Weather on Demand

Since World War II, rainmaking has gone from hoax to high tech to uncertainty. Is it ready for another turnaround?

by Stephen Cole

When drought threatened New York City in early 1950, and official pleas for conservation failed to stem the drop in reservoir levels, the city's water commissioner, Stephen Carney, decided to take a risk. On February 15 he traveled to one of America's foremost industrial R&D centers, the General Electric Research Laboratory, in Schenectady, New York, to investigate a controversial new technological fix. He conferred with the Nobel Prize–winning chemist, inventor, and former associate director of the laboratory, Irving Langmuir. Later that week the two men announced that New York would consider battling the drought using cloud-seeding techniques discovered at GE by Langmuir and his colleagues.

New York, like much of the nation, had been swept up in the rainmaking frenzy sparked by Langmuir's 1946 discovery. The renowned scientist firmly believed that his technology had the potential to turn a light rain shower into a deluge, thwart a hurricane, and alter large-scale weather patterns. His claims astonished and angered meteorologists, but Langmuir's reputation and his vigorous defense of his ideas won them hearings in Congress and the Pentagon. Weather modification became part of the nation's research agenda, and rainmakers proliferated, particularly in the West.

Today, after decades of field research and controversy, Langmuir's technological dream has not materialized. His rainmaking techniques are effective only in very limited situations. The vast complexity of atmospheric physics, which was virtually uncharted when Langmuir began his work, stymied efforts to demonstrate conclusively what cloud seeding could and could not do. Rainmaking as a commercial activity, however, has never disappeared, despite the lack of a scientific seal of approval. A small cadre of practitioners in the United States and around the world can present enough evidence to convince customers that the potential benefits of seeding are worth the relatively small costs involved. Denver's water department, for example, recently fought an extended drought by hiring a rainmaker to increase the snowpack in the neighboring Rockies.

Yet a resolution may be in sight. According to a 2003 report from the National Research Council (a private, congressionally chartered group that advises the government on scientific and technological issues), the time has now arrived when science should be able to settle the dispute between weather-modification skeptics and believers. The panel called for a concerted national research effort using radar and satellite remote sensing to unveil the hidden workings of clouds and document their response to seeding. These observations, plus recent advances in understanding the mechanics of rain and snow formation, could yield the answers that have eluded scientists for more than half a century.

Since the mid-1800s rainmaking has been to meteorology what astrology is to astronomy. Many schemes with little or no scientific basis have been tried. In the 1850s the American meteorologist James P. Espy advocated setting massive forest fires to produce rainstorms. The idea was to mimic the heat-driven convective process that fuels these storms (Espy had noticed that thunder and rain often followed a fire). In the early decades of the twentieth century, one of America's most infamous and successful rainmakers, Charles Hatfield, of California, claimed that the evaporation of his secret chemical brew atop wooden towers could attract clouds. In 1915 San Diego hired him to end a prolonged drought and was rewarded with a 17-day deluge that totaled 28 inches. The downpour washed out more than 100 bridges, made roads impassable over a huge area, destroyed communications lines, and left thousands homeless.

Meteorology does not have the long academic tradition of other fields, and not until the early twentieth century did science find a theoretical foundation for the temperature-driven movements of air masses. The complexities of the precipitation process were largely unknown, and only the most fundamental measurements had been taken of clouds.

With GE and Langmuir behind it, "scientific" rainmaking achieved instant credibility.

Clouds are made up of tiny droplets of liquid water and/or ice crystals that are suspended by rising air currents. They usually form when water vapor condenses around microscopic particles of dust, smoke, sea salt, or other debris in the air. A typical droplet of cloudwater is less than a tenth of a millimeter in diameter, and most clouds have fewer than 200 such droplets per cubic centimeter, unless they are getting ready to rain. Clouds vary enormously, but a rough estimate for the density of water inside an average cloud might be one gram per cubic meter. Using that figure, a cloud one cubic kilometer in size would contain about 1,000 tons of water, or 250,000 gallons.

In the 1930s the first coherent theory of precipitation began to emerge. The "cold cloud" theory assumed that rainfall originates in the frigid upper reaches of a cloud, where tiny ice crystals grow into snowflakes that fall out of the cloud as either snow or rain, depending on the temperature at the cloud's base. In the 1950s, after the weather-control era had begun, scientists at the University of Chicago established a second mechanism. The "warm cloud" process involved water droplets colliding and coalescing into larger drops and eventually falling to earth as raindrops. In either case the idea was that tiny specks of water, either liquid or solid, attracted vapor and other specks and eventually grew into large drops or flakes. Accelerating this process artificially called for adding something that would attract water. This would create nuclei for the formation of tiny droplets, which would grow bigger through collisions.

Defending a gullible American public against rainmakers' fraudulent claims had long been a routine service of the U.S. Weather Bureau. But on November 14, 1946, all that changed with a single General Electric press release: "Scientists of the General Electric Company conducted experiments with a cloud three miles long, and were successful in transforming the cloud into snow." A simple technology—sowing pea-size pellets of dry ice into a cloud from a plane—could "generate hundreds of millions of tons of snow over a large area," said Langmuir. A single pellet, he continued, could "produce enough nuclei to develop several tons of snow."

Langmuir's discovery, which, he said, "may prove ultimately to be considered the most important work I have done," took meteorologists by surprise. But with GE's and Langmuir's reputation behind it, "scientific" rainmaking achieved instant credibility. When Australian meteorologists announced in early 1947 that they had confirmed the process, an editorial in *The New York Times* hopefully predicted: "The time has passed when rainmakers are the proper butts of witty meteorologists."

Those meteorologists were up against a formidable scientific force in Langmuir. The Brooklyn-born, European-trained polymath had held a place in American popular culture in the 1920s and 1930s like that of Thomas Edison a generation before. He was an outspoken and media-savvy proponent of science for the common good. His views often made news. At the outbreak of World War II he was president of the American Association for the Advancement of Science. A few months after Hiroshima, when he spoke at a meeting of concerned scientists about the dangers of a nuclear arms race, the front page of *The New York Times* read: langmuir urges atom pact, says war might strip earth. He was also a vocal critic of junk science.

Langmuir first became prominent with his 1916 patent on an improved incandescent light bulb, based on his discovery that the route to a longer-lasting bulb was to fill it with an inert gas instead of trying to perfect the vacuum inside it. The invention made Edison's light bulb an affordable household product. Langmuir was issued 62 other patents during his 41-year career at the laboratory. He also pursued basic research in chemistry and physics. In 1932 he became the first industrial scientist to be awarded a Nobel Prize, for his pioneering work in the new field of surface chemistry. He was tapped by the U.S. government during World War II, serving at the age of 60 on the National Defense Research Committee and leading several classified research projects at GE.

The key to understanding why Langmuir began investigating weather control lies in his personal research style. He relished cutting a new trail into the unknown, preferably with only a small group of assistants. The freedom he enjoyed at GE to choose his own projects encouraged his independence and wide-ranging curiosity. "Whatever work I have done, I have done it for the fun of it," he said in accepting the *Popular*

Science Monthly gold medal in 1932. He probed deep into fundamental problems of atomic structure, explained unusual wave patterns on the surfaces of lakes, and even calculated the flying speed of the deer fly.

His career in weather research had begun during World War II with classified projects on smoke screens and aircraft icing. He became interested in precipitation formation during research into icing on top of New Hampshire's frigid Mount Washington. Largely unaware of the meteorological work being done at the time, he entered the field as a novice and plowed ahead with his own ideas.

Langmuir said a single smoke generator had changed weather over most of the United States.

His approach to clouds and rainfall was entirely opposite to that of mainstream meteorology. Since he had been trained in the micro-scale sciences of chemistry and physics, rather than the global-scale dynamics of warm and cold air masses, Langmuir focused on the "microphysics" of how individual droplets, snow crystals, and raindrops grew inside a cloud from tiny nuclei. His longtime laboratory assistant Vincent Schaefer, a former GE machinist with a high school education, devised instruments to measure the characteristics of the supercooled cloud droplets streaming over the summit of Mount Washington.

Langmuir's interest continued after the war, and he had Schaefer pursue laboratory experiments on precipitation. In Schenectady, Schaefer made a "cold box" out of a GE freezer to simulate conditions in supercooled clouds, using water vapor from his own breath to form the clouds. He began sprinkling different substances into the artificial clouds to see if they would form ice crystals.

One day in July 1946, when the temperature in the laboratory was too high to get the freezer cold enough for his experiments, Schaefer improvised by putting in a block of dry ice. The hazy cloud was quickly transformed into a shimmering miniature snowstorm. Schaefer had stumbled on a way to jump-start the natural snow/rain process: Adding dry ice to a cloud chilled it and turned the water vapor it came in contact with into millions of ice crystals.

Langmuir instantly saw vast potential in the cold-box blizzard, writing "Control of Weather" in his laboratory notebook above his analysis of Schaefer's results. He lobbied for a military contract on "cloud modification," and GE submitted a proposal to the Army that September. In the fall of 1946 Langmuir invited another GE researcher, Bernard Vonnegut (the older brother of the novelist Kurt), to help. Vonnegut found a chemical compound, silver iodide, that acted like dry ice but could be distributed by being burned along with something flammable to yield fine smoke particles, which could be released inside a cloud or (with less precision) from the ground. Vonnegut chose silver iodide because its crystal structure was the closest he could find to that of ice.

Meanwhile, Schaefer prepared to seed real clouds. In November, when suitable stratus clouds appeared near Schenectady, he took to the skies in a small rented plane and spread a few pounds of dry-ice pellets into them. From the Schenectady airport's control tower, about 30 miles away, Langmuir watched the plane's progress with binoculars. A faint trail of snow fell from the cloud layer after the plane had flown over it. GE issued its press release announcing the news the next day.

The discovery sparked a worldwide sensation. Over the next few months GE's laboratory was deluged with requests for made-to-order weather. The chairman of the Fort Devens (Massachusetts) Winter Carnival sent an urgent telegram: IF NO SNOW 2000 VETERANS AND SWEETHEARTS WILL SUFFER SERIOUS EMOTIONAL DECLINE NO SNOW IN SIGHT … QUOTE PRICE CAN FURNISH PLANE AND PILOT. Government representatives from around the world wrote Langmuir and Schaefer for their secrets. In the summer of 1947 newspapers in Chicago and Phoenix mounted dry-ice rainmaking flights as publicity stunts and claimed that they were successful.

Enthusiasm for the new miracle technology was tempered, however, by fear of the legal consequences of controlling the weather. From the start GE management was nervous about possible lawsuits for producing unwanted storms or stealing wanted ones. In November 1946 Schaefer's seeding trials had been stopped until government funding—and the legal immunity it would give the company—was secured.

In February 1947 GE won its weather-control contract under the sponsorship of the U.S. Army Signal Corps and the Office of Naval Research, with aircraft and crews to be supplied by the Air Force (as the Army Air Forces would be renamed in September 1947). Langmuir's Project Cirrus researchers continued their laboratory work in Schenectady and tried cloud seeding from the air and ground in the Northeast, the Southwest, and Puerto Rico. Their fleet included a B-17 Flying Fortress bomber, specially outfitted with an array of equipment to measure clouds. Few instruments existed for this type of work, so the GE team built their own. Theyalso experimented with imaginative ways of distributing rain seeds, including balloons laden with dry ice, rockets filled with liquid carbon dioxide, and charcoal briquettes saturated with silver iodide, which were burned.

One of the project's first campaigns was also one of its most audacious, nothing less than technology's first attack on a hurricane. In October 1947 a Project Cirrus plane seeded an Atlantic hurricane with dry ice to see what effect, if any, the seeding would have on the massive storm. The target was Hurricane King, which was safely moving out to sea off the Florida coast. Schaefer, observing from a chase plane, saw a long trough carved in the seeded cloud decks, but he was skeptical about whether the dry ice could have any significant effect on the storm's progress. Several hours after the seeding run, however, the hurricane made a sharp left turn and headed back toward the coast, eventually striking Savannah, Georgia, and causing extensive damage.

The cloud seeders denied any responsibility for the wayward hurricane, pointing out that such turnarounds had happened before. But the incident raised public concerns about the safety of the new technology. Langmuir, ever hopeful, saw promise in the results. "With increased knowledge, I think we should be able to abolish the evil effects of these hurricanes," he told the National Academy of Sciences a month after the seeding.

Weather modification was on the fringes of meteorology but may be ready for a comeback.

This type of confident yet unfounded public statement enraged meteorologists, especially Francis W. Reicherfelder, chief of the U.S. Weather Bureau. Although he was careful not to attack the Nobel laureate publicly, in private he was critical of Langmuir's "extravagant claims." "The standards of American science have suffered as a result of Langmuir's indiscretions," he wrote in his personal office notes. As private rainmakers rushed to cash in on the technology, he continued, "hundreds of thousands of dollars have been thrown away by farmers and others in paying for rain that would have occurred naturally."

The GE researchers' initial reports of rainmaking success had been based largely on visual evidence: Clouds changed when seeded with dry ice. Photographs of grooves cut into cloud decks were dramatic, but since they revealed nothing about the inner dynamics of the clouds, they carried little weight with meteorologists. What was becoming clear was how hard it was to prove that seeding was the cause of rainfall, because a seeded cloud might have been ready to rain without any additional help. A further problem, which affected seeding from ground-based silver iodide smoke generators (the inexpensive technology of choice for commercial rainmakers), was determining whether the wind-borne plume had even reached the clouds.

By 1949 the Weather Bureau and Langmuir had begun separate experiments that used rainfall measurements to test the effect of seeding. With the aid of the Air Force, the Weather Bureau conducted nearly 200 seeding runs in different parts of the country over two years. The rules of this experiment credited seeding with producing rain only if no other clouds in the vicinity were producing rain at the same time. Under this conservative assumption, the results were dismal. The bureau concluded that rainmaking was "of relatively little economic importance."

Langmuir countered by claiming to have created a "self-propagating storm" from a cloudless sky using a silver iodide smoke generator near Albuquerque, New Mexico. He compared the track of the smoke plume with the location and intensity of rain-gauge data collected across the state and found a solid correlation, leading him to conclude that all the rain from the storm was the result of the initial seeding. Meteorologists disagreed, saying that the correlation did not prove a causation.

The negative Weather Bureau results did little to dampen popular enthusiasm for Langmuir's claims. His talk on the New Mexico results at a scientific meeting in New York City in January 1950 was enough to convince the water commissioner to try cloud seeding. The city hired the Harvard meteorologist Wallace Howell, who had worked with Langmuir on Mount Washington, to plan a seeding campaign over the Catskill Mountains north of the city, where municipal reservoirs were located.

From April to December of that year Howell seeded 36 times, using dry ice dropped from police-department planes and silver iodide smoke generators pulled around the countryside by water-department station wagons. New York's rainmaking campaign brought renewed media attention to the practice. In August 1950 Langmuir and weather control made the cover of *Time*.

Throughout the New York cloud-seeding project, Howell remained noncommittal about its effectiveness in combating the drought. But once the project was over, he compared the precipitation on seeding days with expected values based on data from the previous 15 years. Howell concluded that cloud seeding had added 15 billion gallons to the city's reservoirs. Meteorologists were less impressed. They knew that precipitation could vary widely from year to year for any number of reasons.

Part of the problem was that scientists who studied rainmaking had chosen the days on which they would seed. This introduced the possibility of unconscious bias, which could skew the results. Without being able to see inside the "black box" of a cloud and understand what happened when it was seeded, rainmaking advocates continued to be on shaky scientific ground.

Undaunted, Langmuir and the Project Cirrus staff devised one last grand experiment to settle the issue using indirect evidence, this time on a continental scale. A silver iodide smoke generator near Socorro, New Mexico, was turned on for several hours at a time, a few days a week, on a repeating schedule, seeding the sky downwind across the Midwestern and Eastern United States. Weather and rainfall patterns were carefully monitored every day. If the cycle of seeding days consistently matched changes in weather patterns downwind over a long period, Langmuir would have statistical proof of a cause-and-effect relationship between seeding and weather.

This experiment began in December 1949, and Langmuir's analysis of the data led him to make his boldest weather-control claim. At the October 1950 meeting of the National Academy of Sciences, held at the new GE laboratories in Schenectady, he reported that his periodic seeding from a single source in New Mexico had indeed changed large-scale weather patterns over much of the United States.

An independent group of experts assembled by the American Meteorological Society disagreed, saying that Langmuir's statistical correlation was not significant enough to demonstrate cause and effect. Langmuir, however, refused to concede, and his ideas continued to intrigue the military and the public. Concerns about weather control led to the proposal of federal legislation to regulate the industry, along with calls for federal research to harness the technology. Instead, in August 1953 Congress created the Presidential Advisory Committee on Weather Control to evaluate the commercial activities and scientific results that had taken place so far and recommend government policy. The committee was appointed by President Dwight D. Eisenhower in December.

While the committee was investigating, Langmuir continued to push his weather-control ideas. In August 1955 NBC's "Today" show traveled to Schenectady for a live broadcast, during which Langmuir told a nationwide audience that taming hurricanes should be achievable. When the presidential committee released its preliminary findings in February 1956, he felt vindicated. The committee reported that wintertime silver iodide seeding of clouds over mountainous regions of the West had produced as much as 15 percent additional precipitation. However, there was not enough evidence to establish the effectiveness of seeding in any other conditions. The committee called for a long-term research effort, and in 1957 Congress provided funding for the National Science Foundation to undertake one.

Langmuir did not live to see his new science flourish. On August 16, 1957, just a few days after the Senate approved the NSF program, the 76-year-old Nobel laureate died peacefully on Cape Cod. His death, which deprived weather modification of its most famous and enthusiastic advocate, also marked a shift in the discipline's status among scientists and the public. As some meteorologists grudgingly conceded that there might be something in it, proponents realized that rainmaking was complicated and uncertain in its results—far from the miracle cure that Langmuir had proclaimed it in his most ebullient moments. It might turn out to be useful, but if so, practitioners would have to gather a lot more data on when and how it worked.

As weather modification became a mainstream scientific endeavor, meteorologists launched a series of elaborate long-term studies that would also provide insights into basic cloud microphysics. The field was well funded for two decades, with federal support peaking in the late 1970s at nearly $20 million per year. To reduce the possibility of bias in the selection of target clouds, a coin flip was sometimes used to decide which clouds would be seeded and which would serve as a control, or whether to seed at all. Such randomization became a staple of cloud-seeding studies.

The most sophisticated and thoroughly analyzed cloud-seeding experiment of this period, the University of Chicago's Project Whitetop, probed summertime convective cumulus clouds, which produce most of the Midwest's rainfall. Starting in the summer of 1960, scientists conducted field experiments in southern Missouri. Ground-based radar monitored the clouds passing overhead, tracking the progress of any rain formation inside them. When suitable clouds arrived, three planes flew back and forth for several hours on a course perpendicular to the direction in which the clouds were moving, heavily seeding the downwind ones with silver iodide smoke. The radar, with a view of both the seeded and the unseeded clouds, documented any changes. At the same time, an instrumented plane gathered data on conditions inside the clouds.

The project continued for five summers, and the results were statistically significant but unexpected: Rainfall was consistently *reduced* by seeding. The explanation: The clouds already contained high concentrations of natural ice crystals, so "overseeding" them with silver iodide created too many crystals, which were competing for too little water vapor. As a result, not enough of them grew big enough to fall as rain.

Project Whitetop added a new twist to scientists' understanding of how rain forms. Precipitation in the Missouri clouds turned out to be created by a combination of the warm-cloud and cold-cloud processes. In "coalescence freezing," warm raindrops in the lower part of the cloud were carried to the higher and colder part by convection. There they froze, forming chunks of ice that brought down lots of precipitation. Scientists were beginning to understand the complexities of rain formation, but it only left them farther away from the goal of reliable weather modification.

At the same time, the U.S. Navy and the National Oceanic and Atmospheric Administration revived the fight against hurricanes with Project Stormfury in the 1960s and 1970s. Research in the 1950s had revealed the inner dynamics of these massive storms, and from that work a theory emerged of how they might be tamed by seeding them with silver iodide. The seeding would make liquid cloudwater freeze into ice crystals, thus releasing latent heat. According to the theory, this would make the cloud more buoyant, causing it to grow taller. By seeding the rainband clouds swirling just outside the storm's central eyewall, scientists hoped to create a second eye-wall wider than the first, effectively opening up the eye and cutting the high wind speeds. Computer simulations showed that the effect would be temporary, with higher wind speeds returning a day after the seeding.

In August 1969 Project Stormfury planes seeded Hurricane Debbie with what seemed like astounding success. After a first seeding run, maximum wind speeds inside the eyewall dropped by 30 percent. A day later they returned to normal, just as the models had predicted. A second seeding on the same storm showed the same effect, although less dramatic. On the basis of this experiment, some urged an immediate start of operational hurricane control, but others felt that not enough data had been gathered about the microphysical conditions inside the seeded clouds to confirm that the hypothetical chain of events had actually taken place. The expensive program was suspended in 1980 after seeding just four hurricanes; tight restrictions on what kind of hurricanes could be seeded, and under what conditions, kept the scientists from seeding any more. Four hurricanes was not a big enough sample to conclusively prove the effect.

In addition to long-term field experiments, this period saw the introduction of new seeding techniques and equipment. Airborne burners produced thick plumes of silver iodide, increasing the amount of the seeding agent dispersed into clouds compared with ground-based burners. To improve pinpoint delivery of cloud seeds, silver iodide pyrotechnics were developed that could be dropped from planes into dangerous situations such as hurricanes. And a new method of seeding warm clouds called hygroscopic seeding, which used a spray of salt, either powdered or in a solution, to boost the growth of nascent raindrops, showed promising results in India.

But despite millions of dollars in research, reliable weather modification remained elusive. In 1973 a National Research Council survey concluded that “ice-nuclei seeding can sometimes lead to more precipitation, can sometimes lead to less precipitation, and at other times … [can] have no effect.” Weather modification also ran into a political firestorm in the early 1970s after press reports disclosed that the United States had secretly been using cloud seeding as a weapon during the Vietnam War. By the 1980s weather modification had retreated to the fringes of meteorology in the United States, although it continued in the mainstream in other parts of the world. The reasons were many. Getting reproducible results was too difficult; when results could be demonstrated, they were not dramatic enough; and the legal questions remained unresolved (a 1993 Montana law restricted cloud seeding so severely that none has taken place there since its passage). Weather modification’s greatest legacy was the insights it gave into the field of cloud physics, which took on a prominent role in the busy new science of climate change.

Yet the discipline may be ready for a comeback. According to the 2003 National Research Council assessment, the time is right for a revival of rainmaking research, because the observational tools and the scientific understanding needed to do the job are finally available. Advanced instruments can now pierce the veil of clouds and track the complex processes inside them. Ground-based networks of Doppler weather radar are in place across the United States to measure rainfall, and airborne Doppler radar can take a close look inside individual clouds. Polarimetric radar can distinguish between water droplets and ice crystals inside a cloud, so it would be able to see how seeding changes supercooled water droplets into ice crystals. New satellite sensors can extend these types of cloud measurements over much of the globe.

With these tools, scientists have documented how rainfall is increased or reduced when natural “seeding” takes place by desert dust storms, smoke from forest fires, sea spray, and even urban air pollution. Some of these particles produce large cloud droplets, thus triggering rainfall, while others form many small ones, slowing or stopping precipitation. One scientist has found that dust from the Sahara Desert reduces rainfall, while dust from the salt-laden Aral Sea area increases it. These “inadvertent weather-modification” studies have validated some of the basic principles thought to be at work in intentional weather modification.

Although the National Research Council’s panel noted promising rainmaking results in Mexico and South Africa with hygroscopic seeding, it stopped short of suggesting that cloud seeding is close to becoming a proven technology. Instead, the panel called yet again for further study, urging atmospheric scientists to heed their responsibility to an increasingly populous and thirsty world to find out once and for all if rainmaking is real or a mirage.

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Reference:

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