What about weather modification?

by

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1. Introduction

Weather modification probably has been a dream of humans for as long as they have been affected by the weather. Who hasn't wished the weather they *get* would coincide with the weather they *want*? This is especially true for those whose livelihood depends on the weather: farmers, ski resort operators, seaside vacation resort owners, etc. Moreover, sometimes the weather turns bad enough that virtually everyone wants that bad weather just to go away and not happen to them.

Rain dances by aboriginal Americans are legendary (though probably apocryphal!) ... nothing is is known about how the effectiveness of "intervention" of this sort was perceived. No doubt other efforts by shamans (or other comparable names) to intervene on behalf of their people have a long history that begins in prehistoric times. I have no wish to patronize the belief systems that existed in these hunter-gatherer societies... rather, I want to characterize their attempts at weather modification as being associated with a great deal of awe when regarding their environment. Rather than hubris, their weather modification attempts were tied to *humility* in the face of overwhelming power.

By the 19th century, atmospheric science was in its protracted infancy, and comprehensive understanding of atmospheric processes simply wasn't available. Meteorology of that age had neither the theory nor the observations to be an effective tool for application in human affairs. Forecasting amounted to "weather lore" that perhaps had some basis in what we now know as scientific principles, but that basis was unusable to forecasters, owing to its theoretical complexity. If the weather lore worked, it was not connected in any meaningful way to the limited topics accessible to pre-20th century meteorologists. There are reasons for this that go beyond my goals with this essay. In any case, the fruits of Newton's revolution in physics were beginning to be felt throughout society; science was increasingly being used to serve human needs and technology was being developed that could have large impacts on the natural world. The belief system that would characterize the technological society to come in the 20th century was emerging. This belief system held that humans could command the forces of nature to bend to human will if we could develop a proper understanding of science.

This situation in the 19th century created a market for a whole array of charlatans to engage in activities purporting to modify the weather to suit a customer's needs, as well as those whose intentions were better than their science. Many of these relatively primitive attempts at weather modification involved firing cannons and other guns of various sorts into the air. The net result of all this this sound and fury was essentially nonexistent. However, in general, something important began to emerge: people under stress from their environment began to operate under the assumption that something more efficacious than prayer could be applied to their weather problems. In short, the 19th century saw the growth of both (a) optimism regarding the application of emerging scientific understanding ... and (b) a huge conceit that eventually the whole of the universe could be controlled by humans once that scientific understanding was sufficiently advanced. One dream that often surfaced in late 19th century and has continued well into this century has been the total control of the earth's weather; its subjugation to human desires has been a theme of "futurists" for many decades.

2. Weather modification *might* work ...

With the growth of modern meteorology in the 20th century, associated with

- the proliferation of electronic communication systems that allowed scientists actually to obtain observations in near-real time, to see the structure and evolution of weather systems, and
- the development of electronic computers that permitted the solution of the nonlinear differential equations that describe the basic physics of the atmosphere,

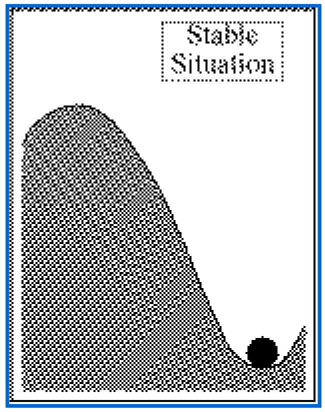
it became possible to observe, calculate, and even forecast the titanic energies associated with the atmospheric processes. Prior to the development of the atomic bomb, the energy commanded by human activity was so tiny in comparison to those in atmospheric processes as to be comparable to a microscopic mite on a flea on an elephant's back. The majesty and power of the atmosphere, revealed by the new scientific understanding that developed as a result of these technologies, was clearly seen for the first time in the era following World War II. Even the new "command" of the power of atomic fission, first, and then atomic fusion (which remains only marginally under human "command") need to be seen as *trivial* in comparison to the vast sweeping forces that control the atmosphere, perhaps up to the level of the flea on the elephant's back.

An interesting example of the magnitude of atmospheric energies can be exemplified by the monetary value of the sunlight we all receive freely every day, as passed on to me by Dr. Edwin Kessler: on the average, over the state of Oklahoma (which covers an area of about 200 thousand km^2), if we had to pay 5 cents per kilowatt-hour for the energy provided by the sun every day (a relatively cheap price), the cost would be around $60 billion per day! It is this level of energy input that is driving atmospheric processes, which constitute a sort of atmospheric "engine" fueled by solar input.

However, it turns out that in a few cases, there are meteorological processes that *might* be amenable to modification. In spite of the enormous energies involved, there are some situations that arise in the atmosphere that can be described as "metastable". In order to understand what metastability means, we should consider what is the normal situation.

a. Stability

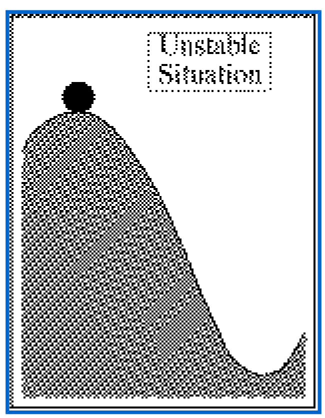
When atmospheric processes are **stable**, it means that they resist any attempts to force them to depart from their current structure. Since atmospheric process command such huge energies, we would have to expend comparably huge energies in order to drive them away from that situation. A simple picture of this sort of stability can be seen in the image of a ball at the bottom of a valley.



For instance, it sometimes happens that large-scale weather patterns are stable, so that dry periods (or wet periods) persist. This is why we have droughts and floods.

b. Instability

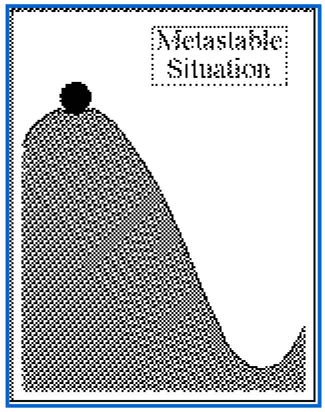
In conditions that are **unstable**, the atmosphere is able to tap some gigantic energy source, and move on its way from one configuration to another. The simple picture of an unstable situation would be the image of a ball balanced precariously at the the peak above a slope. Once things have become this unstable, it is very easy to release the large energies available and pretty tough to stop once things get underway.



It also happens that large-scale weather patterns are unstable, so that dry and wet periods alternate fairly often, such that neither extreme persists very long. Generally, this condition is typical of most locations in middle latitudes.

c. Metastability

Metastable conditions in the atmosphere arise infrequently, but it turns out that in such situations, only a relatively small amount of energy need be expended in order to produce a large change in the situation.The simple picture of a metastable condition is when a ball is at rest in a shallow depression at the very top of a hill. Only a small push will release the huge energy available in that condition.



The extent to which large-scale weather patterns are metastable is not known. We tend not to see conditions of metastability on large scales easily, because if some small "push" is needed to tap the energy, we probably cannot see that push (owing to inadequate data).

In any case, given that we humans as yet cannot command energies on the scale of those associated with atmospheric processes, it is only in conditions of metastability that we can have any hope of modifying the weather.

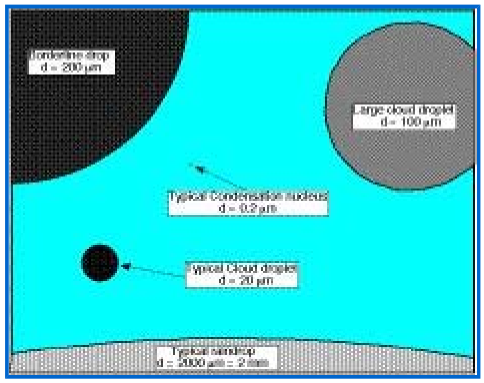
3. Precipitation formation from natural clouds

I need to provide some information about how precipitation forms naturally inside clouds ... sorry, but a little basic meteorology is needed here. When it comes to forming precipitation, there are two basic types of clouds

1. **warm** clouds, in which temperatures remain mostly above 0 deg C (32 deg F),
2. **cold** clouds, in which a significant part of the cloud depth is at or below 0 deg C.

Precipitation forms in warm clouds in different ways than it does in cold clouds. Clouds themselves form when air containing water vapor (an invisible gas mixed in with the air) is forced to cool. The cooling is usually associated with air (containing water vapor) being lifted by some process ... as the air ascends, it cools by expansion [*This cooling by expansion should be familiar to most people; for example, spray cans cool as their contents are expelled from the can, expanding into the air.*] because rising air moves into reduced pressure (pressure decreases as one goes up in the atmosphere). As the vapor-containing air ascends, its relative humidity increases as a result of this cooling, until the water vapor can condense. [*This condensation associated with cooling should also be familiar; for example, the water that condenses from the air on the outside of a glass of ice water.*]

Water vapor tends to condense around particles that are virtually always present in the air, called *condensation nuclei*. A condensation nucleus promotes condensation even *before* the relative humidity reaches 100 percent; an example of a condensation nucleus would be a tiny particle of salt that was produced when a droplet of sea water (thrown into the air by a wave) evaporated. Many sorts of particles can promote condensation, but they all have the property of being *hygroscopic* ... in other words, they attract water, like salt does [*Another familiar experience ... in humid environments, salt attracts water that clumps the salt particles together inside a salt shaker, making it hard to pour.*]. Since the condensation nuclei are extremely small, the condensing cloud droplet is also very tiny. It's so small that it can be held aloft by the normal turbulent motions in the atmosphere ... clouds don't fall out of the sky because they are made up of many, many small droplets. Note that the typical cloud droplet has a diameter about 100 times larger than that of the typical condensation nucleus ... this means its volume is roughly a million times larger than that of the condensation nucleus. Even with the nucleus inside, the water in a cloud droplet is almost pure water.



Schematic figure showing the relative sizes of drops. The unit of size shown as μm is one millionth of a meter (a micrometer). It takes 1000 μm to make up one mm ... one inch is about 25 mm. Roughly, it takes about a million cloud droplets to make up one raindrop! Drizzle drops are about 200 μm in diameter. Adapted from McDonald (1958) - [McDonald, J.E., 1958: The physics of cloud modification. *Adv. Geophys.*, **5**, 223-303.].

As most people already know, however, **clouds don't necessarily mean rain**. Even though a cloud represents a large amount of condensed water, if it doesn't fall out of the sky, no rain will result. So how do we get from *cloud* droplets, which are tiny, to *rain* droplets, which are large enough to fall?

a. Warm clouds

In warm clouds, the main process is called **coalescence**. Warm clouds that produce rain usually have a smaller number of cloud droplets than cold clouds, but the droplets tend to be bigger and they often include some relatively large droplets (like the one in the upper right corner of the figure above). Those droplets that are rather larger than most others fall *relative* to the other droplets. As the largest droplets fall past the smaller ones, they can collide with some and in doing so, some of the smaller droplets will merge with the big ones, increasing their size still further, so they fall a little faster. Thus, through this process, a few droplets can sweep up enough smaller ones to grow into rain-sized droplets (it takes roughly a *million* cloud droplets to make up *one* raindrop!). [*On a drizzly day, you can watch this coalescence process on a window, as small drizzle drops merge and run down the window.*]

b. Cold clouds

In cold clouds, another process can operate on the condensed water vapor. Not all cloud droplets freeze when they reach 0 deg C (the melting level, which is at about 15,000 feet above the surface during the late spring on the American Plains) ... it turns out that water at a temperature below 0 deg C needs to be "taught" how to crystallize into ice. Very pure water (remember, cloud droplets are generally pretty pure water) can be cooled below the melting point, down to temperatures as low as -40 deg C [which is also -40 deg F] ... at -40 deg C, even very pure water will freeze. -40 deg C is called the *homogeneous nucleation* point. Therefore, by the time the temperature in a cloud is -40 deg C or lower, *all* the condensed water is frozen. Cloud droplets that are still liquid at temperatures below 0 deg C are said to be **supercooled**. Now if *some* of the droplets freeze, perhaps because they encountered a **freezing nucleus** (not the same as a *condensation* nucleus), then that part of the cloud between 0 and -40 deg C usually contains a mixture of frozen and unfrozen (but supercooled) droplets. That mixture is mostly water near 0 deg C, and mostly ice near -40 deg C.

When there is a mixture of solid and liquid water droplets within the cloud, the frozen droplets tend to grow at the expense of the unfrozen droplets ... this is because water molecules that are frozen are more tightly bound together (into a crystalline structure) than liquid water. This means that a few frozen droplets get a head start in growing larger (and, therefore, falling faster) than their unfrozen neighbors. With that head start, the frozen droplets then can grow by coalescence into what are usually *graupel* particles (a sort of snowy ice particle). The graupel particles melt, naturally, after they fall through the melting level (where the temperature is exactly 0 deg C).

This process of forming raindrops ... the melting of graupel particles ... is the most common mechanism for forming rain in middle latitudes. It is called the Bergeron-Findeisen process, after the scientists who first proposed this mechanism for creating raindrops.

Clearly, the existence of a freezing nucleus is a big factor in formation of precipitation in cold clouds. Supercooled water is said, therefore, to be in a *metastable* state ... the presence of a freezing nucleus will trigger freezing. It is this freezing that triggers, in turn, the growth into precipitation. Naturally-occurring freezing nuclei are, of course, present in the atmosphere in many cases. Wherever there are adequate freezing nuclei already present, there is nothing that seeding based on enhancing freezing nucleation can do to enhance the production of rainfall in clouds!

4. The water available in a cloud

Imagine a cloud that was 10 km (about 6 mi) tall and 10 km in diameter ... this is perhaps representative of a large thunderhead:

Such a cloud contains a volume of roughly 785 km^3. If the average condensed water content of this cloud is 1 g m^{-3}, this means the cloud contains about 785 million kg of condensed water, which turns out to be 207.4 million U.S. gallons. This sounds like a lot of water, right? Imagine that this water falls directly out underneath the cloud and is uniformly spread on the ground beneath it. Also assume the cloud doesn't move during the process. The area under the cloud is about about 78.5 km^2 (about 30 mi^2, or 19,400 acres) so the depth of the water produced by the fall-out of *all* the water in the cloud distributed evenly over the area under the cloud would be 10 mm, which is about 0.39 inches.

NOTE: Another way to think about this - by assumption, the cloud does not move and the condensed water is distributed uniformly, so we can consider the condensed water per unit area (pick a unit area of 1 m^2, for convenience). The depth of the cloud is 10 km = 10,000 m, so if the average water content is 1 g m^{-3}, there are 10,000 m x 1 m^2 x 1 g m^{-3} = 10,000 g = 10 kg of condensed water above each unit of area. The density of water is 1 g cm^{-3} = 1000 kg m^{-3}, so the volume of the condensed water per unit area is 0.01 m^{-3}, so this gives a depth of 0.01 m = 1 cm = 10 mm per m^2. My thanks to Fitzmaurice Li for sending me this simplification and correction.

Of course, the actual distribution of rain under that cloud almost certainly would *not* be evenly distributed under that cloud, but the *average* over the area covered by that stationary cloud would be 10 mm = 1 cm. Another way to express the total condensed water content of this hypothetical cloud is about 63.5 acre-feet. If you could concentrate all of that water on an area of *one* acre, it would be 63.5 feet deep!

Therefore, if we could get *all* of the cloud water to fall out directly under the cloud as described, the average resulting precipitation under that cloud would be less than 1/2 inch! If the cloud travels any distance during the time the rain is falling, the water is spread out over a bigger area, so that the rainfall at any point would be reduced even more. This suggests that even getting 100 percent of the water in a cloud to fall out as rain isn't going to produce a lot of rainfall. In reality, a lot of the water condensed in a cloud would evaporate in downdrafts produced by the formation of rain before it reached the surface, so the real efficiency is going to be lower than 100 percent. In fact, the efficiency of isolated clouds at producing rainfall can be as low as 10 percent.

Moreover, this hypothetical cloud has a much higher liquid water content (1 g m^{-3}) than the typical cloud chosen for seeding by those who want to increase rainfall. The hypothetical cloud I've described is probably already producing precipitation, or about to do so. The total water content of a more typical cloud picked by cloud seeders is on the order of about 1/4 (or less) as much as my hypothetical example. Thus, the resulting rain at the ground from a seeder's typical target cloud, taking all of the foregoing into account, would be on the order of 1/100 of an inch! Not much of a result - just about enough to wet the sidewalk on a hot day.

5. Cloud seeding for precipitation enhancement

The transformation of clouds into rainfall (or snowfall) is essentially one of creating as large as possible a difference in size between the largest and the smallest droplets in a cloud. It is this size disparity that allows a few particles to grow large enough to fall out of the cloud as rain or snow. Therefore, there are some pretty basic ways to do this.

1. In **warm** clouds, we could introduce some droplets artificially that are larger than the usual cloud droplets. In effect, we could seed the clouds with a spray of drops that would eventually sweep up enough of the existing cloud droplets to fall out as rain. I am not very confident, however, that we could introduce enough of these "seed" drops to get much rain out of the cloud. What I know of warm clouds suggests that it can be pretty tough to enhance warm cloud precipitation via artificial means. [*In the natural world, warm clouds can be prodigious precipitation producers.*]
2. In **cold** clouds, we could create *artificial water ice particles*. Ice particles are quite effective freezing nuclei ... if they encounter a supercooled droplet, it almost surely will freeze. I know of at least two ways to do this. (a) "seed" the clouds with a "snow" made up of dry ice, which is so cold that it causes homogeneous nucleation ... the temperature of dry ice is well below -40 deg C. (b) use an artificial "snow" made up of crushed water ice.
3. Also in **cold** clouds, we could introduce *non-water ice particles* that have a crystalline structure close to that of water ice, to serve as freezing nuclei. Silver iodide is a chemical that has such a structure, and it is possible to create a "smoke" of silver iodide particles through burning that will contain many, many potential freezing nuclei. Other agents might also serve this purpose, but the principle would be the same as with silver iodide.

In order for the last two methods to have any hope of being effective, the seeding agent must reach and be widely dispersed within the layer in which supercooled water is present ... between the melting level at 0 deg C and the homogeneous nucleation level at -40 deg C. Enough freezing nuclei must be present within that layer to produce significant numbers of large water particles (frozen) that they can grow into meaningful rainfall.

Historically, there are three main ways to introduce seeding agents:

1. **ground-based generators** Clearly, ground-based generators must use seeding agents that will survive normal ground temperatures, so the generators typically produce a "smoke" that contains the seeding agent. The ability of ground-based generators to deliver seeding agents to the appropriate level in the cloud is open to question, except perhaps in situations where the clouds are being seeded to enhance snowfall in mountainous regions (where the ground temperatures are already below freezing and the generators are, effectively, already *within* the clouds).
2. **rockets or artillery shells** Again, these delivery methods must use chemical seeding agents. The Soviets used artillery for many years to introduce seeding agents as a mechanism for hail suppression. I'll have more to say on this later.
3. **aircraft** Delivery methods based on aircraft are relatively expensive, but have the clear advantage that it should be possible to put a large fraction of the seeding agent more or less just where it is intended to go. Using aircraft, some of the cheaper alternatives to chemical agents become viable, such as dry ice or crushed water ice.

It's worth noting that if seeding somehow converts cloud water to rain that will fall out of the cloud, it will also act to "kill" the cloud! The production of rainfall creates a downdraft that usually acts to destroy the cloud that produced it. Thus, if seeding *does* create rain, it's not likely to result in a particular location receiving very much rain on the ground. Nothing in the seeding process is going to make clouds last longer ... if anything, they might have the opposite effect. Nothing in the seeding process is going to make *more* updrafts and clouds, or make them move more slowly. In effect, cloud seeders depend on the natural processes to produce seedable clouds. Ordinary little cumulus clouds can't be seeded to produce rainfall ... they don't contain significant amounts of water in any form, so if nature doesn't provide a cloud that is already pretty close to producing rain, cloud seeding can't operate at all.

During droughts, the main problem is that day after day goes by with *no clouds at all*, or only little ordinary cumulus clouds that can't be seeded with any expectation of producing rainfall. Even the cloud seeders will admit that they can't do anything to break a drought if the natural processes don't produce deep clouds that are already close to producing rain Cloud seeding requires the presence of a "suitable" cloud for seeding. The definition of "suitable" is such that the cloud might well go on to produce precipitation even if it is not seeded at all! All that seeders can hope to do is wring a bit more out of such a cloud than would otherwise fall. However, production of precipitation produces downdrafts, which *kill* clouds, especially if the seeding is done too soon during the cloud's lifetime! This is one of the problems with identifying the true net result of seeding ... the desired effect can kill off the clouds, perhaps prematurely. There are lots of complicating factors here.

Suitable seeding targets are relatively rare ... consider the following table associated with the large scale vertical motion, assuming that the potential for cloud formation (moisture and temperature distribution with height) is otherwise favorable

Strong descent	no clouds - nothing to seed (typical drought conditions)
Strong ascent	lots of clouds - seeding isn't needed, as natural precipitation is virtually inevitable and substantial rainfalls are likely
Weak ascent	isolated clouds - considered poor targets for seeding since seeded clouds usually die out and new clouds may not form at all
Moderate ascent	best chance for seeding gains, but proper seeding strategy is needed and the chances for large total rainfall (natural + effect of seeding) are only marginal

If we want to produce a meaningful increase in rainfall at one point, we need to get *more* updrafts (i.e., the rising air that produces clouds in the first place), and then we need to get those updrafts to (a) last longer, (b) move slower. It is the large-scale conditions that make substantial rainfalls possible. Seeding increases of perhaps as much as 50 percent are possible only for certain conditions, and then only when the proper seeding strategy is pursued. The efficiency of the conversion of water vapor into rainfall typically can be increased only by making cloud systems that produce many updrafts, which can happen naturally but cannot be done with any known seeding technology.

6. Does seeding to enhance precipitation work?

The problem with knowing whether or not cloud seeding to enhance precipitation actually works is that precipitation usually varies a lot, both in space and time (shown in this example). Even in the absence of seeding, some years produce lots of rainfall in a specific location and not in others that are nearby. In other years, a place that received copious precipitation last year gets skipped and it falls somewhere else. This is called *natural variability*, and it is this natural variability that makes it challenging to know whether or not seeding was actually effective at producing rain.

If there was no natural variability (every day of every year, a fixed amount of rain fell, with the same amount falling everywhere on Earth), it would be very easy to detect the effects of any modification effort. It's pretty clear that the real situation is very different from this. The greater the variability, the harder it becomes to know whether or not cloud seeding (for any purpose) works.

On the whole, cloud seeding to enhance precipitation is going to be very difficult to distinguish from what Mother Nature produces naturally! Weather modification isn't going to break a drought, which is characterized by infrequent chances even to find clouds worth seeding. It's also clear that seeding only works when a cloud is pretty close to producing rain *without* any intervention at all. Seeders can do nothing to influence the numbers of clouds, nor their motion. It's not obvious that seeding makes clouds last longer ... if anything, they may shorten cloud lifetimes! The absence of sufficient numbers of *natural* freezing nuclei is not something that can be shown to be a very common problem and may not be a substantial contributor to the *lack* of rainfall in most cases.

Therefore, in order to do a proper experiment to determine the effectiveness of a cloud seeding exercise, accounting for this natural variability must somehow be done. Typically, this involves a complex experimental design, not all that dissimilar from the experiments that drug companies must perform in order to determine the efficacy (and safety) of a new drug. The main element in such experiments is that they be done in a so-called "double-blind" way:

Double-Blind Testing: In the drug industry, the patients are divided into two groups: a *control* group that only receives a "placebo" (a substitute for the treatment that is known to have no effect at all), and the *treated* group, who actually are given the treatment. The groups must be large enough for a proper statistical comparison ... the details of which are not relevant in this essay. What makes it a "double-blind" experiment is that neither the people conducting the experiment nor the patients know who is in which group until *after* the experiment is completed. This removes the possibility that patients who would be most likely to benefit from treatment could be selected for treatment; such biases can occur in spite of the best intentions of the persons doing the experiments. The double-blind procedure is the accepted way to remove any hint of such biases.

For cloud seeding, a double-blind experiment would be one in which a "placebo" is created for the seeding agent which cannot possibly have any effect ... perhaps an artillery shell that contains no seeding agent, or a generator that creates some inert smoke. No one conducting the experiment knows which clouds were actually seeded until after the completion of the experiment, including whoever operates the delivery system. Enough trials need to be conducted to ensure statistical significance of the results ... in practical terms, the trials have to go on long enough to have sampled the natural variability reasonably well. In general, this would require many *years* of trials!

Have experiments of this sort been done? Yes, although perhaps they are still insufficient to be absolutely certain of the outcome. And what was the outcome? The most authoritative assessment of the results can be found in the Policy Statement on Planned and Inadvertent Weather Modification, issued by the American Meteorological Society, adopted in 1992. I suggest anyone interested in this should read the whole statement; I offer the following excerpts here.

In layman's terms, the policy statement says that with the exception of some pretty specific situations, the results of carefully-controlled scientific experiments have produced essentially inconclusive results regarding the effectiveness of cloud seeding to enhance precipitation. It's clear that *seeding does affect clouds*, but what is *not* clear is that over the long haul, economically beneficial rainfall results from the process. Given what I've described about clouds, precipitation, and seeding, it's easy to see why solid scientific evidence in favor of cloud seeding is not going to be easy to come by. What results exist that are reasonably well-done support this contention. If the effectiveness of seeding was a really strong, robust result, then the outcome of these controlled experiments would have been different. Seeding might well produce rainfall increases, at least some times, but the effect cannot be very large!

This is hardly a dazzling endorsement of cloud seeding. I came to know about this aspect of weather modification when I moved to Boulder in 1982. During the fall of 1982, I transferred to a new job in Boulder, CO; in the Office of Weather Research and Modification (OWRM). This group included a number of former researchers in the Florida Area Cumulus Experiment (FACE), conducted in large part to be a definitive analysis of the efficacy of cloud seeding for precipitation enhancement. I came to know a number of these scientists personally and was impressed with the careful experimental design of

FACE, including the double-blind methodology. Great effort was expended in order to meet the experimental design requirements of a statistically valid "treatment " study. The outcome of the experiment was quite consistent with the statements I have summarized from the AMS Policy Statement. In short, this carefully-designed study by the Federal Government gave the usual inconclusive results. Partly as a result of this outcome, shortly after I arrived in Boulder, all aspects of weather modification in the Federal budget were "zeroed out" and all of us in OWRM experienced a "reduction in force" (RIF) action ... we had to find new jobs.

However, someone in the hierarchy of NOAA decided it was politically expedient to open a small office in Boulder that would manage the dispersal of Federal funds to some specific states that were supporting local cloud seeding operations ... notably, North Dakota and Kansas ... there may have been a few others. This office, managed initially by Dr. Joseph H. Golden, continued to operate for a number of years, but in 1986 I left Boulder and lost track of this operation. I don't know if something of the sort is still going on, or if it eventually dried up and disappeared, as well.

7. Some questions about safety

In additions to questions about the effectiveness of cloud seeding, there also are some issues tied to the potential negative impact of some seeding agents. Silver iodide (arguably the most common seeding agent), in particular, is toxic when ingested. It certainly can be argued that the seeding agents are very widely dispersed, so that any one location would get only a microscopic dose of this poison in its rainfall. However, there are at least two problems with this line of reasoning.

First, the seeding agent presumably is scavenged from the clouds and the air by the rainfall. Hence, the rain itself will contain and concentrate this poison. It might be taken up by plants (and eaten by livestock) or get into the groundwater supply. I don't know if silver iodide is like lead or not, where each dose accumulates, or if the agent is broken down quickly into some harmless by-product by some natural process. My suspicion is that this product does not bio-degrade readily. I also don't know if anyone has studied comprehensively what actually happens to silver iodide in the environment. There are many toxic chemicals that can have negative environmental effects even at relatively low average concentrations.

Second, if seeding with silver iodide were to become widespread and routine, the amount of the agent being dispersed would increase. What might be relatively safe at the current relatively low dosages might *become* hazardous if seeding becomes a normal behavior, unless it can be shown conclusively that the agent either bio-degrades harmlessly or does not accumulate to toxic levels from repeated applications for some reason.

It's not obvious to me that the environmental impact of seeding agents has been given enough careful consideration.

8. Seeding for severe weather modification?

a. Hail Suppression

As already noted, the Soviets made a number of claims during the 1960s (in the midst of the cold war, of course) for the success of their hail suppression methodology that employed artillery to dispense seeding agents. The science of meteorology remains incomplete when it comes to the understanding of hail formation. However, the principle behind using cloud seeding to suppress hail is the notion that if the zone containing supercooled water is filled with sufficient numbers of freezing nuclei, the overwhelming numbers of such nuclei will create a sort of "competition" for the available supercooled liquid water. Rather than being concentrated on a small number of very large hailstones, the result will be a large number of very small hailstones that will almost certainly melt during their fall below the melting level at 0 deg C. Thus, it is a sort of "overseeding" process that is envisioned to suppress large, crop-damaging hailfalls. Of late, the seeders have been changing their tune, and saying that their hail-suppression works but they don't claim to know the reason why! This is simply a way of altering their strategy, but doing it in such a way that it can't be tested scientifically at all!

During the 1970s, the National Science Foundation supported a field program to explore the validity of these claims by the Soviets. This program was headquartered in Boulder, CO at the National Center for Atmospheric Research and conducted several years of field operations, testing the notion that cloud seeding could indeed suppress hailfalls in what was known as the National Hail Research Experiment (NHRE). Northeastern Colorado is well-known to have a high frequency of summer hailstorms, so this location represented an excellent opportunity for this validating research. Again, the experiments were conducted with considerable care regarding experimental design, including the scientifically-mandated double-blind character. Since I was in Boulder, CO for four years, I came to know many of the participants in NHRE and, again, my take on the outcome of NHRE was that the results cast considerable doubt on the claims made by the Soviets. Here is what the the AMS Policy Statement says.

Like that for precipitation enhancement, this is hardly a ringing endorsement! NHRE came to an end and the subject of hail suppression by cloud seeding was closed as far as the scientific community as a whole was concerned. The import of these careful scientific studies is that the interpretation of the results simply does not permit a scientifically-valid statement in favor of cloud seeding to suppress hail. In spite of the ambiguous scientific results, a number of state-based weather modification programs, notably in North Dakota and Kansas are being funded to suppress hailfalls. In these commercial programs, essentially every storm that can be seeded is going to be seeded. There can be no scientific assessment of the results of such a blanket seeding project ... there is essentially no way to remove the effects of natural variability and, therefore, no claims for efficacy can be supported scientifically.

Some seeding advocates maintain that NHRE's seeding operation was done badly and might be improved upon with today's technology and the experience of commercial seeders. No plans exist at present to redo such a scientific experiment, with all the proper controls for a period long enough to account for natural variability. This is arguably a shame, since so much cloud seeding is being done today in the name of hail prevention, and various claims have been made by commercial seeders which, at the moment, cannot be evaluated. All we can say is that the preponderance of evidence suggests that seeding for hail prevention *might* be effective, but it's not possible to be certain that it is. The absence of any commitment to new experiments suggests the scientific community remains reluctant to revisit the issue, unless something dramatic can be shown to change their collective minds.

b. Other severe weather (esp. tornadoes)

Recently, a cloud seeding company in KS indicated that they might have "prevented a tornado" with their cloud seeding. This suggestion followed in the wake of the absurd notion put forward by President Clinton in his speech in OK after the 03 May 1999 tornado outbreak there, that research should commence into mitigating tornadic intensity artificially ... another form of weather modification. I've talked about the President's speech elsewhere. This story appeared in the Wichita Eagle:

The suggestion made by this company is not scientifically credible ... on the day in question (18 June 1999), according to the cloud seeders, the seeded storm in KS produced a hook echo (indicating it probably was a supercell) and some brief "dust whirls" before it dissipated. The lack of a sustained tornado from this storm was taken to indicate that seeding had terminated tornadogenesis before it could be completed. However, I have seen a lot of *unseeded* storms do exactly the same thing! This is a common evolution for storms on the plains ... in fact, it's a lot more common than for storms to go on to produce tornadoes. Where is the compelling evidence that the evolution followed by the KS storms was a result of the seeding and not perfectly natural?

How similar were conditions in OK and KS that day? I've seen storms that were a lot closer together than the ones in KS and OK, where one produced a tornado and the others did not. I know of no scientific explanation for this behavior in storms that are so close together ... it may well be that conditions that affect tornadogenesis can change significantly over a distance as small as 10 miles or so. The storms on the day in question were more than 100 miles apart, so I have every reason to believe that the conditions in OK favored tornado production while conditions in KS were not quite so favorable. It is quite typical for this kind of variability to occur! (see previous discussion about natural variability) To attribute the difference in behavior to cloud seeding would require an enormous leap of faith that I am quite unwilling to make as a scientist, and I'm confident that most meteorologists would concur that this example is vastly insufficient to make a plausible case for tornado mitigation.

The KS cloud seeders may be trying to climb onto the Presidential bandwagon (!) and start to profit from the fear the public has of tornadoes. Perhaps they even hope to cash in on a Federal grant? For the record, the AMS Policy Statement says, on this topic, that

> No sound physical hypotheses exist for the modification of tornadoes, or of damaging winds in general, and no scientific experimentation has been conducted. Experiments have been carried out to suppress lightning but have not yet yielded methods sufficiently developed for application.

I've also seen KS storms on 31 May 1999 near Meade and Sitka, KS that were seeded (I saw the planes doing the seeding!) go on to produce 4-inch diameter hailstones and significant tornadoes. My storm chase report for 1999 describes this event. Apparently, seeding was discontinued before the storm produced the Sitka tornado. For all anyone knows, seeding might even *help* some storms produce hail and tornadoes. No one really knows, of course ... but the seeding goes on. In the summer of 2000, a killer tornado in Alberta, Canada hit the small community of Pine Lake, plowing through a campground. The storm that produced this tornado had been seeded, and some controversy about that continues. In the spring of 2002, the storm that produced the Happy, Texas tornado on 05 May had been seeded earlier, although seeding operations were suspended on that storm more than an hour before the tornado. I'll have more to say about effects of seeding downstream from seeding operations, later.

9. Another tornado mitigation idea?

Another misguided notion of weather modification has been the subject of a recent media "blitz". This is apparently due almost entirely to a Dr. Eastlund, whose basic idea is to disrupt the activities of potentially tornadic thunderstorms by using some very expensive technology left over from the 1970s "Energy Crisis" ... microwave beams from solar-powered satellites.

Dr. Eastlund and I have had some exchanges.

Some have argued that if we scientists don't get involved in "tornado modification", then the way is clear for folks with bizarre ideas (like Dr. Eastlund or the cloud-seeders) to grab the money that is going to be thrown their way, in the interest of seeking solutions to the "tornado problem". Who could be against mitigating tornadoes? My response takes the following form:

If the only argument against weather modification is the loss of storm chaser entertainment or some vague abstraction about not messing with the environment, then the foregoing argument certainly holds sway. However, consider the following:

> 1. What is the track record of our technology when we interfere with natural processes? It's not that it's somehow not our role to do it, but rather we invariably run into unintended consequences. Unintended consequences are a direct result of not understanding those natural processes thoroughly. Building a single home to create a microclimate doesn't do much, but consider the consequences of *billions* of homes ... the loss of forests, the many negative impacts of mining natural resources to provide other homebuilding materials, the many negative impacts of the energy required to heat (and cool) all those homes, etc. What is obviously beneficial and of trivial impact for one person or one family becomes a problem of considerable impact when multiplied billions of times over. Is everyone so selfish that they only consider what is beneficial to them and to hell with everyone else?
>
> 2. Suppose it's possible to mitigate tornadoes, somehow. Many scientists admit that we don't *know* what tornadoes are "for". If they have no meaningful role in the atmosphere, but rather are simply freak accidents, then perhaps eradicating them is an unmitigated good. Since we currently don't *know* if that's true, do we really want to eliminate them *before* we've satisfied ourselves that doing so has *no* negative consequences? If it turned out that we could change the natural world in this way and there were *no* (none, nada, zip) negative consequences, that would be the first time in history that such a thing was found! A truly meaningless act of the atmosphere? Sorry, I've got my doubts!! If, on the other hand, tornadoes serve *some* purpose, then eliminating them means that there would *have* to be some change, and that change *might* be something as undesirable as the tornadoes themselves. We just don't know, of course. In the more or less closed system of the atmosphere, it's a zero-sum game!
>
> 3. O.K., suppose it's possible to mitigate tornadoes, but only with *some* negative impact. Since I have no clue what that might be, we can't talk specifics. Further, let's suppose that we continue to be unable to predict precisely which storms will and will not become tornadic. To be safe, we would have to act on some large number of storms, many of which might *not* have produced tornadoes naturally. We also might choose *not* to mitigate some, just because we didn't realize at the time that they were going to become tornadic. [*This sounds a lot like our situation re tornado warnings, at the moment.*] Let's ignore the possibility that our method for mitigating tornadoes in some storms might enhance the chances of tornadoes in other storms. Depending on just *how* we mitigated the tornadoes, we might be preventing (or reducing) some of the otherwise beneficial processes associated with that storm (like rainfall).
>
> If, on the other hand, we chose to limit our mitigation efforts only to those events where we consider their unmitigated evolution to be particularly dangerous to humans (Who cares about tornadoes over the desert, for instance?), just how would we go about selecting *which* storms to mitigate, in the face of considerable uncertainty over which storms are actually going to be tornadic *and* interact with humans. The tornadic storms on 3 May 1999 produced their first tornadoes in open country with little or no impact. Will our methodology for mitigating storms allow us to wait until the storm approaches a populated

area, or would we have to act on just the *possibility*? Lots of problems here. The more storms we mitigate, the more negative impacts we accumulate [That's my working hypothesis, here ... that there *are* some negative impacts.]. The fewer storms we mitigate, the more likely a tornado will strike someone because we chose to not act on that storm.

4. I think pledging our scientific resources expressly to the task of mitigating tornadoes will serve primarily to legitimize the aspirations of the crackpots. They won't simply go away because some scientists are working on tornado mitigation. In fact, they'll use that research as the justification for *their* ideas! "See, even the government is trying to do what I proposed to be doing, now! It's just that they're too stupid to see the brilliance of *my* method!" As I said, *the argument will not be over the intent, only the means.*

Dr. Eastlund's idea is not the only one advanced to mitigate tornadoes. Some of us are getting "ideas" about tornado prevention all the time, most of which are crackpot schemes (see Item #26 here). I hesitate to use the term "crackpot" in connection with the cloud-seeders, although they have virtually no substantive evidence to support them. Nor do I wish to label Dr. Eastlund a "crackpot" ... instead, I think of him and his colleagues as *misguided* and naive about atmospheric processes.

10. Standards of evidence

It has been argued (notably, by commercial cloud seeders), that we scientists have excessively high standards of evidence. The typical notion in statistical testing is that we be 90 percent or 95 percent confident that the results of a trial were not the product of mere chance. Some seeders want to turn this around, and say, "Suppose there is a 5, or 10, or 15 percent chance that the seeding is having the claimed effect. Isn't it worth the risk (to the consumers) to take such a gamble on cloud seeding?"

This is a specious argument, of course. Statistical testing in science is not intended to produce results at some specified level of confidence; rather, *it is intended to allow the results of an experiment to be distinguished confidently from pure chance occurrences.* Given the natural variability of precipitation, even if the seeding truly had no effect, some areas would have more hail than average, some would have less. It is also true for random processes that for a small sample, things don't necessarily "even out", especially in small samples (samples that can be strongly influenced by natural variability). Clusters and gaps are typical of random processes, so if a particular area has several years of below-average hail, this still does not mean that the seeding that went on is necessarily the *cause* of that run of below-average hail ... it may just be luck. In effect, with a small sample, such things (e.g., a run of below-average hail occurrences) are *expected* and do not constitute any credible evidence that the result is due to seeding. The more natural variability there is, the longer the test has to be in order to be confident that the results are not the product of pure chance.

In the journal article, Gabriel (2000) [`Gabriel, K.R., 2000: Parallels between statistical issues in medical and meteorological experimentation.` *`J. Appl. Meteor.`*`,` **`39`**`, 1822-1836.`] has considered the case for weather modification by cloud seeding. Here are some excerpts from that article: Clearly, Prof. Gabriel and I both find it useful to consider analogies with the medical field, for considering proper standards of proof of efficacy and safety.

11. Hygroscopic versus glaciogenic seeding

It is interesting and timely that Prof. Gabriel brings up the issue of hygroscopic vs. glaciogenic seeding. Recently, there have been some media articles concerning recent research findings that lead some scientists to wish to re-open the possibility of seeding (i.e., within the scientific community, the topic has been considered closed!). The Washington Post carried an article, excerpts of which I present here.

All of this "excitement" (and controversy) is being created by attempting to modify the precipitation from a cloud by adding hygroscopic nuclei, rather than nuclei to stimulate the production of ice (glaciogenic seeding) ... see the discussion in section 3 (above) for the role of hygroscopic nuclei in promoting the condensation of water vapor. This can take place in either warm clouds or in the parts of cold clouds that are at heights below the melting level. Apparently, by seeding the updrafts of clouds, more water droplets (cloud droplet-sized or larger) are produced, which *might* augment the production of precipitation.

This still depends on the presence of a cloud that is already close to producing precipitation. It will not have any impact on a drought, just as glaciogenic seeding does not alter a drought. The samples being cited are still small and the scientific community (whose prime directive it is to be skeptical!) includes a number of doubters regarding the possibly overoptimistic pronouncements embodied in this newspaper article. Science is not adjudicated in the media and conducting "science by press release" is perilous (recall the flap over cold fusion!). It will be many more years before the potential of hygroscopic seeding has been evaluated thoroughly enough to satisfy the rigorous standards of scientific evidence. Will this prevent unscrupulous seeders from exploiting the situation? Probably not.

12. More on unintended consequences

It seems to me that human history is full of examples where some negative impact of a seemingly harmless application of technology only became clear after years of widespread use of that technology. At that point, it was going to have serious economic implications to change the technology to prevent that unintended consequence. Once big money is at stake, it gets pretty hard to change things!

In spite of assurances from those with vested interests (see the next section), unintended consequences are inevitable. In all of our intervention with the environment, no technology can properly claim to have only beneficial results. We may well choose to ignore those unintended consequences, or we might decide that we don't care enough about them to give up our environmental interventions, but it just cannot be claimed that interference with the natural environment is without its negative impacts *somewhere*. Yet this is *precisely* what cloud seeders claim! "Our seeding for rainfall enhancement didn't create that tornado, that hail, that flash flood." "Our seeding for hailfall suppression didn't kill off the precipitation from that cloud." "Our seeding didn't cause someone to lose precipitation." In other words, we will not accept responsibility for the possibility that what we are doing might cause harm, as well as benefits.

Now it is just as hard to prove negative consequences as it is to prove benefits. The cloud seeders have been particularly adept at using this to argue in court that the plaintiffs can't prove that the seeding had a bad effect. And they've won the majority of their cases, perhaps owing to ignorance among lawyers, judges, and juries about how science really works. Nevertheless, if the seeders are going to make this kind of argument when they wash their hands of any responsibility for bad weather events, they can't *logically* turn around and make legitimate claims for the efficacy of their efforts, either. But that's precisely what they do!

This sort of argument is simply specious and flies in the face of decades of accumulated experience with environmental interference. It would be the first time in history that human intervention did not have *some* negative consequences, as well as some benefits. To make this claim suggests that either the seeding companies are dissembling, or they're ignorant. In either case, such claims are literally incredible, and without any basis.

13. Vested interests of commercial cloud-seeding companies

Clearly, commercial firms have a vested interest in maintaining the belief that weather modification by cloud seeding works. It is quite possible that most of these firms are "true believers" in what they are attempting to do, in spite of decades of inconclusive *scientific* evidence about the efficacy of their procedures. Whether or not they actually believe in what they are doing, these firms have convinced a lot of citizens that they are getting their money's worth. Of course, no number of testimonials from satisfied customers is equivalent to a careful scientific study. [*There used to be testimonials galore in support of snake oil remedies for everything from rheumatism to cancer, too.*] I have shown that the cloud seeders preclude a proper *scientific* test by seeding everything they can! Thus, science can only say that there is no *scientific* evidence in support of these claims of efficacy.

As long as people have a need for more rainfall (or the suppression of hail, or both) and are willing to pay someone to do something about that need, there will be companies to "serve" that need. I am perfectly willing to let the buyer beware ... if the buyers of such services believe that they are getting their money's worth, who am I to say that they shouldn't be able to do it? Clearly, the cloud seeders have the capital to have considerable political clout as well, including getting *state* funding for their programs! It is when such programs receive public funds that I have a problem, since the safety and efficacy of seeding are so much in doubt, it's not clear that the public should be paying for this "service".

14. Claims and responsibility

There are some interesting questions that should be answered when cloud seeding is done:

- **Environmental impact ...** Many cloud seeding agents are toxic chemicals. Sure, the amount of such chemicals per acre is pretty low, but we have found over and over that even trace amounts of toxic chemicals can harm the environment. *Where are the environmental impact studies that would support the lack of any negative environmental effects, especially if seeding becomes widespread and more frequent?*
- **Robbing Peter to pay Paul ...** Let's assume for the moment that cloud seeders consistently are able to wring rainfall out of clouds that would otherwise not have produced any rain at the location where the seeding took place. *Isn't this potentially stealing water that might have fallen elsewhere? Couldn't citizens "downstream" of the seeded area sue in order to get compensation for this "stolen" precipitation?* I've heard that this sort of thing has been tested in the courts, and the cloud seeders have argued that the folks downstream can't prove that the seeding actually resulted in a loss of precipitation. But this is arguing it both ways, folks. For their customers, they argue that their methods work .. but if they get sued, they say it can't be *proved* that their methods

work! If this technology can be shown to work in a conclusive way, then there's no doubt these guys are stealing water from *someone*! Unless seeders can get show they somehow can violate the law of mass continuity, they are simply *redistributing* rainfall, not creating water at the ground out of thin air.

- **Unintended consequences ...** Again, let's assume for the sake of argument that cloud seeding actually accomplishes a consistent effect, enhancing precipitation and perhaps even reducing hailfall. If there is anything we truly know about the environment, it's that we really don't understand the environment very well. Isn't it possible that *any* sort of meddling with the environment might create unintended consequences, as well as benefits? The track record of human intervention in the environment isn't very good! I know it for a fact that if we have some given effect on atmospheric processes, even something as modest as changing the amount of rainfall from a cloud, it is not scientifically possible to predict with any certainty what the consequences of that might be. *If we don't know precisely what the outcome of cloud seeding might be, do we really want to be doing it?*

As I've already noted, this attempt to claim only positive outcomes is logically and scientifically absurd.

a. One man's meat ...

Seeding to enhance rainfall can have negative consequences for certain crops at certain times. If a farmer has cut hay for harvest, more rainfall is a bad thing, whereas in the next field, that same farmer (or the neighboring farmer) might have a corn crop that desperately needs that rainfall. Farmers might be delighted with rainfall while a contractor pouring concrete on a schedule would be quite devastated. It is not always possible to have everyone be equally happy with the outcome of intervention in the natural weather ... in fact, it probably is impossible to have everyone benefit and no one suffer. Are seeders willing to accept the responsibility for negative outcomes of their operation, should it be possible to prove conclusively that a given event was indeed linked to that intervention? Almost certainly not.

Consider the alternative, however. If it is *not* possible to conclude (on the basis of a careful scientific assessment) that a given outcome could be linked causally to the intervention, isn't that something bordering on fraud when the seeders are being paid to produce a particular outcome? Again, they shouldn't be able to have it *both* ways!!

b. Downstream effects

Some seeding advocates go so far as to say that the [beneficial] effects of a seeding operation can persist well downstream of the area in which the operation is conducted. This seems to suggest some disturbing possibilities. First of all, why pay for a seeding operation if you can convince areas upstream to do it and then you can reap the benefits at no cost? Second, it might be that lingering effects downstream of a seeding operation would be viewed as nearly universally negative. That is, those downstream might not want the enhanced rainfall! Claiming that seeding has downstream influences is dangerous and opens up the possibility for those downstream to sue the seeders for any negative effects of their operation.

c. More unintended consequences?

Again, if there are, indeed, downstream effects, then it might also be argued that tornadoes or other severe weather might be the result of upstream seeding operations. If the seeding advocates are willing to accept responsibility for lingering *beneficial* influences of their operation downstream of the seeded area, this seems to open up at least the possibility that they could be deemed liable for damaging influences from those operations. I would think that seeding advocates ought to be reluctant to make such claims, even though some are indeed doing so. Sure, it might be difficult to show conclusively that the bad effects were produced by the seeding ... indeed, it should be just as difficult as it is currently to show that seeding has any beneficial effect. But if the seeding produces benefits, isn't it logically necessary to also accept the responsibility for some negative consequences? I'm not accusing the seeders of anything, but merely asking the extent to which they wish to claim responsibility.

d. Designer clouds?

It seems the seeders are making the claim that they can make a cloud do pretty much whatever they want. They claim to have seeding strategies that can produce more rainfall, or less hailfall, or both, without producing flash floods, and without killing off beneficial rains. Scientifically, my understanding is that we cannot yet predict with any hope of accuracy the behavior of a single cloud or even a fairly large grouping of clouds. If the science of meteorology is unwilling to claim it can predict such things, how is it that cloud seeders can go the scientists one better? Not content with showing off their ability to make accurate predictions of cloud structure and evolution, they assert that they can control that structure and evolution with considerable precision. Sorry, but I'm from Missouri (I actually *lived* in Missouri for a while!) - they need to show us ignorant scientists their secrets before we are going to accept their claims with anything but utter contempt. This is a good example, in my opinion, of the arrogance of these claims.

15. Discussion

These companies have attacked research scientists who argue against cloud seeding, by trying to portray themselves as the servants of the "little guy" - just trying to help farmers do a little better - while we scientists are pointy-headed intellectuals who want to keep on doing research while the citizens suffer needlessly. This is a completely specious argument, but it sometimes plays well in the local press: the poor citizens against the government bureaucrats, who are in league with the uncaring scientists, and all. And the politicians who have bought into cloud seeding can be powerful allies. Further, some plains citizens are notoriously unconcerned about environmental impacts, at least until it starts hurting their yields. Then they want the *government* to bail them out!

On the other hand, I've recently seen an increase in the number of concerned Plains citizen groups who want to return to "natural" weather. It seems that the sentiments against seeding operations are growing out of the "grass roots" within the agricultural community. Some folks feel that seeding is producing harmful side effects ... others believe that the money they are paying for seeding is being wasted because they aren't getting any observable benefits. Most do not want to be used as "laboratory rats" for unproven technology. In my recent experience, these groups have been successful (see below) at getting seeding operations terminated. It's a marvelous thing to see directly that **American democracy at the local level still works when citizens choose to exercise their right to demand change!** These concerned citizens deserve the credit for being successful in achieving their goals.

IMPORTANT NEWS FROM THE FIELD

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1. As of the November 2000 elections, Thomas County, KS has joined Rawlins County,
KS in discontinuing seeding operations. Citizens voted 2-1 against the operations in
a "non-binding" vote added to the ballot. On 22 October 2000, I gave an
informational presentation in Colby, KS at the invitation of citizens who wanted to
return to "natural" weather.
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2. As of 01 October 2002, the TX High Plains Water District voted 4-1 to suspend
seeding operations, in the face of organized opposition to seeding from citizens
within the district. On 25 September 2002, I gave an informational presentation in
Littlefield, TX at the invitation of citizens who wanted to return to "natural"
weather.
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Of course, *inadvertent* weather modification is rampant world-wide these days, as a result of human activities (e.g., the possibility of human-induced global warming, the destruction of the ozone in the polar stratosphere, contamination of the air with cloud condensation nuclei from pollution, etc.). Those inadvertent activities need to be considered in their own right, of course. It certainly is true that strictly "natural" weather may no longer exist over much of the planet. But **citizens still need to decide whether or not they want to have *planned* weather modification.** Cloud seeding advocates blaming bad weather on inadvertent weather modification rather than their seeding operation is only a smokescreen (pun intended) to divert attention from the issue of whether or not we want cloud seeding operations to continue. In my mind, cloud seeding remains, as it has been for nearly a century, an *unproven technology* that might have serious negative consequences for which the seeders continue to deny any responsibility.

Should anyone believe the propaganda put out by these cloud seeding firms who, after all, are *profiting* from their operations? The tobacco companies put out a similar smokescreen (pun intended, again) of propaganda regarding those researchers who wanted to call attention to the health hazards of smoking. All they needed to do was instill some doubt in the minds of the public about the validity of the health hazards and most smokers would keep on smoking. These cloud seeding companies have everything to gain by maintaining the illusion that their operations produce results without any negative consequences, but would lose everything if the paying citizens lost confidence in their ability to make rain (or reduce hailfall), or if someone became concerned about possible negative consequences.

Why *would* anyone believe the arguments advanced by someone with such an obvious self-interest? I think it's because some people desperately *want* to believe that cloud seeding works, especially the customers of these cloud seeders. Our culture has instilled in many of us the idea that if our environment creates problems for us, those problems can be solved through the application of technology. Unfortunately, **cloud seeding to enhance rainfall and reduce hailfall without any bad impacts sounds too good to be true ... because it almost certainly is**!

In effect, these companies are profiting from the misfortunes of those who suffer from the vagaries of the weather. They raise hopes without any substantive evidence in favor of those hopes. People *want* to believe that the money they invested in cloud seeding is paying off. If there were clear evidence that cloud seeding truly worked as claimed, it might be a different story .... although my questions (above) still need consideration. However, since there is no such convincing (scientifically credible) evidence in support of these operations, I think at least the customers should be made aware of the fact that **most atmospheric scientists** (including many, like myself, who have nothing either to gain or to lose should cloud seeding be discredited) **do *not* believe in the efficacy of weather modification by cloud seeding** ... as evidenced by the AMS Policy Statement (above). If most atmospheric scientists don't buy this, then should citizens prefer to believe the cloud seeders?

It seems to me that if we must have cloud seeding, citizens should hold cloud seeders and their advocates to the same standards required of the drug companies in marketing *their* product: double-blind trials to prove both *efficacy* and *safety* (lack of bad side-effects, which I referred to earlier as "unintended consequences"). No drug goes on the market without the proper clinical trials ... **no cloud seeder should be allowed to sell cloud seeding services without scientifically-sound evidence of its efficacy and safety**.

Moreover, it should not be up to the *taxpayers* to foot the bill for this costly and necessary research, especially at the local level. Unless seeding advocates can come up with a compelling reason to assert the significant efficacy of their operation, **why should the taxpayers be forced to foot the bill for expensive research on an issue where it has already been shown that the beneficial effects of seeding are dubious and marginal, at best?** Let the seeders take on the burden of proving their technology, as the drug companies have to do. The drug companies pass the costs for this on to the consumers, of course. It would be fair for seeders to do the same, but only ***after*** they have shown conclusive scientific evidence that their methods are both effective and safe.