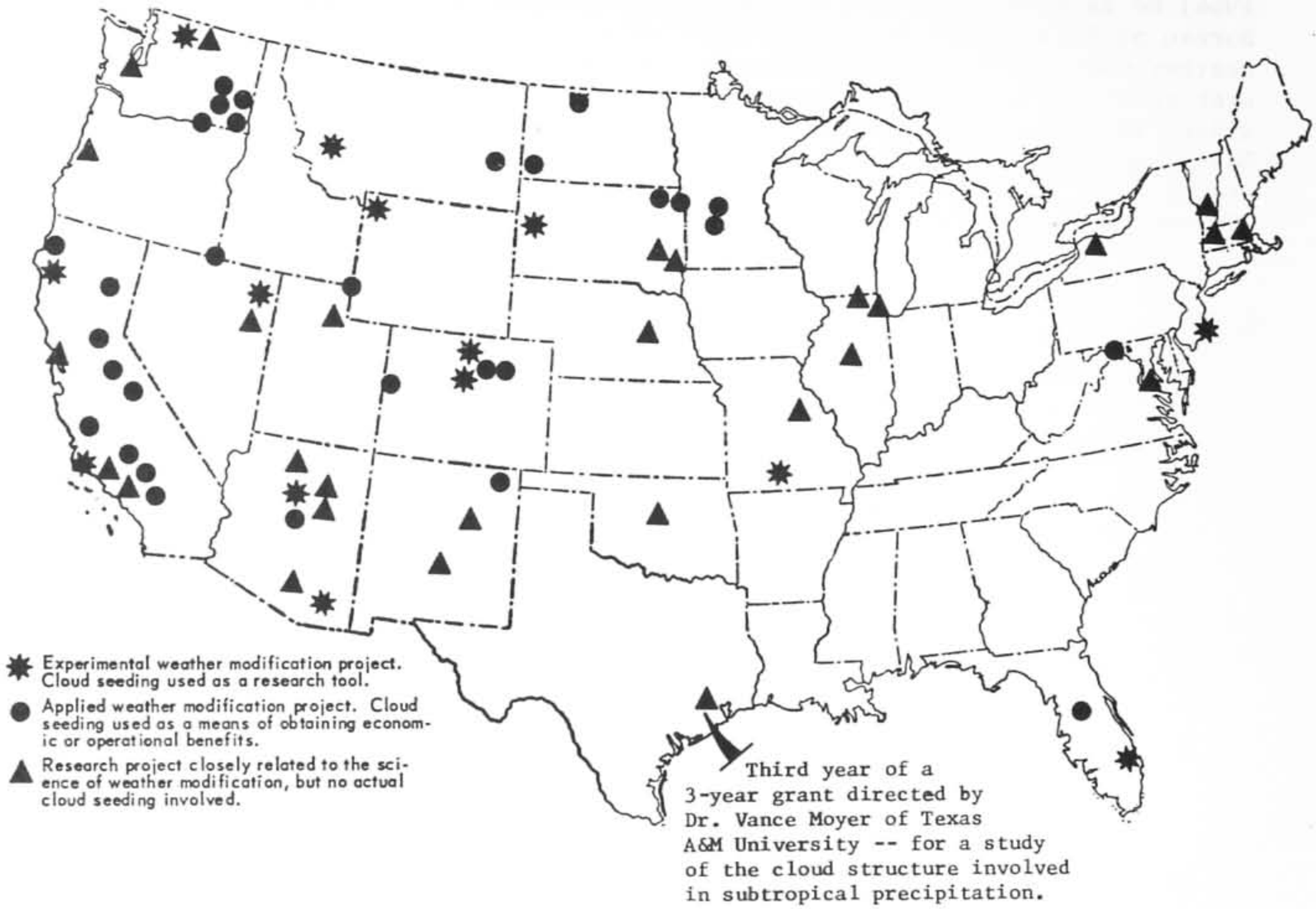


Figure 8

Weather Modification Projects in the United States, Fiscal Year 1962

Adapted from National Science Foundation, 1962, Weather Modification Projects in the United States--Fiscal Year 1962: Weather Modification, Fourth Annual Report, p. 74.

1964) he is requesting that $1,000,000 be written into the appropriation of the Bureau of Reclamation for Fiscal Year 1965 to conduct applied research on weather modification in the Colorado River Basin of the west. The desire for such research, he said, is prompted largely by the serious problems that have arisen in connection with the filling of reservoirs in the Upper Colorado River Basin, specifically in the states above Glen Canyon. Senator Moss further stated that "there has been estimated one extra inch of precipitation above Glen Canyon Dam would result in a runoff of 575,000 additional acre-feet."

A Barrier

One hindrance to continued weather modification experiments in Texas may be the researcher's knowledge that if he conducts field experiments he may be subjected to legal proceedings that might result in work stoppages (Southwest Reporter; 319 S. W. 2d 940; 320 S. W. 2d 211; and 327 S. W. 2d 417) or liability judgements, because clear-cut legal precedent has not been established. No federal law and no Texas statute (Southwest Reporter; 320 S. W. 2d 215) provides worry-free protection for either experimenter or plaintiff. Enumerated below are some points to be considered should Texas ever enact a weather modification statute--these points were supplied by E. A. Morris (personal communication, Nov. 4, 1963):

> "1. Notwithstanding some early statements of unbound enthusiasm, it now appears that the effects of cloud seeding are pretty much confined to that part of a cloud system which would be reached by part of the ordinary smoke from a fireplace chimney located at the same spot as the silver iodide ground based generator. Seeding from an airplane may give more flexibility in directing the seeding particles to the desired cloud.
>
> "2. Silver iodide does not make rain. It only makes snow. However, if, while the rain is falling, it passes through air which is warm enough to melt the snow, then, of course, precipitation in the form of rain actually lands on the ground.
>
> "3. In order for snow to form, the temperature must be below freezing. Actually, laboratory tests have shown that for silver iodide, and for most other inorganic artificial cloud seeding particles, a required temperature of between -5° Centigrade and -15° Centigrade [5 to 23°F] is necessary before ice crystals will start forming on these artificial particles.
>
> "4. Like an ordinary smoke plume, the artificial particles travel down wind until they climb to the necessary freezing temperature in a cloud.
>
> "5. As the plume goes further down wind before it reaches that freezing temperature, it diffuses so that there are fewer particles per volume of the cloud.

"6. If the plume thins out too much before reaching the freezing temperature, then there will be no effect on precipitation when those particles finally get into a cloud at the necessary temperature.

"7. Thus, it is necessary to know the direction and velocity of the winds and updrafts as well as the approximate location of the -5° Centigrade level during the periods of seeding.

"8. Accordingly, it would appear to be a sound requirement in your legislation that the seeding be done under the supervision of a competent meteorologist.

"9. Furthermore, so as to be able to have a means of checking where the seeding plume traveled, there should be a requirement that if adequate wind information is not available from existing weather stations within a reasonable distance of the seeding project, then the meteorologist in charge of the project must provide instruments in order to obtain such information.

"10. The Legislature, after thoroughly investigating this science, should come to the conclusion which was reached by the California Legislature when it enacted Section 400, which states that it is in the public interest that scientific experimentation in the field of cloud seeding be encouraged. I believe that after making such a determination the Legislature should have also advised the courts within the state that it has been officially determined that this activity is subject to sufficient control by the meteorologist in charge that it should not be labeled by the courts as an ultrahazardous activity or an activity which should be subject to 'liability without fault'.

"As far back as 1958, Dr. Vance Moyer of Texas A&M University expressed his concern over the lack of legislation which would afford reasonable protection to the public, while at the same time affording the necessary encouragement of research and scientitific progress in the field of weather modification. I agree with his observations, and feel that a statute should be drafted for Texas which takes into consideration the points I have discussed. As you will realize, the above outline deals primarily with cloud seeding for the purpose of increasing precipitation. I should think that the theory of hail suppression should also be outlined for the Legislature.

"Enclosed for your consideration is a copy of the California Water Code pertaining to cloud seeding. Personally, I feel that the requirement of Section 412, concerning a report as to the estimated gain or loss of precipitation due to seeding is not scientifically realistic. It is not always easy to prove the amount of change in precipitation produced by seeding. The problem is created because one can seldom state as a scientific certainty how much precipitation would have fallen from a given cloud had there been no seeding."

The situation may have been partly alleviated when a California court in early 1964 absolved a Santa Barbara Weather Consulting firm in a $13,000,000 damage suit involving 175 plaintiffs (Water Information Center, Inc., 1964). The court ruled that the accused weather consulting firm did not cause the huge 1955 flood in Sutter County, California. Increased cloud-seeding activities throughout the United States could result from this decision.

A Needed Experiment

A sort of "missing-link" cloud-seeding experiment is needed (see also Appendix E), and could be conducted in Texas after the minds of experimenters have been eased either by legislative enactment or by obtaining immunity-from-prosecution affidavits from landowners over whose land the operation is proposed to be conducted. This important gap that is not now being filled was suggested by MacCready (1963). The project would aim at maximizing precipitation over a given area, without regard to economics or statistical evaluation. This would be a large-scale physical study with a practical aim. In several years, after apparently reasonable seeding methods had been developed from our present research knowledge, one could begin considering how to do the seeding economically and how to evaluate it statistically. By then there would be something worth evaluating. In short, select an area and using present knowledge, seeding agents, and techniques: seed every cloud determined by the project meteorologist to be seedable; keep adequate records; and, at the end of the program have the results evaluated for statistical significance. An important contribution to science will then have been made. There will be unanswered questions about artificially maximizing precipitation in a given area as long as this experiment is not tried by someone.

CONCLUSIONS

Conclusions in the classic sense are inappropriate in this summary because only the results of basic research by others has been studied. However, such conclusions as can be drawn from reviewing the works of others in relation to Texas conditions are offered in the following paragraphs.

A seedable cloud must be provided by nature before dispensing seeding materials can have any possible effect--dispensing seeding materials does not make clouds in a cloudless sky. The determination of which clouds are seedable should be made by a qualified meteorologist. The results of all weather modification experiments should be evaluated by scientists and published in scientific media.

Isolated supercooled convective clouds have at times responded favorably to seeding by producing rain in some cases when rain would not have occurred naturally; in some other cases rain has been caused to fall earlier by seeding than would have been the case if the seeded cloud had been left alone. Selectively seeding supercooled clouds in special meteorological situations may cause more rain to fall from certain types of frontal clouds as the frontal system passes by than would have fallen naturally. The topography in Texas, when studied in relation to the prevailing moisture-laden winds, is such that significant increases in precipitation from orographically formed convective clouds cannot be dependably realized when using equipment and techniques already developed and tested. However, degrees of success will vary from producing heavy rain to outright dissipation of specially selected clouds of this type which form in summertime over the mountains in Trans-Pecos Texas.

A gap exists in weather modification experiments conducted to date, as no weather modification experiment covering a period of time sufficiently long to establish statistical significance has been conducted with the goal of determining if precipitation can be increased in a given area by seeding every seedable cloud forming or coming into the selected area. Such an experiment will have to be conducted eventually to establish whether the present state of the science of weather modification is at a level where cloud seeding on a routine basis is economically feasible.

A number of states have weather modification statutes in some form. Texas does not have a weather modification statute, and when the 88th Congress of the United States adjourned there was no federal Law regulating weather modification. However, the federal government does exercise a measure of control over weather modification experiments with its system of awarding contracts and grants, through the National Science Foundation and other federal agencies, to investigators, universities, and other research groups that are technically qualified to conduct such experiments. It seems reasonable to assume that no contracts or grants will be awarded by these federal agencies if there are unresolved legal questions.

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APPENDICES

Appendix A

Statement on Weather Modification

May 10, 1957

The Council of the American Meteorological Society has assumed the responsibility for issuing periodic statements on the scientific aspects of weather modification and control. Two previous statements were issued in 1951 and 1953. In view of the additional information on this subject that has become available in the interim the Council deems it desirable to issue a revised statement of its opinion at this time. The statement on weather modification approved by the Society's Council at a meeting on 29 April 1957 is as follows:

1. The seeding of supercooled cloud with dry ice will usually convert at least a portion of the cloud to ice crystals. Under appropriate conditions such seeding may release variable amounts of precipitation from fairly deep and active cumulus clouds in which the natural release of precipitation has not already started. Small, inactive cumulus clouds are usually dissipated when they are seeded with dry ice. Holes or valleys may be produced in supercooled layer clouds or supercooled fogs by seeding them with dry ice.

2. The injection of water drops or hygroscopic salt particles into active, warm (non-supercooled) cumulus clouds may release some rain. Small, inactive, warm cumulus may often be partially or completely dissipated by seeding them from above with water drops or other particles; such dissipation may occasionally be accompanied by the release of very light rain.

3. In some cases warm fog and stratus may be dissipated in restricted regions by the use of certain hygroscopic materials.

4. At temperatures below about −5C, silver iodide crystals are known to affect supercooled clouds in much the same way as dry ice. The frequent absence of clear-cut results following the operation of ground-based silver iodide generators is believed to be due to one or more of the following causes: *a*) the failure of the seeding material to reach the supercooled clouds, b) the absence of clouds that could be affected by seeding, *c*) the decay of the silver iodide, *d*) the presence of an ample supply of natural ice crystals, *e*) topographical influences which defy quantitative measurement.

5. Cloud seeding acts only to trigger the release of precipitation from existing clouds. The release of substantial amounts of precipitation by either natural or artificial means requires the preexistence of an extensive moisture supply in the form of moist air currents and of active cloud-forming processes. For this reason the meteorological conditions most favorable for the artificial release of precipitation are very much the same as those which usually lead to the natural release of precipitation. This factor plus the extreme natural variability of precipitation makes the evaluation of the effects of seeding difficult and often inconclusive.

6. Evaluations performed by independent agencies have yielded reasonably convincing evidence of increases of precipitation due to the operation of ground-based silver iodide generators only for operations conducted in cold weather in regions where forced lifting of the air over a mountain range is an important factor. No convincing evidence has been presented which indicates that ground-based silver iodide seeding affects the amount or character of the precipitation over flat country. This does not prove that there are no such effects but suggests that if present they are too small to be detected by statistical analyses of data available to this date.

7. In the absence of a truly quantitative theory of precipitation the best present means for obtaining a quantitative estimate of the effect of seeding on precipitation is through the statistical evaluation of randomized cloud-seeding experiments. The randomization is necessary to insure valid interpretation of the results and a long series of such experiments may be necessary to detect small effects.

8. Present knowledge of atmospheric processes offers no real basis for the belief that the weather or climate of a large portion of the country can be significantly modified by cloud seeding. It is not intended to rule out the possibility of large-scale modifications of the weather at some future time, but it is believed that, if possible at all, this will require methods that alter the large scale atmospheric circulations, possibly through changes in the radiation balance.

9. All cloud-seeding operations should be considered as experiments since the techniques are still under development and there is no sound basis for the quantitative estimation of the results in advance of the operation. As experiments they should be designed primarily to yield optimum scientific results. There is good reason to believe that improved returns from cloud seeding will result from a sound experimental approach and this should be fostered by all concerned.

The first Statement on Weather Modification was issued May 1, 1953.

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Statement on Implications of the Control of Weather and Climate

July 4, 1962

The prospect of controlling weather and climate has social and economic implications so far-reaching that it has been a subject of interest to laymen and scientists for many years. If disastrous windstorms and floods could be prevented, many lives would be saved and much misery avoided. If droughts, hailstorms, and lightning could be diverted, much economic benefit from the saving of crops and forest lands would accrue. Except for religious rites of primitive peoples and prayers of civilized man, the matter was little more than a topic of speculation until the last fifteen years.

Developments in recent years have suggested that limited control of weather and climate may be scientific possibilities. Among these developments are: (1) the demonstration that clouds can be modified artificially by seeding them with dry ice or silver iodide; and (2) the demonstration that physical laws governing atmospheric motions can be cast in mathematical form suitable for processing on high speed electronic computers, to predict the future state of the atmosphere.

The first of these developments was discussed in a Statement on Weather Modification, dated May 10, 1957. This statement pointed out that cloud seeding experiments have indicated that precipitation can be increased over local areas where specific conditions prevail (e.g., over some regions where forced lifting of air over mountains occurs), but that present knowledge of atmospheric processes offers no real hope for large scale changes of weather or climate by cloud seeding.

The second development, application of numerical methods of forecasting by means of high speed computers, together with use of model experiments in studying atmospheric processes, gives promise that it will some day become possible to predict with accuracy the short and long term effects of artificial interference with normal atmospheric processes. This ability to predict accurately what would happen in the absence of modification attempts, and what would happen if they are applied, is an essential prerequisite to any rational attempt at weather control.

While neither of these developments has answered the question whether or not man can control weather or modify climate, they are major steps in the chain of research results which have extended our capabilities for measuring and understanding the processes that produce weather and climate. Continuation of this research progress should lead to systematic unraveling of this formidable scientific problem.

The outcome, with respect to determining the practical and economic feasibility of weather control and climate modification, is likely to remain uncertain for some time to come. Balanced against these difficulties and uncertainties are two important considerations: (1) the tremendous economic and humanitarian advantages if a significant degree of control or modification turns out to be possible, and (2) the likely result that basic research studies required to answer this question will lead to improved accuracy in weather prediction and extension of the time period for which useful weather forecasts can be prepared. In short, the effort will almost certainly be justified by the results.

Two conclusions emerge from our analysis of this matter. The first is that the potential importance of the problem warrants a substantial effort of meteorological research, with a significant increase in the scientific manpower concerned with basic and applied research in the atmospheric sciences at the universities and in government and private research laboratories. The second is that the nature of the problem, its magnitude, and the possible consequences of success in achieving any significant mastery of the atmosphere, are compelling reasons for a cooperative international effort. In our view, this international character of the program should be established immediately, even though the outcome of man's attempt to control or modify his atmospheric environment is still in doubt.

We heartily endorse the resolution unanimously adopted in the United Nations on December 20, 1961, for a cooperative international effort to improve weather prediction and to explore the possibilities of weather control and climate modification. We pledge the resources of the American Meteorological Society in support of such international effort and urge that it be directed toward peaceful humanitarian purposes.

After American Meteorological Society, 1963, Statement on Implications of the Control of Weather and Climate, July 4, 1962: Bulletin of the American Meteorological Society, v. 44, no. 7, July, p. 447.

Appendix C

The Physical Basis of Cloud Modification

The atmosphere surrounding the earth is a mixture of gases, one of the most important being water in the gaseous state. This water gas, called water vapor by the meteorologist, is colorless and odorless. The ability of the air to contain water vapor in this invisible form depends primarily upon the temperature; warmer air can contain more than colder air. Imagine now that we have a parcel of air at a given temperature containing a certain amount of water vapor. If the temperature is progressively lowered, the air will become less and less able to contain all the water vapor and at some point a portion will condense into the liquid form as minute waterdroplets. When this occurs, we say that the air is saturated. In the atmosphere, these droplets form the clouds which we see.

The water droplets so formed are extremely small, their diameters ranging from one twenty-five thousandth of an inch to one one hundred twenty-fifth of an inch, and as a rule they are not heavy enough to fall out of the cloud as precipitation. Thus some other process than condensation must take place before waterdrops will be formed which are large enough to fall out of the cloud and reach the ground before evaporating.

In the 1930's, various precipitation theories were proposed setting forth processes by which the small cloud droplets could be made to grow or coalesce and thus produce waterdrops or snowflakes large enough to fall to the earth. The process considered to be the most active in the temperate and high latitudes calls for the coexistin the cloud of water in all three states: Gas, liquid, and solid. The theory states that since the vapor pressure over ice is less than that over water, the ice particles will grow at the expense of the waterdroplets, eventually reaching a size such that they will fall out as snow or, at warmer temperatures, as rain. This implies that all appreciable precipitation in these latitudes is initially formed at altitudes where the temperatures are below freezing, an implication which we now know is not always the case during the warmer seasons of the year.

The fact which opens up the possibility of modifying clouds, and thereby initiating rainfall or augmenting naturally formed rain, is that water vapor requires a nucleus of solid matter on which to condense or to freeze at temperatures warmer than −40° F. Furthermore, the nuclei on which water vapor will condense as a liquid droplet are different from the nuclei on which it will freeze as an ice crystal. The condensation nuclei are abundant in the atmosphere and any molecule of water vapor which has a mind to condense can easily find a nucleus and do so.

On the other hand, the freezing nuclei are much more complicated in their behavior. They refuse to serve as freezing nuclei until the temperature has fallen to some value considerably colder than the freezing point, depending upon the composition of the nucleus, but in the general vicinity of 5° F. or lower for most natural substances found in the atmosphere. Methods of measuring their numbers are crude and the data available are fragmentary but it appears that the number of these nuclei present near the surface of the earth does not vary radically from day to day. However, variations in the upper air can be as much as a thousandfold or more. Since their effectiveness as freezing nuclei is strongly temperature dependent, the number present at any given time must be related to the temperature at which the measurement was made. Thus statements as to the relative abundance or scarcity of these nuclei are completely meaningless unless a temperature is specified, a fact which has been frequently overlooked and may have been responsible for some of the confusion prevalent on this subject.

As a consequence of the above, the existence of subcooled waterdrops, i. e., liquid water at temperatures colder than freezing, is a common occurrence in all developing cloud systems which extend to a sufficiently high altitude. Cloud modification, as usually carried out, consists simply of using a substance which will be effective as a freezing nucleus at temperatures warmer than the naturally occurring nuclei (the warmer the better) and injecting it in minute particles into subcooled cloud systems by the trillions. If the cloud has not reached a sufficiently high altitude that the temperature has fallen to a point where the natural nuclei are effective, the artificial ones will serve to form the ice crystals necessary for the production of rain. The ability to initiate precipitation from a cloud system under these circumstances has been demonstrated frequently by a number of investigators, since the effect can be identified visually (fig. 1).

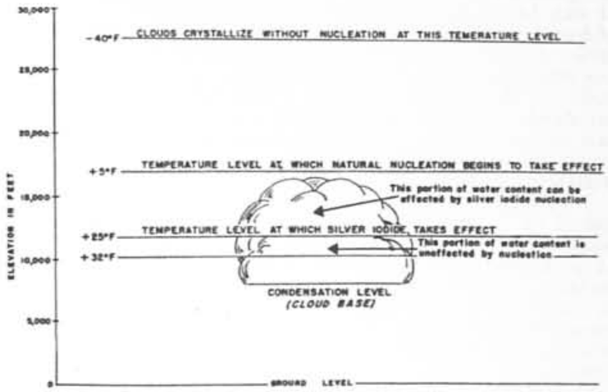

FIGURE 1.

However, if the cloud system has developed to an altitude where the temperatures are sufficiently cold for the natural nuclei to be effective, the artificial nuclei may contribute to the total precipitation which is produced (fig. 2). This effect cannot be identified visually or instrumentally; moreover the optimum number of nuclei necessary for maximum precipitation efficiency is a matter of conjecture. Lacking a satisfactory theory and being unable to predict precipitation amounts, it has been necessary to resort to statistical analysis whereby it has been concluded that, under certain favorable circumstances and locations, precipitation from seeded storms has indeed been increased. Unfortunately, this type of analysis does not tell us whether these increases are due to early initiation of precipitation, augmentation of naturally occurring precipitation, or both.

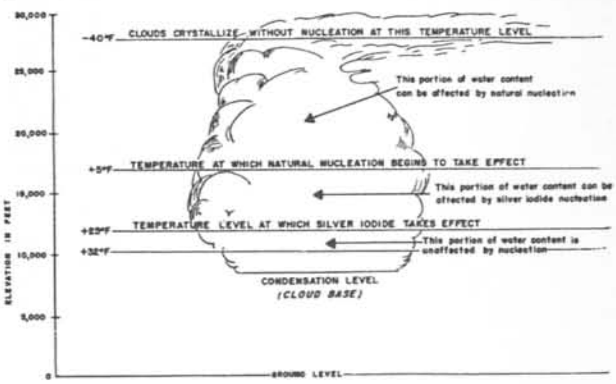

FIGURE 2.

It was mentioned above that a freezing nucleus is required for the formation of an ice crystal at temperatures warmer than −40° F. When a cloud is cooled below this temperature, the waterdroplets apparently freeze spontaneously, regardless of the presence or absence of freezing nuclei. This is the process which is involved when clouds are seeded with frozen CO_2, dry ice. The dry ice, due to its intense coldness, locally lowers the temperature below −40° F., thus producing ice crystals and modifying the cloud. However, this process is not feasible in large-scale cloud modification due to the necessity of using aircraft and the weight of the dry ice involved. This fact led to a search for a substance which would serve as a freezing nucleus at temperatures warmer than −40° F., and which could be released into the atmosphere from the ground in tremendous numbers as minuscule particles.

Such a substance, silver iodide, was identified by Vonnegut. It begins to be effective as a freezing nucleus at a temperature of 25° F., and becomes fully effective at 14° F. It can be vaporized cheaply and effectivey by a variety of burners (so-called generators) producing enormous quantities of crystals. Although there is some loss of nucleating effectiveness with time, in bright sunlight, the magnitude of this decay is small compared to the quantity involved. Thus it can be safely assumed that if the crystals are carried by the air currents up to the subcooled layers of a suitable cloud system, initiation and/or augmentation of precipitation should result.

Numerous other substances have been investigated and found to be effective as freezing nuclei at temperatures warmer than the natural nuclei. Very few are effective at as warm temperatures as silver iodide and these have certain difficulties, such as being soluble in water, difficult to manufacture and disperse, etc. Figure 3, reproduced from the final report of Project Cirrus shows the relative effectiveness of a number of substances as determined by Schaefer.

One major question is the relative frequency of occurrence of deep layers of subcooled waterdroplets in cloud systems. Such data as are available indicate that sometimes storm-cloud systems are composed entirely of ice crystals, sometimes of mixed ice and water particles, and sometimes there exists a deep layer of subcooled waterdroplets. The data are insufficient to give an idea as to the relative frequency of each condition, and hence a categorical answer to the question of how often, theoretically, can cloud modification be effective cannot be given.

It was mentioned above that the theory of rain formation, upon which most cloud-modification operations are based, required that rain in these latitudes be formed initially at altitudes where the temperature is well below freezing. However, a growing body of observational data and improved theory indicates that this is not always the case. In the tropics, along coasts in the middle latitudes, and even over continents in the summer, clouds which never reach the freezing level frequently produce appreciable rainfall. The most likely process which could form rain in these "warm" clouds requires the existence of waterdroplets of varying sizes and the resulting growth of the larger drops by collision with the smaller due to their different velocities of fall, called the condensation-coalescence process. In this process the largest drops will grow most rapidly due to their greater rate of fall and the fact that they "sweep out" a greater volume of cloud particles due to their greater cross section.

Seeding of warm clouds by means of a water spray from an aircraft has resulted in the early initiation of precipitation. Seeding with hygroscopic substances, such as ordinary salt, to accelerate the growth of a few cloud drops into the larger drops necessary for the formation of rain has been carried out with inconclusive results.

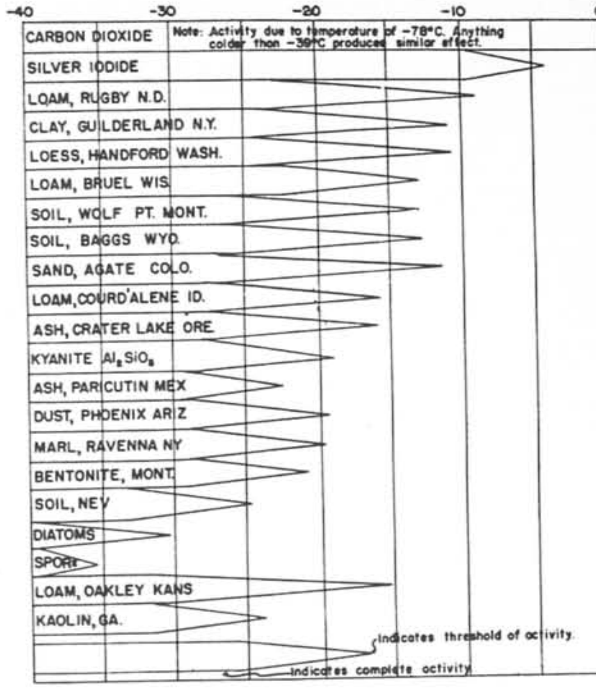

FIGURE 3.—*Temperature activity of foreign particles serving as nuclei for ice-crystal formation.*

The part played by atmospheric electricity in the precipitation process has not been satisfactorily established as yet. We do know that it does have a part but its relative importance is yet to be determined.

It is reasonable to assume that under most circumstances more than one mechanism is at work converting cloud droplets into raindrops. More specifically, in subcooled cloud systems some other processes probably are active simultaneously with the ice-crystal process. Lacking a comprehensive precipitation theory, it is impossible to isolate the effect of any one process and state categorically its relative contribution to the total rainfall. A great deal of intensive, coordinated research in cloud physics, both basic and applied, will be required before final answers can be given to these questions.

After Advisory Committee on Weather Control, 1957, The Physical Basis of Cloud Modification: Final Report of the Advisory Committee on Weather Control, v. II, p. 320-321.

Appendix D

Summary of Findings

A. On the basis of its statistical evaluation of wintertime cloud seeding using silver iodide as the seeding agent, the Committee concluded that:

(1) The statistical procedures employed indicated that the seeding of winter-type storm clouds in mountainous areas in western United States produced an average increase in precipitation of 10 to 15 percent from seeded storms with heavy odds that this increase was not the result of natural variations in the amount of rainfall.

(2) In nonmountainous areas, the same statistical procedures did not detect any increase in precipitation that could be attributed to cloud seeding. This does not mean that effects may not have been produced. The greater variability of rainfall patterns in nonmountainous areas made the techniques less sensitive for picking up small changes which might have occurred there than when applied to the mountainous regions.

(3) No evidence was found in the evaluation of any project which was intended to increase precipitation that cloud seeding had produced a detectable negative effect on precipitation.

(4) Available hail frequency data were completely inadequate for evaluation purposes and no conclusions as to the effectiveness of hail suppression projects could be reached.

B. On the basis of its physical evaluations, the Committee concluded that:

(1) The conventional seeding with silver iodide generators on the ground is a valid technique for producing ice crystals in favorable summer and winter storm situations. (Formation of ice crystals is thought to be essential for the initiation of precipitation from most cold clouds. However, it is relevant to observe that precipitation does not necessarily follow.)

(*a*) Measurements of silver iodide particle concentrations at points several miles distant from the generators were compared with the estimated concentrations there. On the basis of the limited tests made, it was found that the rate of deactivation was low enough to be of no great concern for practical seeding, even during the "adverse" decay conditions of bright sunlight and warm temperatures.

(*b*) Silver iodide particles in sufficient concentrations to produce seeding effects were found at distances up to 30 miles from the ground generators in particular tests.

(2) Measurements and cloud observations in various regions throughout the United States have indicated that sometimes there is a deficiency of natural ice forming particles effective at the temperatures at which ice crystals are formed on silver iodide.

After Advisory Committee on Weather Control, 1957, Summary on Committee's Findings and Recommendations, Summary of Findings: Final Report of the Advisory Committee on Weather Control, v. I, p. vi-vii.

Current and Future Research Problems

NSF-sponsored efforts are being directed among research areas such as the following:

1. *Further Cloud-Seeding Research.* We know the clouds can be modified by cloud seeding and by other means, particularly clouds of certain varieties and origins. Not only can rainfall be somewhat augmented and hail discouraged under certain conditions, but certain kinds of supercooled fog can be dissipated. The possibility for further development of cloud seeding as a weather modification tool should be investigated thoroughly under a variety of conditions, and under procedures where the effect of the cloud seeding can be accurately determined. In this way, we can learn the precise conditions under which cloud seeding is effective, and when it is not.
2. *Research on Controlling Evaporation.* Evaporative processes can be altered to some extent over water surfaces, and possibly over vegetation-covered land. Current research into such methods should be extended, and the effect on the hydrological cycle should be explored through theoretical, laboratory, and field work.
3. *Cloud Electrification.* It has been demonstrated that the electrical properties of cumulus clouds can be altered by artificially modifying the space charge in the lower part of the atmosphere. This technique is sufficiently promising to warrant further development. Its effect upon precipitation can then be explored.
4. *Hurricane Research.* Cloud-seeding experiments on hurricanes, carried out in projects sponsored jointly by NSF, the Weather Bureau, and the Navy, have shown tentatively that cloud seeding may tend to interrupt the smooth circular flow by which hurricanes maintain their intensity. An extension of the cooperative efforts is now being planned.

After National Science Foundation, 1962, A Look Ahead, Current and Future Research Problems: Weather Modification, Fourth Annual Report, p. 44-45.

General Conclusions

In his search for the understanding which he hopes will lead to control over the weather, man is severely limited. He is limited by his knowledge and by his resources. In addition he is limited by the fear that his experiments may engender unforeseen consequences.

Within these limits, there are many things that may be done. It could be argued that no special effort need be made, that the normal course of advancement in the field of meteorology will in time reveal the proper method for weather control. But such an approach may not only delay the achievement of useful control, but may also deny to the meteorological community the knowledge that could be gained through cautious experimentation. The program of weather-control research should be an integrai part of basic meteorological research, not a separate and esoteric study. We believe that a vigorous program of basic research directed toward the ultimate goal of weather control should be pursued. The program must be balanced; experimentation should not run ahead of theoretical developments but should not lag in providing the data necessary for testing reasonable hypotheses and raising new problems.

and further;

The final test of any hypothesis must be a field experiment, and field experiments that will yield significant results require painstaking planning. The field experiment can be no better than the planning which precedes it. If the hypotheses are not precisely stated, the initial and boundary conditions not properly defined and measured, or the statistical design not adequate to account for uncontrolled or unmeasurable variations, the experiment can neither confirm nor deny the initial hypothesis. We do not mean to imply that all field experiments must be complex and large, nor do we mean to imply that proper planning can guarantee definitive results, but the field experiment must be complete if there is to be any hope of verifying the hypothesis.

After National Science Foundation, 1962, A Rationale for Weather Control Research, Conclusions and Recommendations: Weather Modification, Fourth Annual Report, p. 32-33.

88th Congress
1st Session
H.R. 8708

In the House of Representatives

October 3, 1963

Mr. Whalley introduced the following bill; which was referred to the Committee on Interstate and Foreign Commerce

A bill

To amend the Federal Aviation Act of 1958 to prohibit the use of aircraft to carry out certain activities directed toward weather modification unless the occupants of the underlying lands consent thereto.

Be it enacted by the Senate and House of Representatives of the United States of America in Congress assembled, That title XI of the Federal Aviation Act of 1958 (49 U.S.C. 1501–1511) is amended by adding at the end thereof the following:

"USE OF AIRCRAFT FOR WEATHER MODIFICATION

"SEC. 1112. Except for the purpose of diverting or preventing a hurricane or tornado, no person shall eject or drop any matter from an aircraft in flight in air commerce over any State for the purpose of affecting the weather, unless such person has obtained consent therefor from the occupants of all lands underlying the place where such matter is ejected or dropped and the trajectory followed by such matter after being ejected or dropped."

SEC. 2. The portion of the table of contents contained in the first section of the Federal Aviation Act of 1958 which appears under the heading

"Title XI—Miscellaneous"

is amended by adding at the end thereof the following:

"Sec. 1112. Use of aircraft for weather modification."

SEC. 3. Section 901(a)(1) of the Federal Aviation Act of 1958 (49 U.S.C. 1471) is amended by inserting "or section 1112" immediately after "or XII."

Report of Committee on Cloud Physics, AMS

[This report was requested by the Executive Committee and has been accepted by the Council.]

It is the considered opinion of the Cloud Physics Committee, American Meteorological Society, that H.R. 8708 is not in the interest of the welfare of the United States.

It is our view that the prospect of a useful degree of control over some aspects of our natural environment is one of the most appealing of present day science. Although there are many unresolved questions as to the areas of applicability of present-day weather modification techniques, immense progress has been made in this subject, one which is inherently very difficult. The use of airplanes and airborne seeding is an indispensable part of this effort.

The proposed legislation would have two especially deleterious effects:

1) It would prevent the use of aircraft seeding to dissipate supercooled fog and stratus over airports. The clearing of airports may result in great economic savings, add materially to the safety of flight operations, and have important military application.

2) In order to carry out essential cloud physics and weather modification research and to develop useful weather modification techniques it is necessary to carry out some cloud seeding operations from aircraft. Since some of the seeding material may be carried for great distances and over unpredictable areas it would not be possible to contact and obtain permission from all occupants of the underlying lands. Hence this Bill, if enacted, would result in a complete cessation of aircraft seeding in the United States. In view of how little is known about weather and weather modification, American scientists should be expanding their efforts in these areas rather than having them restricted by legislative action.

Cloud seeding from ground generators results in spreading seeding materials over large areas in a manner similar to that resulting from materials dispensed from aircraft. It is not reasonable to permit one type of seeding and not the other.

To our knowledge there is no scientific proof that weather modification experiments have been harmful to anyone—either those occupants of land underlying cloud seeding experiments, or to those located remotely from the seeding sites.

The prevention or diversion of hurricanes and tornadoes as an applied skill is *not* presently possessed by anyone. Research on all phases of cloud physics and weather modification is necessary to reach that goal, if in fact it can be reached. This Bill would prevent, or seriously cripple, such research.

It is our view that it is the responsibility of the American Meteorological Society to use every possible means to establish bridges of understanding between the meteorological community and the general public. Only in this way will scientific research prosper and will the fruits of our research be passed along to the user public.

Herbert S. Appleman
Louis J. Battan
Roscoe R. Braham, Jr.
Robert M. Cunningham
Richard H. Douglas
Vincent J. Schaefer
Helmut K. Weickmann

For the Committee: Roscoe R. Braham, Jr.
Chairman

After United States Congress, 1964, 88th Congress, 1st Session, H. R. 8708, In the House of Representatives, October 3, 1963: Bulletin of the American Meteorological Society, v. 45, no. 2, Feb., p. 116.

UNITED STATES
DEPARTMENT OF THE INTERIOR

BUREAU OF RECLAMATION
For Release to PM's, NOVEMBER 11, 1964

DeWitt - 343-4662

THREE MAJOR CONTRACTS FOR RESEARCH ON ATMOSPHERIC WATER RESOURCES AWARDED BY RECLAMATION

Assistant Secretary of the Interior Kenneth Holum today announced the Bureau of Reclamation has awarded three major contracts totaling $568,729 to expand its research and investigations into the potentialities of atmospheric water resources.

Mr. Holum said the contracts were awarded to the Institute of Atmospheric Sciences at the South Dakota School of Mines and Technology, the University of Wyoming's Natural Resources Research Institute, and E. Bollay Associates, Inc., which will have its headquarters in Colorado.

Mr. Holum said the contracts "mark significant steps forward in our effort to assemble the finest scientific talent available for these investigations."

"Congress appropriated $1.1 million for Reclamation's expanded program in the field of atmospheric water resources for fiscal year 1965," he added. "Our aim is to move as expeditiously as possible, and in a truly scientific manner, to determine the possibilities and the future role of weather modification in our resource programs."

Commissioner of Reclamation Floyd E. Dominy expressed confidence that research and experiments under the contracts "will add greatly to the body of evidence supporting the growing conviction that man can influence the weather under certain conditions when sound engineering and scientific research techniques are applied to the problems."

Commissioner Dominy said that the objectives of the three contracts will be to conduct research into the possibility of developing beneficial weather modification procedures and techniques in the northern Great Plains area, to conduct atmospheric research leading to the development of snowpack augmentation procedures and techniques in Wyoming, and to perform research and scientific experiments over portions of the upper Colorado River drainage basin to determine the extent to which precipitation can be augmented in that region.

The northern Great Plains phase of the investigations will be under the contract with the Institute of Atmospheric Sciences at the South Dakota School of Mines and Technology in Rapid City. Dr. R. A. Schleusener was selected as director of the Institute by the College's President, F. L. Partlo, and has been appointed to this position by the Board of Regents. Dr. Schleusener is a recognized authority in the atmospheric sciences and has conducted outstanding work at Colorado State University under sponsorship of the National Science Foundation.

The second major contract is with the University of Wyoming's Natural Resources Research Institute under its director, Dr. John C. Bellamy. Dr. Bellamy is well known for his pioneering work in causing snow to fall from "cap" clouds, which form over high mountain peaks in certain areas. The Wyoming snowpack augmentation research will be undertaken by Dr. Bellamy's group.

The third contract is with E. Bollay Associates, Inc., a private meteorological organization with extensive experience in the atmospheric sciences. Eugene Bollay, president, has an international reputation in atmospheric research and is coauthor of a standard textbook on meteorology. The Bollay firm will conduct the precipitation experiments in the upper Colorado River drainage.

In addition to the investigations and research that will be inaugurated under these three contracts, activities are continuing under an existing Reclamation contract with the University of Nevada's Desert Research Institute at Reno. Dr. Wendell Mordy is institute director.

Commissioner Dominy said that an Office of Atmospheric Water Resources is being established in the Bureau to administer the contracts and to facilitate engineering research in the atmospheric sciences with the initial goal of determining the feasibility of increasing the water supply on Reclamation projects throughout the Western United States. The office will be at the Bureau's engineering center in Denver, Colo., under the direction of Chief Engineer B. P. Bellport.

Walter U. Garstka has been named by Commissioner Dominy as chief of the new office. Mr. Garstka, a career Reclamation engineer-scientist, was formerly chief of the Water Conservation Branch of the Bureau's Division of Research.

Archie M. Kahan, Commissioner Dominy said, will become the principal physical scientist for the program beginning February 1, 1965. Dr. Kahan is now executive director of the Research Institute at the University of Oklahoma. He was formerly head of the Research Foundation at Texas A&M, and received his doctorate in meteorology at that university.

Discussing other aspects of Reclamation's many-faceted program to unlock the secrets of atmospheric water resources, Commissioner Dominy said that negotiations are underway with other universities, interested Federal agencies, and private meteorologists for the purpose of establishing a thoroughly coordinated attack on the problem of augmenting precipitation to increase the water supply on Reclamation projects in the chronically water-short Western States.

In addition, Commissioner Dominy said, an advisory committee is being formed. It is to be composed of representatives of other Federal agencies and outstanding authorities in the atmospheric sciences. This committee, Commissioner Dominy added, will ensure the utilization of all existing competence in this important field.

P.N. 54824-64

INDEX

(Definitions are provided for selected terms.)

Collision-coalescence, or simply coalescence process. The process through which cloud particles go while growing in size. Cloud droplets collide and merge and ice crystals collide and stick together; p. 14.

Condense. Separate invisible water vapor from the air and make it visible as clouds by lifting, expanding, and cooling the moisture-laden air; p. 20.

Condensation-coalescence. p. 20, 21.

Condensation nuclei. Extremely minute solid particles around which water vapor condenses to form a cloud droplet; p. 14, 17, 19.

Convective (clouds). Clouds formed as a result of updrafts, without regard for what causes the updraft; p. 1, 10, 26, 27, 47.

Cooling condensation. p. 13.

Cry, G. W. p. 20.

Dessens, Henri. p. 11, 29.

Dissipate (clouds). Evaporate or vaporize visible cloud particles; p. 37, 53, 61.

Eaton, M. A. p. 27.

Echoes, or radar echoes. Cloud particles (or other matter) of sufficient mass and/or density to reflect ultra high frequency radar waves and return them to the radar for image-viewing on the oscilloscope; p. 32, 37.

Extratropical. Of tropical origin or nature, but no longer in the tropics or possessing tropical characteristics; p. 8.

Freezing nuclei. A nucleus around which supercooled water will readily freeze; p. 14.

Fukuta, N. p. 38, 46.

Generator. The apparatus in which silver iodide is vaporized by applying heat; p. 39, 40.

Glaciated, glaciation. Turned into ice crystals, as a cirrus cloud; p. 17.

Goetz, A. p. 35.

Houghton, H. G. p. 22, 42.

Herrin, D. W. p. 35.

Horizontal transport. Transported by the wind; p. 42.

Huschke, R. E. p. 6.

Hydrometeors. Rain, snow, drizzle, sleet, hail, etc.; p. 11.

Hygrophilic. Water sensitive--absorbs or collects water or water vapor; p. 19, 25.

Ice crystals. p. 14, 18, 33.

Insolation. Incoming solar radiation (heat from the sun); p. 20.

Joint Hearings. Weather Control and Augmented Potable Water Supply, JOINT HEARINGS, before Subcommittees of the Committees on Interior and Insular Affairs Interstate and Foreign Commerce and Agriculture and Forestry, United States Senate, Eighty-second Congress, First Session, on S. 5, S. 222, and S. 798, March 14, 15, 16, 19 and April 5, 1951; p. 4, 7, 8, 43.

Kassander, R. K., Jr. p. 22, 26.

Korb, G. p. 37.

Krick, I. P. p. 7, 10.

Landsberg, H. E. p. 17.

Langer, G. p. 37.

Langmuir, I. p. 21, 22.

Lifted air. Expanded and cooled air; p. 13.

Ludlam, F. H. p. 27.

MacCready, P. B., Jr. p. 5, 7, 10, 22, 26, 52.

Malkus, J. S. p. 4, 27, 40.

Mason, B. J. p. 16.

Mixed cloud. A cloud containing vapor, water, and ice; p. 14, 18, 19, 29.

Moller, F. p. 37.

Moore, C. B. p. 20.

Morris, E. A. p. 5, 43, 50.

Moyer, V. E. p. 5, 14, 20, 51.

Muller, H. p. 40.

National Science Foundation Fourth Annual Report, 1962. A report made by the NSF for the Fiscal Year ending June 30, 1962; required by the NSF Act of 1950, as amended by PL 85-510, July 1958. The Report is an 81 page chronology of NSF supported weather modification activities through June 30, 1962; p. 3, 26, 29, 42, 44, 47, 53.

Neuberger, H. H. p. 4

NSF. National Science Foundation; p. 3, 26, 29, 53.

Sublimation. Moisture going from vapor to solid (ice) state; or, from solid to vapor state, without going through the liquid state; p. 13, 17.

Supercooled. Water cooled to below freezing but not yet frozen. Called "undercooled" or "sub-freezing" by some scientists; p. 1, 14, 18.

Supersaturation. Relative humidity greater than 100 percent; p. 14, 18.

Thermal, or thermic updraft. Vertical air movement due to heating from below; p. 27.

Threshold temperature. p. 16, 64.

Todd, C. J. p. 22.

Veraart, A. W. Dutch scientist; p. 4, 34, 48.

Vittori, O. p. 40.

Vonnegut, B. p. 20, 34.

Wallis, W. A. p. 31.

Warm cloud. p. 14, 18.

Warm-cloud precipitation process. Condensation, collision, and coalescence of cloud droplets to form drops large enough to fall out of the cloud; p. 18, 19.

Water vapor. Invisible water in the air; p. 13, 20.

Weather modification. Any artificial alteration of natural weather elements; p. 4.

Weickmann, H. K. p. 11, 35, 38, 41.

Wells, H. J.

Wigand, A. Univ. of Hamburg Professor; p. 4, 34, 48.

Woodcock, A. H. p. 19.