PROSPECTS FOR WEATHER MODIFICATION

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Can man willfully change the weather around him? This question has puzzled man for centuries. If man could control the weather, he would be able to reduce some of the damages and consequent economic losses caused by hurricanes, lightning, hail, and fog and to benefit society by enhancing precipitation at the right time and place. There is much evidence that man can intentionally modify or possibly eliminate many types of weather hazards or will have the capabilities to do so in the near future.

HISTORY OF WEATHER MODIFICATION

The history of weather modification has gone through several eras. First was the mystical era. In the beginning, man tried to influence rainfall by hope and faith, magic and ritual. Many primitive societies have practiced some type of religious or ritualistic rainmaking. The ceremonies and rituals have varied from dowsing holy men with water to burying children up to their necks in the ground in hopes that God would be sympathetic and drop tears from the heavens. Witch doctors and medicine men in some societies continue to perform mystical rites in hopes of increasing rainfall.

In the 1800's it was observed that the use of explosives in some of the great battles, such as in the Civil War, caused significant rains. However, experiments in rainmaking based upon these theories proved inconclusive. Another belief focused around the possibility of increasing rainfall from convective currents caused by forest fires. An American meteorologist, James Espy, recommended that farmers burn brush and timber in dry weather to stimulate rainfall. Other early scientists suggested the use of extremely cold substances, such as liquid carbon dioxide or liquid air, which upon release into the atmosphere would result in condensation and precipitation. These early attempts were on a hit-or-miss basis with virtually no knowledge of the physical principles of precipitation.

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During the 1930's and 1940's, several important concepts or theories were developed regarding the precipitation process. In 1933, a Swedish meteorologist, Tor Bergeron, advanced the theory that rain in appreciable amounts could be released principally by the presence of ice crystals formed in or transported through water clouds. Five years later, a German physicist, Walter Findeisen, reconfirmed this discovery. This theory formed the basis of present day techniques of seeding supercooled clouds.

In 1946, two General Electric Company scientists, Vincent Schaefer and Irving Langmuir, discovered that dry ice caused the formation of ice crystals in miniature super-cooled clouds and thereby triggered the precipitation process. Shortly afterward, Bernard Vonnegut, a co-worker, demonstrated that smoke of silver iodide crystals would accomplish the same results.

The 1950's brought on the rainmaker era. During this era there were many operations in the western United States, and a few in the Midwest and East, which employed ground based silver iodide smoke generators for cloud seeding to attempt to increase precipitation. Unfortunately, few programs were used to evaluate the effectiveness of the seeding operations. Meanwhile, the drouth in many areas of the country and the claims of some of rainmakers and criticism within the scientific community prompted Congress to create a special committee to study weather control. In 1957, this committee reported on the state of the art at that time. It found that precipitation was probably increased 10 to 15 per cent by seeding storms during the winter and spring months in the mountainous areas, and supercooled stratus-type clouds (low hanging clouds) could sometimes be dissipated by seeding with aircraft. There was some theoretical basis at that time, but little experimental proof that lightning or hail could be surpressed.

In the 1960's, the scientific community became interested in the possibilities of weather modification. This was prompted partially by seeing the

dramatic effects of artificially modifying clouds. Also, two reports were released in 1966 which indicated increased scientific and governmental interest in weather modification, one by the National Science Foundation (12), and the other by the National Academy of Science (21). These two reports were optimistic about future weather modification.

During the past decade, significant changes occurred which created an attitude making possible a more rational and systematic exploration of the potential for weather modification. These changes were derived primarily from (1) formulation of more complete theories of the atmospheric processes, (2) the use of high speed digital computers to solve the complex mathematical formulas of the atmospheric processes, (3) the ability to measure and observe the atmosphere with radar techniques, meteorological satellites, and airplanes, plus many other advances in instrumentation, and (4) significant advances and statistical procedures for resolving questions of cause and effect relations and field experimentation.

PRESENT STATUS OF WEATHER MODIFICATION

To look at the present state of the art of weather modification, different scales ranging from small-scale to large-scale weather phenomena might be considered.

Micro-climate Alteration.

When one looks at the climate near the ground surrounding plants and animals, one is concerned mainly with preventing frost, suppressing evaporation, or reducing the effects of wind or temperature. The most important methods of influencing soil micro-climates are irrigation, drainage, mulching, soil tillage, and windbreaks.

Frost protection of plants can be performed by using several different methods. A popular method of frost protection is using a sprinkler irrigation system. Heat is released when ice forms around the leaves. The released heat reduces the possibility of the temperature becoming cool enough to freeze the leaf. Other methods of frost protection include the use of heaters or wind machines.

There are many ways to control snow movement due to wind. Vegetative cover, dead or alive, is one of the most effective and most economical controls of soil and snow movement. Windbreaks provide a formidable barrier to the wind. Other barriers are crops in narrow rows, snow fences, solid wood or stone fences, and earthen banks (20).

Fog Dissipation.

There are two types of fog: cold fog, where the water droplets are below 32 degrees Fahrenheit; and warm fog, where the water droplets are above 32 degrees Fahrenheit. Cold fog dispersal operations are based on the physical principles that super-cooled water droplets cannot remain liquid, but must be turned to solid crystals below -40 degrees Fahrenheit. Thus, dropping dry ice from an airplane or injecting liquid propane from a ground unit makes the cold fog precipitate out into fine crystals.

Another cold fog dispersal method employs helicopters to fly slowly across the top surface of a cloud or fog deck using the downward action of the rotors to force clear (normally drier) air from above the cloud top down into the cloud deck. The air, upon descending, entrains and mixes with the cloudy air and causes evaporation in the cloud. This method has been used to create clear trails in stratus clouds and fog over Thule Air Base, Greenland (11).

Warm fog dispersal techniques have eluded researchers for many years. Only recently has warm fog dispersal become a reality. Warm fog dispersal is based on the principle that when small water droplets are combined into bigger droplets, the number of droplets per unit volume of air become less and visibility correspondingly improves. Moreover, when the water droplets grow to a size where they cannot remain suspended in the air they will fall out in a fine drizzle—again improving visibility. Hygroscopic materials, such as salt (sodium chloride), are generally used as a seeding agent for warm fog. The material has been seeded by airplane and also dispensed through ground-based fog machines. A California airport has found about 70 per cent success for this method (10).

Precipitation Increase.

In 1966, the views of the Panel on Weather and Climate Modification of the National Academy of Sciences (21) on the prospects of modifying clouds and storm systems to stimulate precipitation were summarized:

> "There is increasing but still somewhat ambiguous statistical evidence that precipitation from some types of clouds in storm systems can be moderately increased or redistributed by seeding techniques."

Results in South Dakota (16) have established beyond any reasonable doubt the ability to modify individual cumulus clouds or portions of continu-

ous cloud decks. In many cases, modification treatments of the clouds were followed by precipitation from the base of the cloud to the ground. The results of this project indicated that cloud seeding produced significant increases in rainfall, especially when cloud systems moved from the southwest.

Reviewing projects over the past 10 years (5, 7, 16), seems to indicate an average increase of 10 to 15 per cent in the amount of rain reaching the ground. Note that this figure applies only to an increase in rainfall from clouds which are already raining or late rainfall from air masses which do not contain a natural reservoir of water vapor or from clouds which are too shallow to contain the necessary liquid water content.

Rainfall patterns and drouth cycles are produced by variations in the global circulation of large scale air masses. Cloud seeding is ineffective if the upper level air masses are dry.

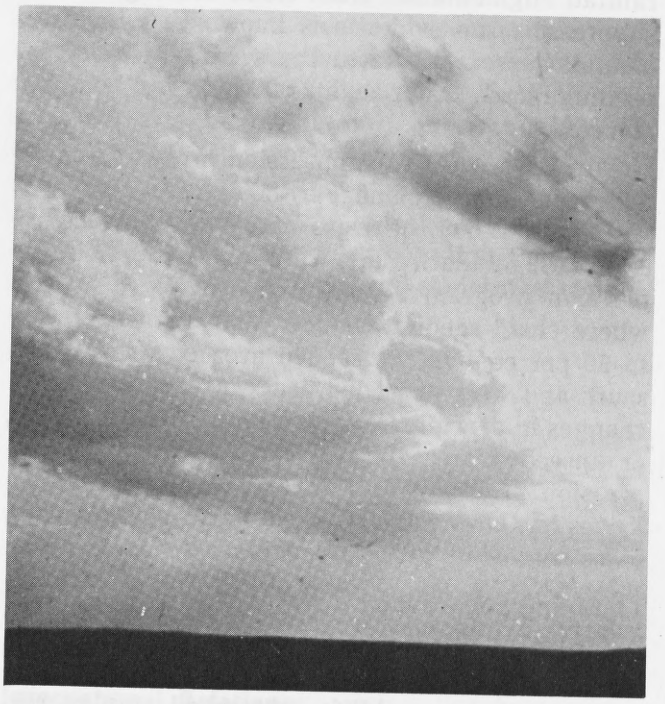
The answer to drouth problems will not come from cloud seeding, but will require means for influencing the large-scale motions of moisture-bearing air aloft. Also, it may be possible that increased urbanization and the accompanying air pollution may be affecting large scale weather patterns, especially in the northeastern United States.

HAIL SUPPRESSION

Annual losses due to hail in the United States have been estimated to exceed $100 million (15). The most serious hail damage occurs in the Great Plains area.

A hailstorm is a severe storm containing violent updrafts which sustain large super-cooled liquid water contents in suspension at temperatures below freezing. Ice crystals formed at lower levels of the storm are driven violently upwards into the super-cooled liquid water accumulation zone where they grow by successive collisions with super-cooled water droplets. When the ice particles grow large enough to overcome the updraft forces or are turbulently tossed out of the updraft, a hailfall results. The exact mechanism of hail formation is still not well understood, although through radar and airborne sensing devices scientists have gained considerable knowledge of hailstorms.

Hail modification attempts in the United States, Russia, Switzerland, Argentina, and Kenya have utilized silver iodide as a seeding agent. It is hypothesized that silver iodide serves to freeze the liquid water in the accumulation zone of the storm and no longer make it available for accretion on other ice particles passing through the zone. In the United States, the silver iodide is usually dispensed into updraft regions from airplanes by burning the silver iodide-in-acetone solution or by burning flares containing silver iodide. In Russia, artillery shells containing silver iodide are fired directly into the hail formation zone of the storm.



The buildup of a high cloud formation that results in a severe hail storm. Research is searching for ways to prevent the costly devastation of a hail storm.

Farmers are all too familiar with the aftermath of a severe shower of hail, and the damage that can be the result of hail on a field of ripening grain.

Evidence to date indicates that cloud seeding for hail suppression does have an effect on hailfall (14). Hailfall may increase under light seeding rates (under 1,000 gms. per hour per storm) and be reduced by heavier seeding rates (over 2,000 gms. per hour per storm). There also is evidence for rainfall augmentation from cloud seeding for hail suppression; no evidence is known that indicates rainfall decreases due to the seeding activity for seeding rates greater than 2,000 gms. per hour per storm.

In Russia, a hail suppression program reportedly reduced crop damage by 80 per cent compared with nearby control areas and with previous records (18). Similar results were found for a hail suppression program in southwestern North Dakota where cloud seeding reduced hail intensity by 30 to 60 per cent in the seeded area compared with south and west unseeded areas (1). No significant changes in precipitation were found for the seeded or unseeded areas in the North Dakota hail suppression program. In Kenya, hail damage to tea leaves has been reduced by 40 per cent for seeded cases compared with unseeded cases (8).

Lightning Suppression.

Lightning is the greatest single cause of forest fires in the western United States, causing severe losses of timber, wildlife, watershed, and recreational resources (17). Massive seeding of lightning storms with silver iodide by the U. S. Forest Service has indicated a significant reduction in cloud-to-ground lightning strokes. Over a three-year period a reduction of 32 per cent in cloud-to-ground lightning was found for seeded storms compared with unseeded storms (22). The U.S. Army has experimented with the release of millions of tiny metallic needles from an aircraft into a thunderstorm and observed a significant reduction in electrical field gradient in the vicinity of the charged cloud. The practicable reduction of lightning strokes from clouds appears to be possible through modification techniques in the reasonably near future.

Tornado

Tornadoes are the most violent storms known to man. Their time on earth is short, and their paths are small but devastating. Nothing known to man can presently control tornadoes. However, progress is being made toward a better understanding of the phenomena associated with tornadoes. Hopefully, scientists will find some possible mechanisms that they can alter to modify the destructive power of tornadoes.

Many tornadoes possess a high amount of electrical activity, as evidenced by nocturnal tornadoes having luminous characteristics and by sudden electric and magnetic field changes near tornadoes. It has been hypothesized that the control of the electrical heating mechanism of a tornado requires primarily the shorting of the electrical energy to the ground by another less harmful path (3). Some possible control methods might include: (1) distribute a fine wire chaff in the cloud, shorting the charge to the ground, or (2) add an electronegative gas such as Freon 12, as well as smoke particles, to change the electrical conductivity of the air.

The approach to tornado modification has been mainly confined to laboratory simulation and theoretical computer modeling. There is hope that severe storms which spawn the tornado may be amenable to treatment rather than the tornado itself. A more feasible approach would be to prevent the storm from reaching the proportions of tornado generation.

Hurricane

Under Project Stormfury, a joint ESSA - Navy program involving large-scale hurricane and cumulus cloud modification research, experiments are being performed to test models and mechanisms of hurricane modification. The intent is to produce warming in the outer zone of the hurricane eye wall by releasing latent heat of fusion from the seeding and thus alter pressure and wind distributions. Research is being conducted to discover the mechanisms of hurricane development and to find a critical ingredient for possible modification while the hurricane is in its formative stages (22).

Inadvertent Weather and Climate Modification

Unintentional alteration of the atmosphere by man is a serious problem. Man has been using the atmosphere as a dump without understanding the possible consequences. For instance, the amount of carbon dioxide in the atmosphere has increased by 10 to 15 per cent in this century, primarily from increased burning of fossil fuels. The increased concentration of carbon dioxide has possibly created a "greenhouse effect" and is thought to have caused an increase in surface temperatures of about 0.2°C since 1900. Other inadvertent changes in weather may arise from condensation trails of jet aircraft, pollutants arising from automobile and industry sources, urbanization effects from heat sources, and agricultural activities from wind erosion of soil, burning of residues, and deforestation or denuding the land (23).

Climatological studies of several large midwest and eastern cities have indicated urban-

produced weather changes (2). Substantially greater increases in annual precipitation (5 to 16 per cent), thunderstorm days (7 to 20 per cent), and hailfalls (31 to 246 per cent) have been observed in an area downwind from a major steel mill complex.

Air pollution from automobile exhausts also might account for high concentrations of ice crystals downwind of larger cities (13). Laboratory studies have shown that particles of lead compounds can be found in auto exhaust. When these lead particles contact iodine vapors, they form lead iodide which is a nucleating agent just like silver iodide. Apparently, wood smoke and other organic sources, and the ocean, supply iodine vapors to the atmosphere.

Air pollution is also a threat to the environmental health of man, animals and crop production. Air pollution causes losses to agriculture alone in excess of an estimated $325 million annually (9). Damage to structural materials is estimated to be $11 billion annually (23). Although difficult to determine precisely, there does appear to be a correlation between certain lung diseases and air pollution or smoking.

PROBLEMS

Weather modification may not benefit everyone. Some of the serious questions about weather modification center around the biological, economic, social, legal and international consequences (12).

Biological Problems

Great uncertainty has been encountered regarding the biological consequences of weather and climate modifications particularly precipitation changes. If properly controlled, weather modification may furnish a means to overcome some of the world's major problems, such as providing food for a growing population. However, there is an accompanying possibility that imbalances may arise in biological communities. Ecological changes from weather modification may result in moderate shifts in rates of reproduction, growth and mortality of weather-sensitive species of plants and animals (4).

Economic Problems

Natural weather occurrences (hail, drouth, frost, floods) lead to serious economic losses. This has motivated many to pursue a means for modifying the weather. Weather patterns directly affect many industries, ranging from recreation to transportation and manufacturing.

However, weather modification may not serve the interests of everyone at the same time. For instance, an increase in precipitation may benefit a wheat farmer, but may ruin the crop of a fruit farmer in the same area. Benefit-cost analysis needs to be performed to determine economic benefits to an area (6).

Social Problem

The impact of weather modification may reach deeply into social relationships and into aesthetic and spiritual values. The effects on some societies may be much more profound than on others. Some have wondered whether man really should aim to control his environment and its resources, for it would deny him the sense of excitement and the spiritual enrichment that comes from trying to cope with sudden, and sometimes violent, changes in the weather.

Legal Aspects

Weather and climate modification poses legal questions as to the existence of "property" interests in weather and the responsibilities of weather modifiers for damage to others, as well as problems of regulation. Many states have laws regulating weather modification. However, many of the legal aspects are still in the developmental stage. More comprehensive regulation in the public interest may be required.

International Relations

By its very nature weather transcends national boundaries. It is anticipated that weather modification may require international cooperation (e. g. hurricane modification). There is also a remote possibility that one country could use weather modification to alter storm paths or weather patterns to inflict damage on the economy and civil population of another country.

SUMMARY

Our knowledge of weather modification has progressed greatly in the past 20 years since the discovery that rainfall could be stimulated artificially. There now appears to be a scientific consensus that weather modification is a subject of prime importance and one for legitimate scientific inquiry and engineering development. There is evidence that small scale weather systems can be modified for man's benefit. However, as the complexity of the weather systems increase, greater uncertainty exists for their control. Thus, a greater chance for success is evident for modification of precipitation, hail, and lightning than for large storm systems such as tornadoes, hurricanes, and large-scale or global weather systems.

The present state of the art of weather modification appears to be as follows.

1. Microscale weather changes can be affected by windbreaks, irrigation and local heating to alter the environment near ground level.
2. Cold fog can be dispersed around airports by seeding stratus clouds with silver iodide.
3. Warm fog (water droplets above 32 degrees F.) has been dispersed around some airports by salt seeding; however, modification efforts are still in the developmental stage.
4. Precipitation increases of 10 to 20 per cent for both mountainous and plains regions have been observed depending upon atmospheric conditions and when properly seeded.
5. Hail suppression appears to be feasible with reductions in hail intensity of 30 to 80 per cent following seeding reported in the U.S., Kenya, and Russia. More intensive research is needed to understand the exact mechanisms of hail formation in storm systems.
6. Lightning suppression attempts indicate promise that operational techniques will be available in the near future.
7. The suppression of severe storms, such as hurricanes, appears promising but much more research will be needed to find the "trigger mechanisms."
8. The modification of tornadoes appears unlikely with current technology. Intensive research efforts are being made to gain a better understanding of the characteristics of tornadoes and the mechanisms that form them in hopes of finding methods to diminish their destructive power.
9. Large-scale weather patterns cannot be modified in a deliberate or predictable manner yet.
10. Inadvertent changes in climate may be occurring as a consequence of human activity (e. g., urbanization, air pollution, increased carbon dioxide levels, wind erosion).

In conclusion, weather modification appears to be a reality for small-scale weather systems but more uncertainty exists for economical modification of weather systems as they become more complex. Some of the major problems appear to be the inadvertent modification of weather due to man's activities and the social, economic, biological, legal and international consequences of weather modification.

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