Will efforts to change the weather ever attain scientific legitimacy?

CLOUD DANCERS

by DANIEL PENDICK

Water. Everybody needs it. Almost everybody who has it could use more of it. And those who don't have it would do almost anything to get it. For millennia, the traditional technology for obtaining water was simple enough—a hole in the ground. Shamans and charlatans alike also appealed to the sky to boost their water supplies. Half a century ago in a laboratory in Schenectady, N.Y., scientists came up with an entirely new version of the tribal rain dance: cloud seeding. By scattering chemical "seeds" in rain clouds, they hoped to augment natural rainfall to replenish water tables and reservoirs.

Rainfall enhancement, as its practitioners like to call it, remains just one variation of the much older dream of controlling the weather. Taming tornadoes with A-bombs, short-circuiting lightning storms with metal chaff, smothering hurricanes at sea, quashing damaging hail—all have been proposed or attempted since that fateful day in Schenectady.

Decades of equivocal research have failed to quell enthusiasm for weather modification. True, the U.S. government all but abandoned investigations into cloud seeding five years ago. But in 1998, reports the National Oceanic and Atmospheric Administration, 48 nonfederal weather modification projects in 10 states were under way. And according to the most recent statistics from the World Meteorological Organization, 26 countries were conducting a total of 84 projects in 1995. Although many such projects are for hail reduction—reducing potential damage by making hailstones smaller—cloud-seeding projects still abound and are motivated by thirst for water. "They always say the same thing," notes Thomas J. Henderson, head of weather modification firm Atmospherics in Fresno, Calif. "The value of water is so high that we can't afford not to do it. If there's any indication at all of positive results, they've got to keep doing it."

Rainmaking has generated renewed optimism lately because of field trials in South Africa, Mexico and Thailand of a technique called hygroscopic cloud seeding, which accelerates the natural raindrop-forming process in clouds. One proponent, Nico J. Kroese of the South African Weather Bureau, has characterized this method as the most exciting development in cloud-seeding research in the past 50 years. But before hygroscopic seeding lives up to its initial billing, a stubborn question needs to be answered: If you seed a cloud and it rains, how can you be sure that it would not have rained anyway?

SEEDING THE SKY: Flares from a two-engine propeller airplane contain microscopic particles, often silver iodide, that are emitted in a flare and blown by updrafts into clouds. Larger than normal water droplets may form around the particles, some of which may grow big enough to fall to the ground as rain.

The rainmaker is a well-ensconced figure in U.S. history. In 19th-century America, where agriculture was king, itinerant rainmakers found willing dupes in times of drought. On the scientific front, kites and balloons were used to set off explosions to see if the concussion might coax a few extra drops from the clouds—an attempt to probe whether there was any validity to the lore that rain followed big battles. Indeed, the U.S. Congress appropriated $9,000 in 1891 for rainmaking experiments under the direction of an agent of the Department of Agriculture, Robert Dyrenforth. Experiments continued sporadically into the 20th century, involving everything from igniting fires to stimulate updrafts and spawn new rain clouds to scattering shovelfuls of sand into the clouds from the open cockpit of an airplane.

Eureka! It's Snowing

In 1946 at the General Electric Research Laboratory in Schenectady, the dark ages of rainmaking came to an end. Nobel Prize–winning chemist Irving Langmuir and junior researcher Vincent J. Schaefer were studying airplane-wing icing in supercooled clouds—clouds in which tiny water droplets were chilled to below the freezing point of water. Schaefer had rigged up an electric freezer and breathed into it to create a miniature cloud. Intending to cool the chamber even more, he slipped some dry ice (at –109 degrees Fahrenheit) into the

THOMAS J. HENDERSON *Atmospherics*

LET IT RAIN: Unseeded clouds (*top*) have less moisture content than the same bank of clouds after seeding (*bottom*). The seeded clouds managed to produce rain showers.

SCHENECTADY MUSEUM ARCHIVES

SNOWSTORM IN A BOX: **General Electric scientists Irving Langmuir (*left*) and Bernard Vonnegut look on while Vincent J. Schaefer performs a snowmaking experiment. All three scientists were involved in developing the field of weather modification.**

chamber. Eureka! The droplets precipitated out as a blizzard of tiny ice crystals—the researchers had produced a pint-size snowstorm inside a box.

Thus was born glaciogenic (ice-forming) cloud seeding. If supercooled cloud water could be made to grow into large enough clumps, they would fall out of the sky as snow or—if they passed through warm air—as raindrops. Physical chemist and meteorologist Bernard Vonnegut (the brother of writer Kurt Vonnegut) joined the effort. He reasoned that a substance with a similar crystal structure to that of ice might also work as a glaciating agent. He found that the smoke from burning silver iodide did the trick brilliantly in laboratory experiments. Way up in the frigid tops of clouds, supercooled droplets cannot freeze until they encounter a bit of ice, a mote of dust or a fleck of soil. The crystals of silver iodide in the smoke mimic ice, providing a nucleation site for the water to freeze onto.

The rainmakers had found their seed, and the sky was the limit. By the 1950s commercial cloud-seeding companies actively hawked their services on the open market in the American West. In those heady early days as much as 10 percent of the sky over the U.S. may have been under cultivation by cloud seeders, who claimed increases in rainfall of up to 15 percent or more. This development caught the skeptical eye of Congress, which in 1953 established the Advisory Committee on Weather Control to look into the matter. Its 1957 report stated that based on data provided primarily by commercial cloud seeders, seeding seemed to have real potential to enhance precipitation. But statisticians and others attacked the report for the poor quality of data and the statistical methods on which its conclusions were based. What was needed, the scientists said, was better science.

The cloud seeders obliged. Throughout the 1960s and 1970s—the glory days of weather control—they expanded the scope of their activities. Researchers mounted a number of major campaigns in what became a veritable war on weather. They explored techniques to clear fogs from airports, either by seeding from above or heating the air from below. Hailstorms were targeted, too, in the hope of slowing the growth of the large, damaging stones that form when cloud droplets transform into crystals. In the Soviet Union, hail-suppression researchers even fired artillery shells impregnated with silver iodide into storms.

In the U.S., the war on weather took on an even more formidable enemy: Atlantic hurricanes. Starting in 1962, the federally funded Project Stormfury tried an approach called dynamic seeding. The thought was that heavy seeding with silver iodide would release large amounts of latent heat in the inner rainbands of storms as liquid droplets were converted to ice—perhaps enough heat to destabilize the storm and blunt its winds. In addition, the military has always mused on the tantalizing possibility of weather modification as a tool of warfare. During the Vietnam War, American pilots secretly doused clouds with silver iodide over Vietnam, Laos and Cambodia, hoping to bog enemy supply lines in mud.

These attempts at weather control were not entirely in vain. The seeders learned much about clouds and rain. They failed, however, to achieve the level of certainty they needed to gain broad and lasting scientific respectability. "There have been so many experiments, and a few looked sort of encouraging," says

SIGNAL CORPS PHOTO

EARLY EXPERIMENTS: **In preparation for a cloud-seeding test near Schenectady, N.Y., in 1949, soldiers crushed dry ice, the first seeding material, which was later displaced by silver iodide.**

K. Ruben Gabriel, an emeritus professor of statistics at the University of Rochester. "But the sum total of 30 years of experimentation with silver iodide is that there is so little that is positive that I don't feel optimistic about it at all."

One experiment in particular—the seeding of wintertime clouds over Israel—highlights some of the gremlins that tormented virtually all attempts at rainmaking. In the early 1960s Gabriel devised the statistical design for a major series of cloud-seeding experiments conducted by the late Abraham Gagin of Hebrew University in Jerusalem. The experiment included target and control areas, randomly assigned seeding days, and other features to minimize bias and shuffle the deck enough that Gagin and his colleagues would be unlikely to mistake the effects of silver iodide with the natural wax and wane of rainfall.

The first set of experiments, dubbed Israeli I, ran from 1961 to 1967. The scientists reported a 15 percent increase in rainfall in one of the two target areas. "That experiment looked good," Gabriel recalls. "It was statistically significant, and that was just fine." To confirm these apparently successful results, the scientists undertook a second trial in 1969, focusing on the catch basin of the Sea of Galilee. Israeli II concluded in 1975. Again, the scientists reported positive results: it rained more in the northern target area when clouds were seeded.

For a time, the Israeli experiments were considered the best evidence to date for traditional silver iodide seeding. But in 1995 two atmospheric scientists from the University of Washington, Peter V. Hobbs and Arthur L. Rangno, called into question, with a lawyerly eye for detail, seemingly everything about this much-heralded project.

Not So Fast

Hobbs and Rangno argued that many of the targeted clouds were already rich in ice crystals. The clouds were most likely not the fertile fields of supercooled droplets the Israelis had assumed they were. Therefore, seeding may have affected some clouds but probably not nearly the number the Israelis thought. Hobbs and Rangno also raised doubts about the statistical evaluation of the seeding data. By analyzing regional climate patterns, they determined that the Israeli seeding coincided with greater rainfall over the whole area. Was the extra rainfall the Israelis measured because of a natural upturn or the seeding?

The debate does not end there. Daniel Rosenfeld, a former student of Gagin and currently head of the Laboratory for Cloud Physics at Hebrew University, has rebutted Hobbs and Rangno point for point. Even now Rosenfeld does not accept a word of the critique—except maybe that the Israeli clouds were rich in natural ice and therefore less seedable. "The seeding must have worked differently than what was thought a priori," Rosenfeld acknowledges. But even if the critique was not correct in all the details, the end result has challenged the faith in the Israeli results and, more generally, in silver iodide seeding.

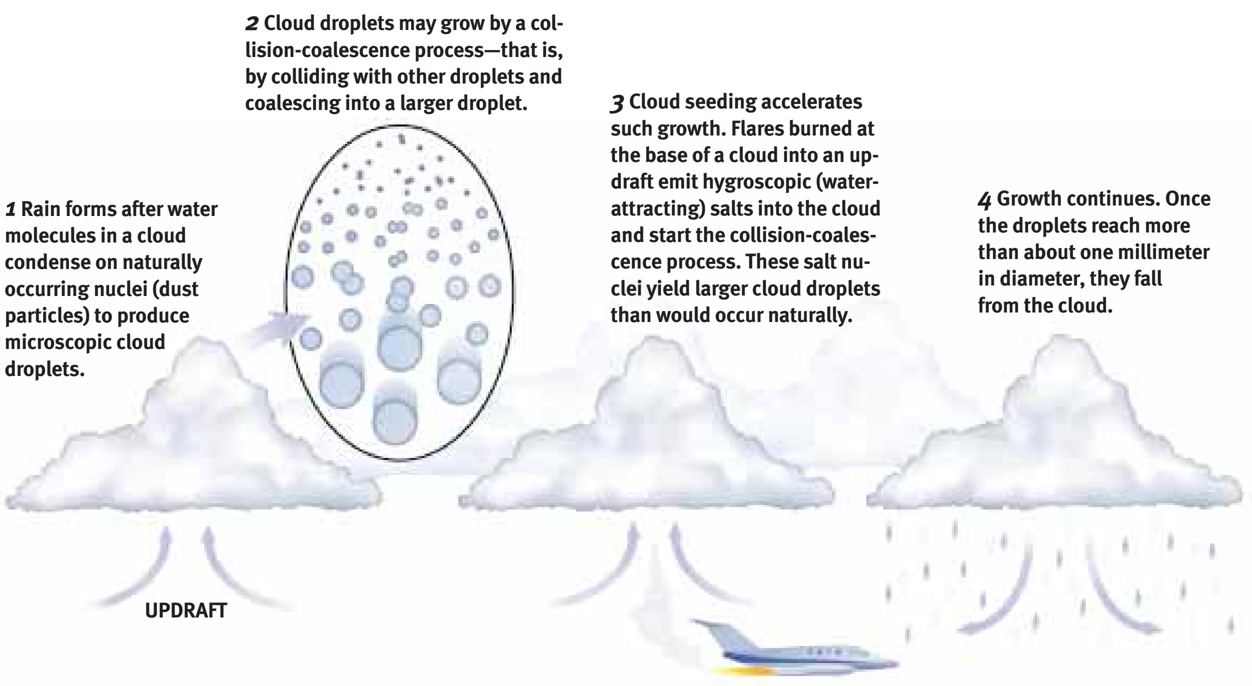
Notwithstanding past disappointments, meteorologists retain hope. The latest make-or-break test of cloud seeding is

SIGNAL CORPS PHOTO

SIGNAL CORPS PHOTO

DOES THIS WORK?: Cloud-seeding trials in the late 1940s by the U.S. Air Force and the U.S. Weather Bureau raised questions about the technique. An air force sergeant filled a hopper with dry-ice pellets for an experiment in Wilmington, Ohio, that showed seeding to be relatively ineffective (*left*). Stratus clouds seeded with dry ice in another experiment displayed a characteristic racetrack pattern (*right*).

BOOSTING RAIN BY HYGROSCOPIC CLOUD SEEDING



happening in Mexico. In the state of Coahuila meteorologist Roelof T. Bruintjes of the National Center for Atmospheric Research in Boulder, Colo., along with researchers from Mexican and American universities, is testing a technique for seeding warm clouds that has shown heartening results.

It could be said that the single best thing the Mexican experiment has going for it is that it does not involve silver iodide, given the material's checkered history. The technique involves warm rain clouds, where droplets do not go through a freezing phase to form precipitation. The clouds are seeded with microscopic salt particles that attract water and form larger droplets. The particles collide with still more droplets, eventually growing large enough to fall to the earth. Scientists and commercial rainmakers have for decades used this technique, hygroscopic (water-attracting) seeding, in which salt particles make water vapor condense into little droplets. In a key new development, flares that supply large quantities of salt crystals when they burn have supplanted the relatively unproductive liquid sprays of particles used in the early experiments.

The flares were first tested in South Africa in the early 1990s. The late Graeme K. Mather and his colleagues in the government-sponsored National Precipitation Research Program claimed increases in the size of particles within individual clouds of 30 to 60 percent. Bruintjes decided to see if he could back up the South African results in the most rigorous way possible. In 1996, with funding from Coahuila and a local steel mill, Bruintjes began a new round of experiments. To avoid uncertainty about whether the clouds were seedable (whether they had enough liquid in them), the first year of the program focused entirely on studying the characteristics of the clouds. The seeding itself, conducted in 1997 and 1998, was modeled after double-blind clinical trials used to test new pharmaceuticals. The researchers incorporated randomly assigned "placebo" flights: instructions from envelopes unsealed after takeoff would sometimes tell them to fly through a targeted cloud without actually lighting the flares that release the hygroscopic chemical salts in their smoke. They even hired the same pilots who had flown in the South African experiments.

After two seasons of seeding, with observations of 48 seeded clouds and 52 placebo clouds, the research team was encouraged to find that the preliminary results from Coahuila matched the South African findings. Over time, the seeded clouds appeared to be producing significantly more precipitation than the unseeded clouds were. Furthermore, Bruintjes says, it appeared to rain over a larger area and for a longer time. The Bureau of Royal Rainmaking in Thailand has just completed trials with hygroscopic seeding that also seem to back up the results from South Africa and Mexico.

Despite the promise, Bruintjes cautions that the studies have shown only that hygroscopic flare seeding makes wetter

In Mexico, researchers are testing a technique for seeding warm clouds that has shown heartening results.

clouds, not that it necessarily produces more rain for crops and drinking. In Mexico and South Africa the effect of seeding was not measured as rainfall on the ground but as radar reflections. Stronger reflections off a seeded cloud mean that the cloud contains more precipitation—near the base of the cloud. So what does that mean in terms of more raindrops falling on our heads? The only direct test of rainfall enhancement is the amount of water that actually reaches the ground. Bruintjes says that the Coahuila seeding did involve a network of gauges, which he hopes to use to calibrate the radar measurements of rain volume.

If hygroscopic seeding proves itself, the story is not over. Even if more rain falls from a given cloud, "the next logical question is whether you really increase rainfall over an area," Bruintjes comments. "Is this a worthwhile alternative, or should we build more reservoirs? Should we build a desalinization plant?" In the Mexican state of Durango, where the project has relocated, researchers want to observe a watershed to determine if increases in precipitation in the clouds can be linked to increases in the water supply. "If we can show that it doesn't work, that will still be a tremendous result," Bruintjes remarks. "Then I know I've gone through all the necessary steps, and people wouldn't be wasting their money on this."

THOMAS J. HENDERSON *Atmospherics*

A FLARE FOR RAIN: Weather modification company Atmospherics uses hygroscopic seeding to increase precipitation over a reservoir near Fresno, Calif. Flares emit microscopic salt particles onto which water vapor condenses into droplets.

Deploy the Thunderheads

Assuming that warm-cloud seeding bucks the 50-year trend in weather modification research—promising results followed by dashed expectations—it would seem that the prospects for weather control in the 21st century have begun to improve. Even some in the military have had a rapprochement with weather control, despite a 1976 United Nations agreement against the hostile use of "environmental modification," in part a response to the military seeding in Vietnam. In a 1996 report, "Weather as a Force Multiplier: Owning the Weather in 2025," the projected scenarios for weather warfare included unmanned cloud-seeding planes that would loose thunderstorms on enemies or throw a "cirrus shield" of cloud cover over friendly forces.

Yet the apparent optimism does not guarantee public acceptance of rainmaking, even among the farmers who would most stand to gain. Cloud seeders have at times found themselves at odds with farmers. Often the disputes have involved accusations that seeding in one area robs moisture from adjacent fields—an atmospheric variation on robbing Peter to pay Paul. In northwestern Kansas, some are now questioning the wisdom of fiddling with natural forces for human benefit.

A group of farmers in Rawlins County, Kansas, has formed Citizens for Natural Weather to speak out against a regional hail-suppression program. The opponents of the program, based on their own anecdotal observations, believe the seeding has robbed them of rain. "If we miss out on an inch of rain, the impact of that in a dryland county is phenomenal," says Keith Downing, a dryland farmer in Colby, Kan., who heads the group. "We do not want to take the risk of that." In July 1999 citizens in the county voted nearly 4–1 to ditch the seeding program. "Nobody can prove anything about this," Downing notes. "It's not scientific. It's strictly experimental, particularly on the rainfall end of it." Ironically, the same uncertainty that has allowed commercial cloud seeders to operate despite the absence of sound scientific backing is coming back to dog them.

Downing has also raised a more fundamental objection to cloud seeding. Kansas's Groundwater District No. 4, which includes his property, is supposed to manage the aquifer, he remarks, not create one. "They are spending way too much time on cloud seeding and not enough time on managing the depletion of the groundwater," he says. Downing would like the seeders to hang up their silver iodide burners and water managers to adopt a policy of zero depletion, allocating as much water to farmers as possible yet maintaining the water table at current levels. "I'd just as soon let Mother Nature take care of the weather," he urges. Even if Downing's view becomes the consensus, the age-old dream of human control of the forces of nature will probably never die. But the underlying science has failed to move the technology far enough beyond its shamanistic origins to quell the skepticism that still surrounds the rainmaker's art. W

DANIEL PENDICK is a freelance writer living in Brooklyn, N.Y. He was formerly an editor at *Earth* magazine.