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Increasing Rain Artificially

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DROUTH HAS BEEN A PRESSING PROBLEM in the Southwest for fifteen years. The present drouth is generally regarded to have begun around 1942 in the California area and, though it is hard to define these things exactly, it is seemingly progressing eastward. Arizona has had deficient water supply since 1941 and we are all up against a problem that is a peril to the economy of the Southwest. All must be concerned with it.

When you study what is known about the long-term fluctuations of climate, and fluctuations of precipitation in particular, you find that what is happening now has happened many times before. It occurred long before there were cattlemen grazing the West and, let's say, wheat farmers in Kansas plowing their fields. Drouth has come and drouth has gone. It is not clearly understood, metorologically—lots of work has been devoted to it—but we do know it has occurred many times before and in much more serious proportions than we see it now.

The tree ring studies at the University of Arizona have thrown a lot of light on this problem, extending back to the earliest parts of the Christian Era. We find, for example, that in the period 1273 to 1296 there was a drouth of such intensity that there simply were no tree rings laid down on the trees. That has never happened since that time. Why did it occur then? We don't know.

What I want to do here with particular reference to the cloud seeding problem is to trace briefly the history of how cloud seeding has come to where it is in 1956. Then I want to try to tell you in non-technical terms, speaking as I am to non-meteorologists, what the big problems are right now; what I think, in my own opinion, the possibilities are as of 1956; and finally, I want to tell you what I think ought to be done. This seems to me to be fulfilling the reasons for my coming here.

Cloud seeding began in its modern era, as distinguished from early fraudulent attempts, in 1946. Within a couple of months one might celebrate the tenth anniversary of the discovery of dry ice seeding by Schaefer in the General Electric Laboratories. Its discovery is an interesting example of what often happens in research. They were after something else. I am not going to emphasize the details. Schaefer happened to put dry ice into a cold box. He put dry ice in and lo and behold, he saw a super-cooled cloud of drops, that is, liquid water at sub-zero centigrade temperatures, turn into ice crystals. Schaefer had the presence of mind and the breadth of awareness to realize that this was a significant, incidental phenomenon, and today we are talking about what happened as a consequence.

This is the research Phenomenon that Langmuir himself likes to preach about that is called serendipity. Serendipity is the general principle that if you will go out looking hard enough for anything, you will certainly find something. The Princess of Serendir went out looking for certain treasures, according to the old fable. She didn't find the treasure, but she looked so diligently that she found other things equally valuable. Langmuir is a great exponent of serendipity and the very discovery of dry ice seeding was an example of this principle.

What happened after 1946 was a peculiar thing in many respects. It turned out, you see, that after the first few months of GE laboratory research on this phenomenon, it was widely known that dry ice thrown into super cooled clouds would induce super cooled droplets to freeze into ice crystals. It was already suspected that this freezing action might possibly initiate one of the two main mechanisms for precipitation. (One of the two main mechanisms for the growth of drops large enough to be counted as rain must begin with ice crystals in the very cold upper reaches of the clouds.) Schaefer knew this. He saw just what might be done with this and did it. His colleague, Vonnegut, quickly sensed that if this could happen with dry ice there might be other ways of doing it, and purely by studying a table of crystallographic properties, he went up and down the columns until he finally found a substance whose crystal properties, dimensions and crystal habit, were very similar to those of ice, the thought being that perhaps one could fool the water into crystallizing on such a particle. He found the proper distances and crystal habits in silver iodide, which is the seeding agent we all talk about now. That is how it all happened.

This all occurred within a very few months late in 1946 and early in 1947, and then something happened that was really unfortunate from the point of view of science, in a sense, but if you look at it a little further, it is perhaps not so unfortunate. Briefly, it was possible then for just anybody to go out and start seeding clouds. It was not intrinsically a difficult thing to make a pass at it and the rush of amateurs that burst onto the scene was quite phenomenal. It led to great confusion. People with no training at all and no awareness of the complexity of what they really were dealing with could, in a little airplane, go out and throw out dry ice; could make these thing called silver iodide generators; and off the parade went.

That phase had a relatively short lifetime because people were not fooled too long about the requirement that you do something resembling the scientific approach. So there next developed, late in the 1940's and early in the 1950's, the business approach. This was where rather substantial seeding enterprises were undertaken. Seeding businesses formed and some failed. There are now about a half-dozen of some size in the country. That was the next stage of the cycle, where it became a business effort to make contracts with various groups to seed clouds. The little operators with one plane or one silver iodide generator went out of the picture, but, of course, not entirely, as we all know.

However, concurrent with that development was the development of the point of view that might be summarized with the statement—"Let's get the facts." A great deal of meteorological research began to concern "cloud physics," whereas before 1946 the term was scarcely in the vocabulary of the meterorologist. The amount of research that went into this terribly important problem of how water gets out of the sky and into the ground was, before 1946, almost negligible. Now, fortunately, we see a great deal of effort going into study.

What happened as more and more effort was devoted toward studying this process of how clouds form and how they lead to precipitation? The answer is that the problems appeared more and more complex. I think this is a familiar occurrence in research. The closer you look at anything, the more that complexity comes to light. But in cloud physics this was essential complexity. This wasn't just a question of more little by-ways to go into after the main points were settled. These problems were essential to the very thing that we were trying to do, which was trying to make rain, the knowledge concerning which was uncertain; and this knowledge was truly essential to the whole problem.

It was fortunate that by the late Forties, about at the same time the big seeding companies came into the picture, universities and other agencies around the country began doing cloud research, and this is going on with increasing tempo right up to the present. That is pretty much a thumb-nail sketch of where we've been and where we've gone.

The periods I have summarized here might be broken down as follows: (1) The period of initial discovery and exploitation, which was very short, measured in months; (2) the period of a couple of years of what you might call "barn-storming," which is a more appropriate term than might seem at first glance; then came (3) the advent of extensive commercial seeding, and concurrently the advent of a "Let's get the facts" approach.

The reason there has had to be a lot of hurried cloud physics research is that meteorologists were really caught unprepared by Schaefer's discovery of 1946. Even now they know only a fraction of what they must learn in order to exploit intelligently the possibility of triggering the release of precipitation. The main message that I want to get across here can be summarized in this sentence: We just do not yet know where and when seeding is economically feasible. Looking at it from the practical and scientific point of view at the same time, I say we do not yet know where and when seeding clouds is economically feasible.

Is that the picture you get from reading the papers? Particularly in Texas, say during the last few months? I do not think so. While in Dallas for a time yesterday I went to the Weather Bureau and took a look at the weather maps. Then it occurred to me that Weather Bureau offices always keep a file of clippings about all the things pertaining to weather in their area. I asked to have a look at their recent clipping file, knowing that Dallas and Fort Worth have been concerned with the seeding question. The more I read the more disturbed I became at the extreme discrepancies between the newspaper articles and what I consider the scientific status of this problem. There just is no parallel. I don't understand the scientific basis for the positiveness of some seeders' claims. I would like to ask representatives of the Water Resources Development Corporation, which was the seeding firm concerned in most of these Dallas clippings. "How do you know that when Stephenville had 6 or 8 inches and one of your target watershed areas got about 4 (I forget the exact figures) that you were responsible for any of it?" Most of it fell well down outside of the watershed, if I have my geography right, yet a little of it fell up there. In the newspaper stories the claim was made that seeding had caused a "finger of rain" to go up into the target area—150 miles away. I would like to know how in the world anybody thinks he can know that they put that rain up there because the complexities of that problem, when you look at it as a cloud physicist, are so great that it seems ridiculous to make such a claim.

With nearly a dozen scientists on the ground and in airplanes, at the Institute we've been doing a comparatively simple test of what happens to particles released from the ground. We are not releasing silver iodide; we are releasing fluorescent zinc sulfide, a tracer agent that can be detected quantitatively by ultra-violet irradiation techniques. Whatever happens to this micro-size stuff will also happen to silver iodide. We have a difficult time keeping track of where this material goes with all these people at work on it, using airplanes and double-theodolite pilot balloon observations on the spot. It goes over a mountain and we, half the time, aren't anywhere near it. It is very difficult to anticipate just where tracers and nuclei really go in the presence of mountains and even in the presence of ordinary amounts of turbulence; and when you add to that difficulty the unknown factors involved in the "turn-over times" of material entering clouds and going out, the short lifetime of clouds, and the general ignorance about the structure of clouds in any part of the country; then find that the public is being told, "We produced fifty per cent of this," or what have you, "150 miles from the release point," then I ask the question, "How in the world do you really know this with the degree of positiveness you claim to the public?" I for one do not understand it.

I was frankly annoyed with another clipping. There was someone in Dallas, possibly a TV broadcaster, who, if this clipping was correct, objected that there isn't much known about these seeding problems, that the claims are not proven facts, and that one cannot be quite sure about having produced observed effects. A representative of the Water Resources Development Corporation objected, and asked "How can this fellow who is not an expert in this complex,field say what happened?" The article went on to say that this seeding firm has a staff of over one hundred people—climatologists, chemists, physicists, and so on. I know only a little bit about the staff of that corporation, but I suppose I know about what they might be able to do and what they might not, and I am therefore not impressed with this rebuttal. The TV man was essentially stating what, in my opinion, is the consensus of scientists at this present time. The efficacy of seeding is not proven. One does not know enough about this vast and complex subject to be dogmatic about it at all. Then to find that one who urges caution and close scrutiny of strong claims is criticized as a mere non-expert makes me want to pose as an expert and say that I agree with the TV forecaster in suspending final judgement.

This problem of how the public has gotten its information is very distressing to me and to many of my colleagues. It is a "case study" in the relationships between science and business and the public. There are many other examples of it and they all have similar features. If there is a controversial area where there become vested interests of some sort tied up with one point of view, let it be a pollution problem, let it be a new drug, cloud seeding, or what have you, and then if there are scientific possibilities, but also scientific ambiguities and uncertainties, then I say, the public all too often gets a very distorted view.

One of the reasons for this distorted view is the nature of newspaper reporting. I was rather naively unaware of this before I went to the Institute, but being out there where we are known as a group working on a problem which has lots of public interest and potential importance, we've again and again come up against the problem of how to get clear-cut information into newspapers. And the thing that all too often happens is that the newspapers want to take something and look for the sensational aspects of it. They long to take the cautious "brave new world" comment of a scientist out of context; or sometimes they will look *only* at the person who talks the line of "the desert will bloom again" in this field of cloud seeding, and then that gets spread over the newspapers. It's no ill faith on the part on any newspaperman; it's what makes papers sell, and it's what the City Editor wants, but it's a real problem because in the end the public doesn't get the true picture. The public doesn't want to hear me talking to you about how many monolayers of water are absorbed on silver iodide when it is photolyzed vs. the much larger number when it is unphotolyzed. They don't have the patience with this, unfortunately. All that they read is that we can make fifty per cent increases; that we seeded; and after we seeded, it rained. The most egregious lot of *post hoc* reasoning that I have ever seen in my life has come about because of seeding. This is a problem, and a serious one, whenever it involves the name of science.

We had an international conference at Tucson last April to assess the present status of cloud modification. There was quite a bit of controversy that centered around some parts of this problem, notably controversy centering around the report of the President's Advisory Committee on Weather Control, which had made some statements that in the West Coast storms 9 to 17 per cent increases had been demonstrated. It is now not quite clear what the present status of this finding is, because all the technical reports (4 or 5) that had gone out have now been called back in. I must make the point that when a group withdraws documentation of its work, then it is not for publication. The unfortunate part of it was that there was a news story on these tentative findings that went all over the country. This occurred before the Tucson conference and there was quite a bit of discussion of this matter in one conference session. Several statisticians found it very difficult to understand how the type of commercial seeding data (non-radomized seeding data) that was used could give the answers that were being stressed in this report. The point is still not settled, I should mention.

As program chairman of this conference I wrote what I thought were the essential findings of the conference and before publishing my summary, submitted it to all of the 35 participating scientists as to whether they thought my summary gave a fair account of the proceedings. I was pleased to get about 30 answers out of the 35. There were four or five persons who felt that I was a little too pessimistic about the possibilities of seeding. All of the rest agreed that it was a fair statement of the findings of the conference. My interpretation was to the effect that the research that has been done in recent years—the evaluations of seeding programs that have been carried out by disinterested groups and the detailed cloud physics studies—imply need for much greater caution in assessing the potentiabilities of cloud seeding than one would have been led to believe from the glowing claims that were made in the early days of seeding, and that are still issuing from some quarters. At the same time, the conference certainly brought out the fact that we still know so little about clouds and rain that there may well be much progress awaiting the perseverant investigator.

One person after another at this conference stressed the unknown factors that confront us. We had no commercial cloud seeders speaking at this meeting. This has been criticized, and perhaps it is a fair criticism that we didn't have seeders there. I would like to make a recommendation that if Texas is really concerned about action in the direction of seeding, then they could make no more solid contribution to this problem than to call together a small meeting of seeders and researchers. An expenditure of around two per cent of the yearly budget in one of these Texas seeding projects would bring three or four cloud physicists—working cloud physicists—and three or four representatives of main seeding companies together. It would be very informative and interesting to you and extremely so to cloud seeders, as well as to all the public, to give these two groups a full chance to ask each other questions.

I think it might be very revealing to all concerned if disinterested meteorologists could, for instance, ask a representative of the Water Resources Corporation just how they *knew* they themselves got that finger of rain a distance of 150 miles in the case referred to earlier in this talk. "How," a scientist might well ask some of the seeders, "do you monitor the output of your seeding generators when you turn over your generator to a rancher or gasoline station operator and give him the word as to when to seed? Aren't you essentially turning over to a layman a physical-chemical process of such intrinsic complexity that a lot of lab workers would have trouble keeping the thing at steady output and optimum output even on a lab bench? If so, what were you doing to be sure how many nuclei per second you are getting?"

The difference between 10 to the 16th and 10 to the 15th effective silver iodide nuclei per second may make the difference between whether there is going to be enough there to cause a rain or not enough. If you try to make good this 10 to the 15th vs. 10 to the 16th difference, you've got to put a lot more dollars into the silver-iodide, etc. These cloud physicists could ask these questions and clarify these many issues. It would be very informative if you could do this to find out what is actually meant by some of these statements that you have apparently been reading in your Texas newspapers recently.

To say, as one official of Krick's organization recently did via the Denver newspapers, that seeding is an accepted science draws into the picture all of the implications that science with its long history means, and all that is best in science is invoked to support what is, in the end, a business gamble. Now, is it fair to do that in a situation where there are so many unknowns that the working scientists themselves do not claim to know a fraction of what must be known scientifically to modify cloud processes on a large and reproducible basis? Is it quite fair to use the name "science" in that sort of a situation? I think there is an educational problem there that all of us who are scientists must not shirk. I say, just for the record, that I do not think "seeding" is an accepted science.

I certainly have no objection to commercial seeding, and no objection to it being done on a good solid business basis, because that is the only way it will get to the public. But as long as it is an uncertain process, let us keep the record clear.

It's pleasing that I can mention one more quote from this pile of clippings that I poured over yesterday afternoon before my plane came. Another representative, of Krick's organization —and these are all Dallas newspaper clippings remember, and thus refer inevitably to Krick's program—put the case just as I would put it. He said in response to a newsman's question, "How do you *know* you are making rain?" This meteorologist, Lewis Grant, said, "Our clients gamble with us."

Now that is just my point of view. Seed if you will. If you are in desperate straits in some water district and you try to make more rain, you may in fact get it! If you pay anybody to do this, you may be getting your money's worth and then some; you may not be getting it, also. There may be something happening over your watershed that is very favorable. The clouds and air currents may be of just such type to make seeding work. The output of the generators in your area may (for reasons that would baffle a lab researcher) operate just right all of the time without any monitoring and with no scientific know-how on the part of the ranch-hand who runs them. You may, then, get some rain. It is important for me to underline the statement that I certainly do not know scientifically that one cannot make it rain by standard commercial seeding techniques. I do not know that, and I submit, the seeder doesn't know that he can. So it is a gamble, is it not? Grant said, "Our clients gamble with us." That I like.

If that point of view is held by anybody who is considering putting some of his funds into seeding, he at least knows where he stands. If he reads too many newspaper clippings of the type I just discussed, he will not. I have talked to enough people in our part of the country and even talked with you a little bit here at this conference, and I believe I know what to look for as elements of confusion in this seeding question. Your confusion is clearly understandable. You cannot afford to look at all the literature as a researcher in the field can. You read the newspapers and also the magazine articles which always tend toward the sensational. Reporters have a sharp eye for the person who has the most interesting story to tell, so slowly you get either misled or bewildered. It is very much to the point for me to try to remove from your mind at least some parts of your confusion.

I turn to a few key questions then, that I would emphasize do exist now in this field. I wish to get a bit more technical here even though I am not talking with meteorologists. I think it is well to do this so that you will have some notion of the central research questions which remain unanswered in cloud seeding today. I have an optimistic attitude, let me say,—a hopeful attitude—that research will give the answers to these over a period of time. Whether the answers will favor seeding or not is, of course, not known, but at least none of them is completely insoluble. I think that Langmuir's serendipity principle will enter into all research that is done to seek answers to these problems and that useful findings will be forthcoming at any event.

First of all, you might ask the seeder which precipitation process is responsible for the *natural* rain he's trying to enhance. I wish I had been in Arizona when commercial seeders were operating out there in 1951 and 1952. I would like to have asked their representatives, when they seeded with dry ice and silver iodide, how they *knew* that the ice crystal process was the dominant precipitation process in Arizona and hence the proper one to stimulate to further yield.

The competing process is called the coalescence process—the water drops collide and grow into large aggregates that fall. There are these two processes which are very different in their nature. They have some features in common in their later stages, but to trigger one off you don't do anything resembling what you do in the other case. You pour water into the top of the cloud, as the University of Chicago has done, from a B-17, to initiate the coalescence process. If you are trying artificially to enhance the ice crystal process, however, you put silver iodide or dry ice into the cloud. Very different methods for these two natural processes. Hence you see I would like to ask them—and you might well ask anybody who comes to you to seed in your area—"How do you know which is the dominant precipitation process in this area?"

This was one of the first research problems of the Institute of Atmospheric Physics. We have a fairly large array of research equipment. The University of Chicago has cooperated with us by flying its B-17 through our clouds. We worked a whole summer. We sought to find out where the radar echos begin, since they are the tell-tale evidences of where precipitation is occurring within a cloud. If they occurred above the freezing level in the atmosphere by quite a substantial amount, we would be strongly—but I emphasize the point, not indubitably—led to conclude that Arizona summer rain was formed chiefly by ice crystal process. If, instead, the echoes first appeared well below the breezing level-below about 15 or 10 thousand feet—we would have been led to surmise that it was dominantly a coalescence collision process of water, not an ice process.

This was not known. Seeding had been done in the area and lots of money had changed hands and many positive statements made as to how to how to wring more water from these Arizona clouds, yet it wasn't known whether the ice type of seeding was even the right one to use, so this was clearly one of the first things for a research program to ascertain. We made radar studies in detail during the summer of 1955. Some 500 case studies were taken out of a thousand that we analyzed, and the results determined and, in Nature's usual conspiring way, the average height of the first echoes was almost exactly *on* the freezing line! You researchers in the audience know the feeling well.

This was after an intense effort to get at this key question which ideally should be settled before one does any kind of seeding. Ask yourself or your meteorologist or those who are approaching you with a seeding contract, how they *know* one of the other process is dominant. Again and again when meteorologists have gotten up into the air with all the tools at their disposal—radar and cloud probing aircraft, and so forth—they have found that the things that were really going on in these clouds were completely baffling to them.

A Weather Bureau seeding project was undertaken in Seattle about two years ago to seed what they thought were the migratory cyclonic systems that come in off the Pacific in rather large scale. They chose this area because they thought that here would be the ideal place to get around the subtle statistical-evaluation problems. You looked at these cloud bands and they look solid all over the area. You ought then to be able to pick a nice target area and also a nice control area, and because of the apparent uniformity you should be able to make good comparisons with small statistical scatter. They got up there with their seeding planes and began looking in detail with droplet samplers and radar and they found that the actual precipitation structure was very different from what they first thought. The whole design of the experiment had to be altered—statistical and operational. The vertical structure was quite complex. I think this and many similar research findings do argue caution. They argue: Get the facts; get some research going whenever you seed. So, I say, you might always ask a seeder, "How do you *know* what is the dominant precipitation process in my area?"

The University of Chicago group has been water-seeding in the tradewind clouds; that is, spraying water into the tops of these clouds to induce the coalescence process. They are the only group that has found a statistically significant seeding effect in a statistically randomized test. They would open sealed envelopes of random numbers to decide whether they would or would not seed such a cloud with water. They found positive effects, but notice the caution: they found positive effects only in the sense they apparently created a radar echo. They had no evidence as to whether any of that water got to the ground. They created radar echoes and the effect was statistically significant, and to my knowledge there has been no other truly randomized test pre-planned wherein a positive effect of seeding of, say, silver iodide or any other method has been obtained, at least none has been published on the subject, to my knowledge. While down there seeding these clouds they found that tradewind clouds which go over the sugar plantations of Cuba and Puerto Rico seldom, if ever, build up above the freezing level. Some do, but most do not, but almost all of these little clouds miraculously gave rain before they even got to the freezing level. The conclusion that a meteorologist reaches—in this case he is not ambiguous—is that it is the coalescence process operating perhaps on the large salt nuclei that were measured to be so very dense down there, that was doing it.

While they were finding these interesting results, there was a seeder operating in this area who was seeding with dry ice! Dry ice won't do the trick if Nature doesn't first get the drops super-cooled. There isn't the slightest chance of getting anything out of it, yet this operator was busy doing just this and getting paid for it.

Amusingly enough, another seeder in the same area was seeding with salt. There was a much better basis for this, in principle, because the evidence seems rather clear now that Caribbean clouds rain chiefly for coalescence reasons, and salt may well stimulate this very coalescence process by steps whose details I must omit. Well, while here was a fellow seeding with salt, the Chicago people were *measuring* natural salt counts and their salt counts in the area were phenomenally high. If every one of those natural salt particles could grow into a cloud drop, it would be "carrying coals to Newcastle" in real measure to seed these areas with salt. Yet here was a seeder who had sold someone on that plan. Dry ice and salt are drugs on Nature's Caribbean nucleating market, but apparently the plantation managers were unaware of this. The moral is: Get the facts, and preferably from someone who doesn't have a contract in hand.

I do not at all wish to imply that everybody who has ever seeded a cloud, or every company who is now seeding clouds, is selling services in a way that warps the facts. I wish I knew more about every company's approach to the public. In fact I try to learn all I can about this and there are certainly real differences. You, as members of the paying public, should be well informed about these matters. You should know what kind of questions to ask. So here is another very good one: "How does a seeder know with certainty that there is a deficit of nuclei in the area in which he proposes to seed?"

How does he know that Nature doesn't already provide all the nuclei needed to exploit fully the possibilities of getting water out of your clouds? You go to literature and you look for counts. Somebody in Austria made some counts. A fellow made some counts at sea level in England; Australians have made quite a few; some measurements were made at Mt. Washington in Massachusetts; we made some counts in Arizona; and rather recently somebody made some flights across the whole Gulf area, making counts. And that is about it. Very little is known about this critical question. If you were a researcher trying to make the counts yourself, because it is very hard to count freezing nuclei, you would know you would always have to apologize for your counts. There are grave experimental difficulties with getting an untainted measurement in this case. You might well ask the seeder, "How do you know there aren't so many nuclei in our area that Nature is doing a full job herself?"

One of my colleagues just yesterday summarized the point of view of one of our big commercial seeders by saying that he now doesn't want to give God any credit for *anything*. Are there natural nuclei at all? Well, one doesn't know, but it was very interesting last week at the American Meteorological Society meeting at Albuquerque to hear Ted Smith relate some measurements made by Paul MacCready in flying to and from Florida to California. I don't think they would want me to say that these results are final, and I heard these just as a member of the audience and haven't seen the figures in print, but it is an indication of the sort of thing that may turn out when you get some people to go up and try to measure these things. They found that there were very few counts in Los Angeles, except in the southeast part of the city, he said, near some industrial area where they get very large counts—800 particles per liter, I think it was. But there were virtually none on the coast itself. With this same equipment operating in the same plane and with observations taken in the same way, going across the mountains and over Texas heading toward Florida, they found that the natural freezing nuclei counts rose markedly. They found counts in the Gulf area as reported by Smith which were already at the level where the natural processes might well go on at rates that were adequate to use up all available water. This may be right; it may be wrong, since nobody knows what these natural nuclei are and the mysteries that surround this question are very great. The important thing to dwell on is the pressing need of getting this kind of answers. If there is any possibility of you finding out what the natural nuclei populations are, why merely assume you are making up a natural deficit of nuclei by seeding? Try to get the facts. This is the central problem of cloud seeding. It has not yet been answered. What do you know about the nuclei in Texas? You will only find out for sure by sending up into the air properly trained people to figure this thing out scientifically as I see it.

Photolytic decay is the next point that I suggest you ask your seeder about. What is he doing about increasing evidence, increasing to the point of near certainty, that when the silver iodide particles waft into the daylight the same processes occur on these tiny crystals as occur on a piece of Eastman film. You expose photographic film to light and the silver iodide crystals are reduced photo-chemically—silver iodide particles form a different lattice pattern on the surface. That lattice pattern of reduced silver atoms is not compatible with the ice lattice so that it no longer fools the water into starting a crystal on it. It is fairly well established by very recent research that the adsorption of water molecules onto a photolyzed—that is, exposed—silver iodide surface, only goes on to the extent of about 25 or 30 molecular layers. Texas won't get very wet with only 25 monolayers on every silver iodide crystal floating overhead. The difference between that and unphotolyzed, unexposed, solver iodide crystals is not a difference of order of magnitude; it is a difference of wind. Unphotolyzed, unexposed silver iodide adsorbs water molecules up until they form over 200 molecular layers and then the system is in equilibrium with water vapor and goes on growing to form an ice crystal, if recent laboratory work by Birstein is correct. That is how unphotolyzed silver iodide does what it is known to do in a cold box. The people at the New Mexico Institute of Mining and Technology in the 1951 period were the first to find experimental evidence that exposure to ordinary sunlight of silver iodide decreased the nucleating efficiency of that subtance and they found rates of this decrease of efficiency of tenfold to one hundredfold per hour. This was contradicted by subsequent measurements by Vonnegut in the GE Laboratories, which was confusing. Then along came several others who confirmed the photolytic decay process, so that now the evidence for decay during daytime seeding is almost incontrovertible.

What does this mean? If the seeder calculates how many nuclei he thinks he needs in the cloud and doesn't take into account photolytic decay, he's low by a factor of 10 for every additional hour it takes his nuclei to get to the cloud, under daylight conditions. A factor of 10 when you are just barely making it is quite enough to undo the whole thing. Perhaps he then says he will up his silver iodide; he'll increase it tenfold in daytime for every hour of transit-time from generator to cloud. I am not sure about the economics of the seeding business, but if you increase by, let's say, a hundredfold the budget for silver iodide, I am not sure you can sell your improved services at the same old rate. So I wonder what they are doing about photolytic decay.

I have never seen a discussion of this by any seeder. In fact it seems very significant that for the most part you see nothing at all in the literature as to what the seeders are doing. One or two of them have contributed a couple of good papers to the literature. I know of one paper from Krick's group published in 1949; a short statistical paper that was criticized very severely. Now, by contrast, I know quite a bit about what Bowen is doing in cloud physics research in Australia and what Mason is doing at Imperial College in London. It is very difficult however, to say what the seeders are doing, so I ask them, 'What are you doing about photolytic decay?" If the answer is, "Oh, we don't worry about it because we only seed on cloudy days," then I would say that Smith and Heflin in the last issue of the Quarterly Journal of the Royal Meteorological Society found no correlation between cloud cover and decay. It's a bit hard to believe that, but the inference one would tentatively draw is that even with cloud cover the flux of ultra violet is sufficient to photolyze the particles at the rate of tenfold per hour. If the answer, conversely, was "Well we seed chiefly at night," then I'd be curious about the lid-action of nocturnal inversions, and so on.

Then you should ask the seeder about this vertical dispersion problem. It, too, is unsettled. We are trying to do some work on that at the Institute. We cannot believe that, in the absence of inversions under daytime conditions, the silver iodide doesn't get above 5 or 6 thousand feet. The only existing scientifically reported data that you could go to now leads you to believe that it doesn't get much higher than 5 or 6 thousand feet in distances of the order of at least ten miles, and in New Mexico ground-released particles were traced for a hundred miles and didn't get above 5,000 feet off the terrain. Out in the West clouds are a lot higher than that above the terrain and so we must wonder about this point. In Arizona during the past summer near a big mountain range, in an extremely unstable atmosphere (10,000 feet of adiobotic lapse rate) we studied this with fluorescent zinc sulfide tracers, and we did find sulfide to 10,000 feet and higher. We also found other things that were pertinent. We have been quite impressed with the difficulty of anticipating where the stuff is going. So much impressed that I don't think I will ever be able to listen with a straight face to those who say, "Why you can see it go up into the cloud and make it rain." We hope to do a lot more research in Arizona on this nuclei-dispersal problem. At the moment I believe we must consign it to the category of questions about which neither seeders nor researchers can be dogmatic.

What about over-seeding? This has been kicked around on all sides. Some people say you can over-seed; some, you cannot. It is a research question that needs much, much more careful attention, but I pass over it here.

What about cloud dynamics? What goes on inside of these clouds? How do you know where the nuclei enter? What kind of mixing process goes on in the clouds? One of the things that was strongly emphasized at the Tucson conference last April was that we know practically nothing about cloud dynamics and this is a problem that needs a great deal of attention. It must be attacked regionally. The pertinent dynamics and kinematics of the clouds that give you rain in Texas are going to be different in some respects from the dynamics of our clouds over mountain ranges in Arizona. We must always attack this problem locally. It must be done in many places around the world before we can draw meaningful conclusions. There is a great need for more knowledge of the simplest characteristics of clouds. I could document these, but shall not, for reasons of time.

What do we know about the water vapor flux? Mr. Gilchrist abhors the thought of a Federal Bureau to allocate rainfall. Yet, it is, in fact so large-scale a phenomena that if seeding is ever shown to be truly effective "vapor-rights" legislation will be indispensible. If we make rain artificially, we will have to know a great deal more about this flux of water vapor. At the Institute with our growing IBM facilities, we are undertaking a study of all the past ten years of radiosonde data to track the flow of water vapor in and out of the western United States, and we hope then to throw some light on this problem. Texans will be able to use our results in their understanding of their phenomena, just as we would hope we could use some of the things Texas meteorologists will be doing.

Ask a seeder just how he knows what happens when he allegedly takes a little extra rain out of a State. What happens to the next State downstream? The problem Mr. Gilchrist summarized there would be with us immediately if it weren't for the present uncertainty as to whether the seeders are or aren't "making rain."

Let me tell you one interesting thing in the one study that has been made on this vapor-flow problem by Benton at Johns Hopkins. The indication was that the flow of water vapor over, say, El Paso (this was in summer half year) up toward the North and Northeast in summer was smaller than the total flow of water vapor over Dodge City, Kansas, and that Dodge City flow was smaller than the total eastward flow of water vapor over Chicago. That, in turn, was smaller than the total flow of water pasing overhead at Buffalo, etc. Do you see what this means? If the figures are correct? (It is only one year's data). It means that all of the water that the Salt River people in my State are pouring out to evaporate and transpire from their cotton fields and alfalfa fields in summer, plus the water vapor that came in across the international border are available to Colorado, but still more evaporates in the summer from fields irrigated with the preceding winter's accumulation.

Each State is contributing more and more to Mr. Hoff in Delaware. The Brandywine Valley, you see, then, is in the ideal location in summer. It seems to be getting the water extracted from all our irrigation projects step by step across the country! Can this be the true summer picture?

Benton's study is very intriguing and it is for that reason that we now are undertaking to extend it a very great deal with our new electronic computor and using Weather Bureau Radiosonde data for the past decade. This, I stress, is just one more research area where cloud-seeding has caught us unprepared to answer questions of the greatest practical importance.

Let me summarize: The subject is vast and ignorance is truly profound.

Our water table is dropping ten feet a year. There are many indications that the whole West is currently getting drier. The mesquite is invading Texas and out our way. There are biological changes: I have heard that the armadillo is moving north into Texas in keeping with the recent warming trend. When I was in Iowa I knew of the northward movements of the beaver. It is a familiar ecological phenomenon in Arizona: the Mexican turkey vulture appeared in Arizona about ten years ago. Last year I never even observed a single vulture, but this year they were frequently flying over Tucson. I have never talked to irrigators up Phoenix way about this, but I suppose they think these vultures are coming to get them. If your water table is dropping 10 feet a year, the vultures have real reason to be hopeful I suppose.

What is to be done? This is the last question. Again, I say, if you are desparate and if the risk seems worth it—seed. It is a gamble. "Our clients gamble with us" is a point of view I will applaud. It may be the right thing to do and you may get rain out of it. But if you really look to the historical lesson that is taught by these reoccurring drouths, you will do something to understand these things in basic scientific terms. We can go on with the kind of non-randomized seeding work that has been going on all over the country for years and years, and we won't get any final answers. Final answers come only from long, hard scientific research supported at a level adequate to carry on fundamental studies on all of many fronts.

This is what I would urge Texas to do: Texas should support research on fundamental problems. There is great need for it. There are many unknowns. Many of these questions are regionally peculiar. Anything that can be done in the Texas universities and colleges where you have programs of meteorology and competent people, is very much to the point. Unless you support them in basic research I do not think you will ever get out from under this confusion that you operate on everytime you say, "Well, shall we or shall we not seed?"

I would recall a cartoon, in closing. There was, in *The New Yorker*, in the early days of seeding a terribly pertinent cartoon. It showed a picture of a couple of clergymen looking out of a window—a stained-glass window—obviously in a church, with the rain spattering on the outside window. One cleric was wearing a very puzzled expression as he posed his colleague the question, "I wonder if it's theirs or ours?" That, I feel, is still a question that is very much with us. Thank you.