History and Problems in Weather Modification

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Introduction

Weather modification is the effort of man to change naturally occurring weather, for the benefit of someone. The best-known kind of weather modification is *cloud seeding*, with the goal of producing rain or snow, suppressing hail (which can ruin crops), or weakening hurricanes.

This essay is a companion to my earlier essay, Weather Modification Law in the USA, which concentrates on a discussion and analysis of court cases in the USA involving weather modification, and contains a detailed review of tort law in the USA that applies to weather modification.

This essay is intended only to present general information about an interesting topic in law and is *not* advice for your specific problem. See my disclaimer.

I cite articles and books in the (Author, year, page) format; complete bibliographic data is given below.

Basic Technology

It is a common misconception that pure water freezes at a temperature of zero celsius (32 degrees Fahrenheit). Zero celsius is actually the temperature at which ice melts. Water freezes at a temperature between 0 and -39 celsius, depending on the type of nuclei (i.e., contaminants) present. Liquid water with a temperature of less than 0 celsius is called "supercooled water".

In November 1946, Dr. Bernard Vonnegut discovered that microscopic crystals of silver iodide (AgI) nucleate water vapor to form ice crystals. Vonnegut choose AgI crystals because there is nearly the same distance between molecules in the crystal lattice for both ice and AgI, which makes AgI the optimum material to nucleate ice. (Vonnegut, 1947) Vonnegut's discovery is a classic example of doing the right thing for the right reason at the very beginning of new technology, as a result of scientific knowledge. (Usually, progress is made by a series of small improvements on past practices, as a result of bumbling and guesswork. In contrast to the usual way, Vonnegut used his scientific knowledge to make a giant leap that has persisted as the state-of-the-art for more than fifty years.)

Vonnegut not only discovered the ice-nucleating properties of AgI, but he also invented a practical way of generating tiny AgI particles to serve as nuclei for ice crystals. Vonnegut dissolved a mixture of AgI and another iodide in acetone, sprayed the solution through a nozzle to make droplets, then burned the droplets. (Vonnegut, 1949; Vonnegut & Maynard, 1952) In this way, one gram of AgI can produce 10^{16} nuclei for ice crystals. More than fifty years later, Vonnegut's method continues to be the common way to seed clouds.

Release of AgI into an existing supercooled cloud (i.e., air temperature between -39 and -5 celsius) can convert water vapor to ice crystals, which is called sublimation. The ice crystals nucleated by the AgI will grow and local water droplets will shrink. The latent heat released by converting water vapor (or liquid water) to ice will increase vertical air motion inside the cloud and aid the convective growth of the cloud. Raindrops or snowflakes will grow larger by falling through a taller cloud. Also, moist air from evaporated moisture in the soil will be sucked into the base of the cloud by convection (i.e., updraft), thus increasing the total amount of water in the cloud. Perhaps 30 minutes after the AgI release, snow may fall below the cloud. Depending on the temperature and humidity below the cloud, the snow may change to rain, or even evaporate, before reaching the ground.

AgI is the most common ice nucleus used in cloud seeding, but it is not the only material used. Substances with temperatures less than -40 celsius (e.g., solid CO_2 ["dry ice"] pellets, liquid CO_2, liquid propane, liquid nitrogen, etc.) can be dropped from airplanes into the tops of clouds, to induce formation of ice crystals.

seeding warm clouds

Clouds that do not contain appreciable amounts of supercooled water are known as "warm clouds". In warm clouds, most of the liquid water droplets will have temperatures greater than zero celsius. Seeding warm clouds with AgI or dry ice makes no sense, because the air temperature is too high. Langmuir (1948, p. 170 of *Collected Works*) proposed that using an airplane to dump liquid water into warm clouds might initiate a chain reaction that would produce rain below the cloud. Later, Langmuir (1951, p. 196 of *Collected Works*) proposed an alternative technique for seeding warm clouds: using an airplane to dump hygroscopic materials (e.g., NaCl) in the form of a dust particles, with each particle having an approximate diameter of

25 μm, into such clouds to convert water vapor to a droplet of liquid water. These new droplets fall and either collide or coalesce with other droplets, to form rain drops.

Seeding clouds with either a water spray or hygroscopic materials requires dumping a large mass (e.g., 1000 kg) of seeding materials from an airplane, in contrast to the much smaller amounts of AgI needed to seed a different kind of cloud.

Such use of hygroscopic materials are condensation nuclei, *not* ice nuclei. While the physics differs in cloud seeding with ice nuclei and with condensation nuclei, both seeding methods have the same legal issues.

Earlier History

It is commonly stated that cloud seeding was invented in 1946 by employees of the General Electric Research Laboratory. This "fact" is wrong. There were at least three earlier *scientific* attempts to modify weather:

1. Prof. Emory Leon Chaffee at Harvard University dispensed charged sand from an airplane during 1924, to attempt to modify weather. (McDonald, 1961)

2. W. Veraart in 1930 dropped dry ice into clouds, in an attempt to modify weather. His technique and results were apparently published only in his book, which was in the Dutch language. (Byers, 1974, pp. 5-6)

3. Prof. Henry G. Houghton of MIT sprayed hygroscopic solutions into fogs in 1938 to dissipate the fog.

None of these early scientists had adequate financial support for their research, so society was unable to benefit from their ideas. Looking back in time, it is clear that it is not enough to have a good idea or theoretical scientific insight into a problem. One must also have the financial resources to pay both salaries and expenses of scientists with ideas and insight. General Electric provided such resources to Langmuir and Vonnegut, and General Electric management was able to quickly arrange contracts with the U.S. Military.

Early History of Weather Modification at General Electric

There was concern about legal liability from the earliest days of cloud seeding.

At the time of his discovery, Dr. Vonnegut worked in the research laboratory of Dr. Irving Langmuir at General Electric Company in Schenectady, New York. Their initial work on cloud seeding was funded by the Company, *not* the U.S. Government. General Electric rented an airplane and

released dry ice into clouds on four days during November and December 1946. The last day of seeding coincided with the "heaviest snowfall of the winter" in the Schenectady, New York area, which made the Company management concerned about the *possibility* of cloud seeding experiments causing harmful weather. (Havens, Jiusto, Vonnegut, 1978, pp. 7-8) A history of early cloud seeding produced by General Electric Company says:

> It was recognized that the possibility of liability for damage from cloud-seeding experiments was a very worrisome hazard in this new form of cloud experimentation. Since such a threat to the share owner's money would not be balanced by any known gain to the Company's products or business, there was a great reluctance to incur risks of uncertain but potentially great magnitude.
>
> This was another – and particularly important – reason that any seeding experiments be conducted under government sponsorship. No further seeding flights were made until such sponsorship was provided.

(Havens, Jiusto, Vonnegut, 1978, p. 8)
Just two months later, the U.S. Army Signal Corps began a contract with General Electric for cloud modification experiments. Part of this contract stated:

> ... the entire flight program shall be conducted by the government, using exclusively government personnel and equipment, and shall be under the exclusive direction and control of such government personnel.

(Havens, Jiusto, Vonnegut, 1978, pp. 8-9)
Management at General Electric Company

> immediately notified all those involved in the research "that it is essential that all of the General Electric employees who are working on this project refrain from asserting any control or direction over the flight program. The General Electric Research Laboratory responsibility is confined strictly to laboratory work and reports".

(Havens, Jiusto, Vonnegut, 1978, p. 9)
This rigid division of contractual responsibilities was designed to isolate General Electric from any tort responsibility for harmful weather that might be caused by cloud seeding.

seed hurricane

On 13 Oct 1947, the U.S. Military (as part of Project Cirrus involving General Electric) dropped 80 kg of dry ice into a hurricane in the Atlantic Ocean, safely off the eastern coast of the USA. (Havens, Jiusto, Vonnegut, 1978, pp. 41-42) The hurricane changed direction and traveled inland, where it did extensive damage to property in Georgia. The U.S. military classified the data from the seeding of this hurricane to frustrate litigation. (Ball 1949, pp. 225-226, p. 233)

Attorneys for General Electric reviewed and censored Langmuir's scientific publications to avoid tort liability for damage by this hurricane.
A biography of Langmuir says "For the first time in Langmuir's long career [38 years] at GE, officials occasionally wanted to know in advance what he was going to say in his public reports." (Rosenfeld, p. 205)

Langmuir (1953, p. 212 of *Collected Works*) believed that there was approximately a 99% probability that this hurricane's change of direction was the

result of the cloud seeding. Langmuir's opinion about the effect of the cloud seeding on this hurricane is *not* mentioned in any of his publications in scientific journals, but is mentioned in the 1953 final report on Project Cirrus, which was classified by the U.S. Military. It is likely that attorneys for General Electric directed Langmuir *not* to make any *public* admission that cloud seeding caused the hurricane to change direction, in order to avoid litigation against General Electric by victims of the hurricane.

Subsequent analysis of the data by meteorologists showed that this hurricane had already begun to change its direction when the seeding was done. (Mook, Hoover, and Hoover, 1957) A modern assessment is: "... it seems very unlikely that the 1947 seeding could have had much affect on the hurricane except for the seeded clouds." (Gentry, 1974, p. 506)

Langmuir's cloud seeding in New Mexico

The General Electric / U.S. Military research project released AgI and dry ice in the vicinity of Albuquerque, NM during October 1948 and July 1949. Langmuir initially claimed that this release caused rain all over the state of New Mexico and possibly in Kansas.

Langmuir's group continued to release AgI in New Mexico between November 1949 and July 1951. Langmuir claimed that the release of AgI modified the weather, not only in the state of New Mexico, but also *more than 1000 kilometers downwind.* (!) Langmuir's claim was rejected by the meteorological community, because Langmuir's evidence was *in*adequate. [citations]

The release of AgI "was discontinued in July, 1951 during the great floods in Kansas and adjacent states." (Byers, 1974, p. 20) This flood was no ordinary flood: the 13 July 1951 flood at Kansas City was described as "the most devastating flood in the nation's history"; 17 people died as a direct result of that flood, despite weather forecasts and warnings. (Alexander, 1951) It is still *un*known what effect, if any, the AgI release in New Mexico had on rain and floods in Kansas. The modern consensus of meteorologists seems to be that the release of AgI in New Mexico probably had no effect on the rainfall/floods in Kansas, but *if* there was an effect, the effect would be only a small enhancement of the total rainfall. As discussed below, perhaps the more interesting lesson is not one of science, but ethics: Langmuir sincerely believed that AgI release was modifying weather at long distances from the point of release, yet he continued to engage in such weather modification for two years, despite the *possibility* of harm from such modification, and despite the lack of consent by affected people.

other historical details

On 27 December 1950, the General Electric Company announced that it would no longer enforce its patents on weather modification methods. (Havens, Jiusto, Vonnegut, 1978, p. 53) By effectively putting its weather modification patents into the public domain, General Electric further isolated itself from tort liability for harm that might arise from weather modification technology that was developed by employees of General Electric. (Rosenfeld, p. 205)

Dr. Vonnegut, appearing in 1952 before a U.S. Senate committee that was considering legislation on weather modification, said:

> Theory has predicted and experiments are confirming the fact that a few pounds of silver iodide released into the atmosphere in the form of fine

> particles can exercise a profound influence over the weather hundreds of miles away from the point of release. Clearly no private individual or group can be permitted to carry on operations over thousands or hundreds of thousands of square miles.
>
> The potentialities, both for good and bad, which attend silver-iodide seeding are so large that the development and use of this technique must be placed in the hands of the Federal Government.

(Havens, Jiusto, Vonnegut, 1978, p. 53)
Despite Dr. Vonnegut's clear insight into the nature of the problem, the U.S. Congress never passed a statute regulating weather modification.

Problems with Experiments

Before one can understand legal problems of cloud seeding, including tort liability for cloud seeding, one must first understand something about cloud seeding experiments. The following terse discussion is a summary of some of the problems associated with cloud seeding. Because I have not had the time to make a thorough review of the meteorological literature, but only looked at some review articles, I have not provided citations to the original sources.

The traditional cloud seeding experiment randomly selected clouds to seed (or not to seed) and measured precipitation in the target area as the sole criterion of the effect of seeding. Such experiments reported in the meteorological literature superficially appear to give contradictory results: some experiments show a significant enhancement of precipitation, other experiments show no effect, and some experiments show a decrease in precipitation. Cotton (1986) has clearly explained why such a simple experiment is not adequate.

Most importantly, we lack detailed scientific knowledge on the natural production of rain, hail, or snow. Without such knowledge, we can not predict the best time and place to seed clouds. Different physical processes may be important at different times in each cloud's life cycle, which may give a narrow window of opportunity for intervention via injection of AgI nuclei. Further, we can not accurately predict when and where the effect (if any) of seeding will occur.

Some cloud seeding has used smoke containing AgI from generators on the ground to provide nuclei for clouds. The AgI is supposedly transported to approximately the -10 celsius region of a cumulus cloud by naturally occurring updrafts. However, there is concern whether the AgI actually reaches this region of the target cloud and, if it does reach that region, whether the AgI is uniformly dispersed over this region of the target cloud. While ground-based AgI generators are less expensive to operate than AgI generators aboard airplanes, airplanes are a much surer way to deliver the AgI to the appropriate region of the target cloud.

AgI does not magically disappear a few hours after its release. There have been sporadic suggestions in meteorology journals and symposia that enhanced rainfall may [also] occur between 100 and 300 kilometers downwind from the point where the AgI was released. Aside from possibly modifying the weather at great distances from the intended target area, such effects could contaminate scientific experiments so that "natural" clouds in

the control (i.e., nonseeded) group may contain some AgI. Such contamination would make it more difficult to prove that AgI is effective in modifying clouds.

However, even with our limited knowledge of atmospheric physics, we know that different types of clouds behave differently. For example: isolated orographic clouds differ from large, multi-celled clouds associated with a front on a surface pressure map, and both differ from tropical cumulus clouds with a top warmer than -5 celsius. Therefore, one must be careful not to apply successes (or failures) with one type of cloud to another type of cloud.

Current knowledge suggests that cloud seeding produces a small perturbation (e.g., perhaps 10% extra rainfall as the result of cloud seeding) of a phenomena that has much larger natural fluctuations [e.g., in the range from 250% to 400% (Grant, 1977, p. 13)]. While a 10% increase in rain can be economically significant, this small increase superimposed on much larger natural fluctuations poses a very difficult problem for statistical analysis of cloud seeding experiments.

There are hundreds of articles in the scientific literature on the subject of cloud seeding, but few are available on the Internet. Dr. William R. Cotton, a professor of atmospheric science at Colorado State University in Fort Collins, has posted a comprehensive review of weather modification experiments during 1989-1997. There is also a good critical review of cloud seeding experiments in Australia, written in May 1995 by Brian F. Ryan and Brian S. Sadler.

American Meteorology Society's Policy on Weather Modification

In anonymous policy statements without any bibliographic citations, the American Meteorological Society declared:

> Operations that dissipate supercooled fog and low stratus (clouds containing water droplets at subfreezing temperatures) by seeding with ice-forming agents (e.g., dry ice, liquid nitrogen, compressed air, silver iodide, etc.) have become routine at some airports.
> . . . .
> There is statistical evidence that precipitation from supercooled orographic clouds (clouds that develop over mountains) has been seasonally increased by about 10%. The physical cause-and-effect relationships, however, have not been fully documented.
> . . . .
> Some experiments with warm-based convective clouds [bases about 10 celsius or warmer] involving heavy silver iodide seeding have suggested a positive effect on individual convective cells, but conclusive evidence that such seeding can increase rainfall from multicell storms has yet to be established.

(AMS, 1998, p. 2771)

> There are indications that precipitation changes, either increases or decreases, can also occur at some distance beyond intended target areas.

> Improved quantification of these extended (extra-area) effects is needed to satisfy public concerns and assess hydrologic impacts.

(AMS, 1992, p. 333). Similar words at (AMS, 1998, pp. 2771, 2775).

> The efficacy of projects intended to mitigate the severity of hailstorms remains indeterminate. Statistical assessments of certain operational projects indicate successful reduction of crop hail damage, but scientific establishment of cause and effect are incomplete. Results of various operational and experimental projects provide a range of outcomes.

(AMS, 1992, p. 334; AMS, 1998, p. 2775).

> Hurricane modification experiments of the 1950s and 1960s were inconclusive. Although strong research interest continued into the 1970s, no organized research effort was undertaken, and few studies have been devoted to this subject for the past 20 years.

(AMS, 1992, p. 334; AMS, 1998, p. 2776).
[Actually, a total of only three hurricanes were seeded during 1961-69. (Gentry, 1974, p. 507)]

> The use of untested weather modification techniques during severe droughts, as a means of increasing precipitation, is not recommended. Opportunities to increase precipitation are typically minimal during droughts and only well-tested techniques should be considered, realizing that only limited precipitation augmentation will probably result.

(AMS, 1992, p. 336). Similar words at (AMS, 1998, pp. 2772, 2778).

The above-cited Policy Statements from the American Meteorological Society are apparently intended to provide easy-to-read guidance to nonscientists (e.g., government officials, legislators, and potential clients of cloud seeders). These policy statements provide an authoritative, consensus view of the then current scientific knowledge. However, these policy statements are *not* a limitation on what might be achieved in the future.

The World Meteorological Organization (WMO) has a statement on weather modification.

Ethical Issues

There are several broad classes of ethical issues that are relevant to cloud seeding:

1. a scientist's alleged ethical responsibility for use of his/her discoveries or knowledge for "undesirable" goals. This concern was initially voiced in response to scientists who designed and developed nuclear weapons, which could kill millions of people. I say "alleged ethical responsibility", as I believe that information is morally neutral, and it is the *use* of that information that causes benefits or harms. Any ethical or legal responsibility for the use of information clearly belongs to the user, not the discoverer, of the information.

2. a scientist's obligation to conduct his/her research in an ethical manner, including obtaining consent from affected people. This concern was initially voiced in response to physicians who conducted medical experiments on people without their consent.

3. society's ethical or legal obligation to use technology wisely, to avoid long-term adverse effects on the environment. This ethical concern was initially voiced in connection with industrial pollution of air and rivers, which are natural resources that belong to everyone.

4. the ethical obligation of a professional scientist to share his/her discoveries with other scientists through publication in scholarly literature or books.

From this viewpoint, it is remarkable that research scientists in the late 1940s and during the 1950s apparently had no hesitation in releasing AgI into the atmosphere, as if the atmosphere were their private laboratory, instead of part of the natural environment that belongs to everyone. Perhaps the enthusiasm of those scientists was part of the Zeitgeist in the early 1950s in which science and technology could solve all problems and make a better world. And there was no governmental mechanism in the late 1940s and early 1950s by which scientists could have asked permission to experiment with the natural environment. It is *in*appropriate to apply modern ethics and laws to scientists in the late 1940s and early 1950s.

Even more remarkable to me is the rapid development of corporations that performed operational cloud seeding, which intended to modify everyone's weather in a large area, without the consent of a majority of the affected people (indeed, without informing most affected people).

Among other concerns, it is possible that some unregulated commercial cloud seeding contaminated scientific experiments on cloud seeding. In my opinion, it was premature to be conducting operational cloud seeding before such programs had been scientifically proven to be safe and effective, a point that I make later in this essay.

Ethical Obligation to Publish?

Unlike scientists who share their discoveries and knowledge in journals published by professional societies, the early commercial cloud seeders regarded their knowledge as proprietary information (i.e., protected by the law of trade secrets) to be used to enhance their ability to earn an income, but *not* to share with others.

One commercial cloud seeder, writing just four years after Vonnegut's discovery, said:

> It is estimated that fully 85% of the cloud seeding conducted in a reasonably professional manner has not been reported on in any scientific or technical journal.

Elliott, 1951.

An analyst who examined approximately 1300 articles in the meteorological literature, published between 1946 and 1960, concluded:

> ... commercial projects place in the open literature only about one-tenth as much information as that generated by comparable non-commercial

projects. This is not to say that complete documentation may not reside in the files of commercial operators and their clients. Huschke, 1963, p. 425.

Below, I mention the need for publication of the results of weather modification experiments in archival professional journals and books to share knowledge, to prevent repetition of past mistakes, as well as to provide a basis for public recognition of a technique as safe and effective.

There are two contrasting attitudes about publication. Scientists doing basic research are oriented toward publication, because that is how they build their professional reputation amongst other scientists. On the other hand, industrial employers of technicians and engineers commonly regard their discoveries as proprietary information that gives the employer an advantage in a competitive marketplace.

It is incorrect to frame these contrasting attitudes about publications as professors vs. employees of industrial corporations, because research scientists employed by major for-profit corporations (e.g., Langmuir and Vonnegut at General Electric Company) are often prolific authors. Industrial corporations can protect their financial investment in scientific research through patents, or make a profit on research contracts with the government that involve publication of results of basic scientific research.

However, commercial cloud seeders are small for-profit companies that can not afford to engage in basic research (i.e., these small companies can not afford to do what General Electric did in 1946 in sponsoring Langmuir's and Vonnegut's work on cloud seeding, nor what Bell Telephone Laboratories did in other areas of science and engineering). The goal of a company is to serve its customers: clients of commercial cloud seeders want modified weather, *not* scientific experiments, and *not* technical publications in scientific journals.

Environmental Zeitgeist

From the viewpoint of the history of technology, it is interesting to speculate on the effect of the environmental protection movement during the late 1960s and early 1970s on weather modification. The Zeitgeist of 1950 was that science and technology were Good, and could cure all problems. The Zeitgeist of 1970 was that technology caused many problems and that "natural" was better. The point here is not to discuss which Zeitgeist is correct or preferable, but simply to recognize that each Zeitgeist affected public enthusiasm for the technology of cloud seeding.

There is no evidence (and no reason to suspect) that cloud seeding produces long-term (e.g., time durations of years or tens of years) environmental changes. In this way, cloud seeding is *un*like slowly decaying radioactive waste, accumulations of toxic chemicals in the ecosystem, or long-term inadvertent weather modification (e.g., global warming or destruction of the ozone layer in the stratosphere). However, environmental awareness may have convinced many people to avoid cloud seeding, only because cloud seeding was "unnatural".

Support of Basic Scientific Research

Many of the problems with the law of weather modification are attributable to our lack of basic scientific understanding of how clouds produce rain, and how cloud seeding modifies processes in the cloud. Specifically, the lack of basic scientific understanding has led to:

- perplexing problems with deciding where, when, and how to seed clouds.
- misleading advertising and false promises to farmers and ranchers, who are customers of weather modification.
- uncertainty about how government should regulate cloud seeding (i.e., many states have repeatedly enacted and repealed statutes regulating weather modification, in a blind struggle to make appropriate laws).
- allegedly insurmountable problems for plaintiffs in proving that cloud seeding caused the harm that they suffered, so that courts were unable to provide a remedy to possibly injured plaintiffs.

Cotton & Pielke, (1995, p. 57) show that financial support from the U.S. Government for weather modification research steadily increased from 1960 until 1972, crashed in 1974-75, increased in 1976, and steadily declined during 1979-84.

Writing just ten years after the invention of AgI cloud seeding, Prof. Henry G. Houghton of MIT said:

> Early overoptimistic claims of increases of rainfall of several hundred per cent have given way to much more modest figures. In spite of increased scientific knowledge and experience with many rain-making projects we still lack a definitive and generally-accepted statement on the quantitative capabilities of rain making.

(Houghton, 1957, p. 568).

> Many past failures have doubtless resulted from seeding the wrong storms and from a failure of active seeding materials to reach the proper regions of the clouds. The full potential of rain making will not be realized until we acquire more complete knowledge of natural precipitation processes and refine seeding technology.

(Houghton, 1957, p. 569).

> A prerequisite to the control of any phenomenon is complete knowledge of its operation. Our understanding of atmospheric processes is still too incomplete to permit us seriously to propose methods of control. Nevertheless our recent progress in meteorological research is such that it no long appears visionary to talk about weather control.

(Houghton, 1957, p. 569).

> It would be unthinkable to embark on such a vast experiment before we are able to predict with some certainty what the effects would be. Without such knowledge the effects might be catastrophic or, as a lesser evil, there might be no noticeable effect after expenditure of large sums. A much more reasonable approach lies in continuation of basic research.

(Houghton, 1957, p. 569).

In his final paragraph, Prof. Houghton said:

> All too often we Americans confuse technological progress with research. Basic research is the search for an understanding of nature's mysteries with no immediate practical applications in mind. The life-blood of technological progress is the results of such basic research and we can no longer depend on other countries to supply this vital plasma. Basic research in meteorology can be justified solely on the economic importance of improved weather forecasting but the possibility of weather control makes it mandatory.

(Houghton, 1957, p. 570).

From the perspective of more than 45 years later, Prof. Houghton was exactly correct in calling for more basic scientific research. Unfortunately, politicians and government bureaucrats were oblivious to Houghton's wisdom. Thirty five years later, the American Meteorological Society's policy statement (AMS, 1992) echoed Houghton's earlier statement.

As one example of the practical value of basic research, Vonnegut in 1947 was able to use published measurements of the size of the atomic lattice in various materials, to find the optimum material for nucleating ice crystals. Vonnegut (1947) cited measurements for ice published in London, England in 1929 and measurements for AgI published in Amsterdam, the Netherlands in 1928. Thus, basic research in crystallography led, twenty years later, to the discovery of the optimum material for nucleating ice in clouds, a finding of immense practical importance for weather modification. It is inherently not foreseeable what the benefits of basic scientific research will be. Again, quoting from Prof. Houghton:

> ... I wish to emphasize that all aspects of basic research in meteorology should be carried forward. For all we know some other phenomenon such as atmospheric electricity may hold the key to weather control. No matter what happens we can cannot lose on this course. Even if weather control proves to be impossible, the knowledge gained from a sound research program cannot fail to result in improved weather forecasts and many other, as yet unimagined, benefits to mankind.

(Houghton, 1957, p. 569).

A famous atmospheric physicist wrote in 1958:

> ... we face here one more of those many instances in the history of science where far too little research support was given to investigations while they were *apparently* of only academic interest. When, after 1946, there seemed to exist some prospect of control over a natural phenomenon whose economic value is so high, support of cloud physics research jumped by, what I would estimate must surely have been, a factor of two to three orders of magnitude, and total numbers of workers in the field must have increased by a factor of something like two orders of magnitude. Yet so complex are the phenomena one encounters in attempting rational modification of precipitation, that even after a decade of investigations at these unprecedented levels of support, meteorologists still face many very fundamental questions not yet answered. Had fundamental meteorological research been sustained during earlier decades at a level in keeping with the importance of meteorological phenomena in all man's affairs, this embarrassing dearth of basic observational and theoretical background would not have so limited rapid progress toward evaluation of, and improvement upon, the discovery in 1946 of means of modifying cloud processes.

McDonald, 1958, pp. 234-235.

It is particularly disappointing, but not really surprising (in view of the following paragraphs in this essay), that financial support for work in atmospheric physics began a rapid decline in 1979.

government has short-term view

Both legislators and government executives in the USA work on time scales between two and six years, which are the lengths of election cycles. Cotton & Pielke (1995, p. 219) noted, these legislators and executives demand "significant progress" within this short duration. Their unrealistic demands cause several problems:

1. preventing consistent long-term (i.e., tens of years) financial support for scientific research. The government's short-attention span disrupts scientists' careers, as scientists are forced to chase the latest fad in government funding. Scientific research is difficult enough without politicians and government bureaucrats disrupting long-term financial support for research.

2. overemphasizing achieving practical goals (i.e., developing useful technology), without first understanding the basic scientific principles. Such a policy puts the cart before the horse. There are two bad effects of this policy. First, solving practical problems is made unreasonably difficult, since workers have inadequate knowledge and must guess instead of design. Second, when a solution to a practical problem is found, adverse side effects of that solution are unknown, because of the lack of basic scientific knowledge.

3. leading scientists to make false promises of quick benefits from research, in exchange for financial support for that research. Cotton & Pielke (1995, p. 218) remark on "overselling" the promise or benefits of cloud seeding:
   > The claims that only a few more years of research and development will lead to a scientifically-proven technology that will contribute substantially to water management and severe weather abatement, were either great exaggerations, or just false.

   The hyperbole of scientists doing research, and also of commercial cloud seeders, is unprofessional and may diminish the trust that laymen have in scientists.

This is not the place to discuss the complex subject of how the government in the USA has failed to properly support basic scientific research since the mid-1970s. However, it is important to understand that the resulting lack of basic scientific understanding underlies the failure of law (i.e., both statutes, regulations, and common law) to adapt to the new technologies offered by weather modification. Worse, meager financial support for scientific research means that the benefits of science and technology are long delayed to society who wants to avoid to avoid harm from natural weather (e.g., drought, floods, hail, hurricanes, etc.).

my suggestions

Basic scientific research should occur first. Only *after* the applicable scientific principles are understood can we have a rational application of law to weather modification, such as determining in tort litigation if a cloud seeder caused a flood or drought, or determining if a cloud seeder was negligent. Good laws and good regulations can not be based on possibilities and conjectures.

Therefore, I suggest a two-step process:

1. Until there is scientific proof that a weather modification technique is both safe and effective, *every* attempt to use that technique should be part of a scientific research program that is carefully designed, conducted, and analyzed. It is essential that every such program be reported in archival professional journals and books, to share knowledge and to prevent repetition of past mistakes, as well as to provide a basis for public recognition of a technique as safe and effective.

2. After there is scientific proof that a weather modification technique is both safe and effective, then that technique may be used in operational programs. However, it would still be a good policy to have a government agency review and approve each operational plan, before granting a permit for operational weather modification.

Above, I mentioned the fact that commercial cloud seeders have generally been reluctant to publish new knowledge that they create, as companies are loath to help their competitors. Further, small companies can not afford to pay the entire cost of basic scientific research projects. To solve the conflicting goals between (1) the need of society for unbiased scientific information and (2) the desire of commercial cloud seeders to be profitable, the federal government should give generous financial support for basic scientific research in a broad range of atmospheric sciences, including scientific evaluations of unproven weather modification techniques.

I suggest that society ought to insist that basic scientific research be published in exchange for the government financially supporting that research, and also in exchange for society tolerating the [probably small] risk of harm from weather modification experiments.

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About the author

I took several classes in atmospheric physics during 1971-76, while I was in graduate school, although my emphasis was in general physics. My first peer-reviewed scientific publication was a paper that reviewed the published literature on the toxicity of silver iodide used in cloud seeding. I did scientific research in atmospheric electricity and lightning during 1971-79 and earned a Ph.D. in physics in 1977. The drastic decrease in the U.S. Government's financial support for scientific research in atmospheric electricity caused me to change fields in 1982 from basic scientific research to practical engineering research on protection of electronic equipment from transient overvoltages, such as caused by lightning. When financial support for research in all of my areas of science and engineering was annihilated in 1990, I began to change careers to law. I am currently an attorney in Massachusetts.

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