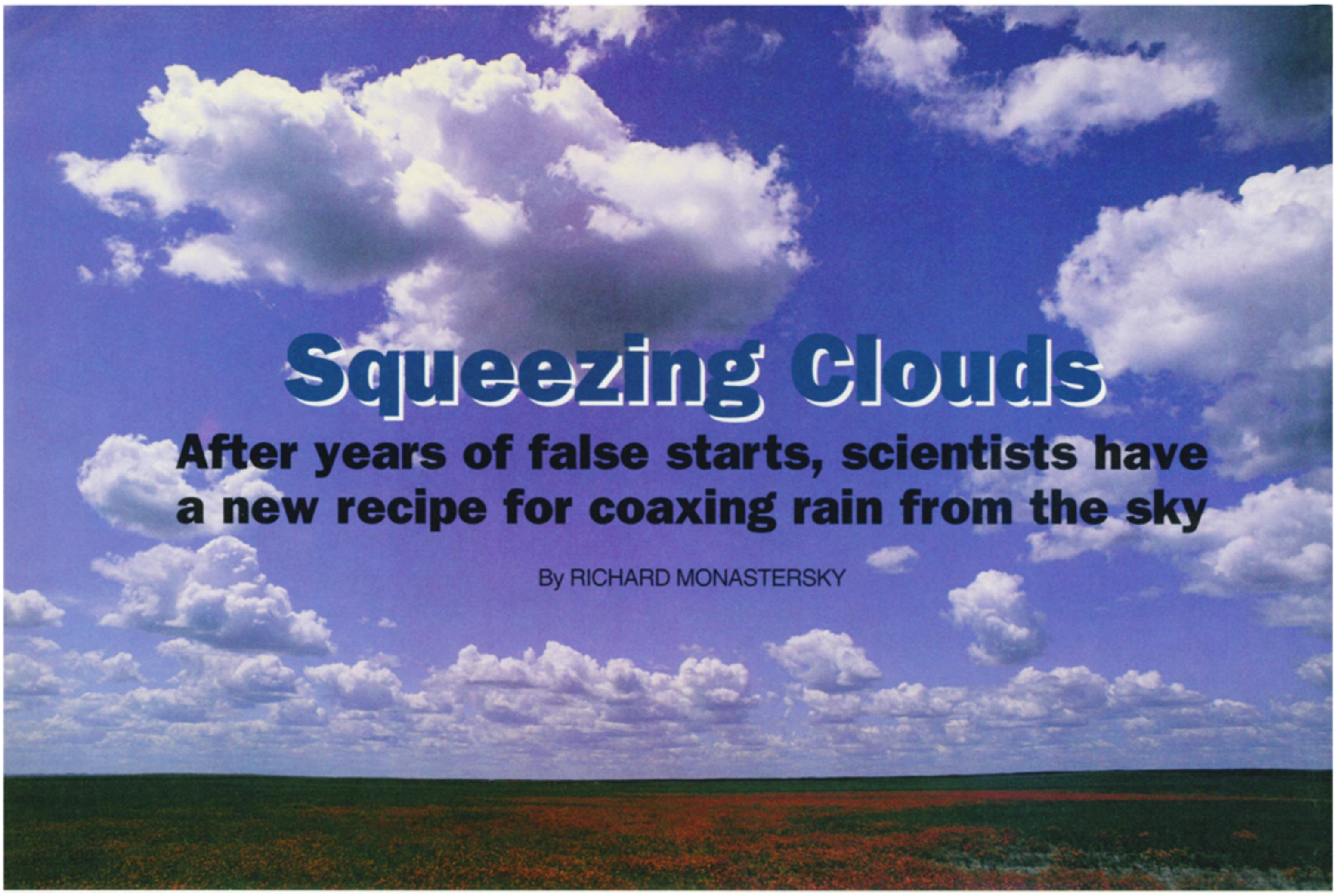


Squeezing Clouds

After years of false starts, scientists have a new recipe for coaxing rain from the sky

By RICHARD MONASTERSKY

The pilot of the Piper Cheyenne noses his twin-engine plane toward the cloud until he just tickles its underbelly. With the flick of a switch, an orange flame erupts from flares mounted on the plane's left wing. The fire leaves a trail of salty smoke, visible for only a few moments before powerful updrafts sweep it into the heart of the growing cumulus. Some 20 minutes later, fat raindrops start falling from the same cloud, moistening the arid landscape of northern Mexico.

Welcome to the new age of weather modification, a concept born by accident just after World War II. Since then, researchers have been trying to develop reliable methods for drawing rain from bashful clouds. Yet with each set of promising experiments over the decades, the flood of initial optimism has always dried up under subsequent scrutiny, making it difficult to tell whether seeding clouds actually increases precipitation.

"Most experiments haven't shown an effect when you seed with silver iodide, the standard seeding procedure," says K. Ruben Gabriel, a statistician at the University of Rochester, N.Y., who has helped design and analyze cloud-seeding experiments since the early 1960s. "When you put some 45 years of experimentation together and you have so few experiments that have positive results, you can't be very sanguine about it. You can't say that, clearly, it works."

The rains now falling in Coahuila, Mexico, however, are nourishing new hope among would-be rainmakers. In this parched northern state, a team of U.S. and Mexican researchers is finishing a 4-year-long test of a cloud-seeding technique first conceived in South Africa. The preliminary results from Mexico are bolstering the findings from Africa, where investigators reported that flares containing water-absorbing, or hygroscopic, salts can significantly and reliably boost the amount of rain falling from clouds.

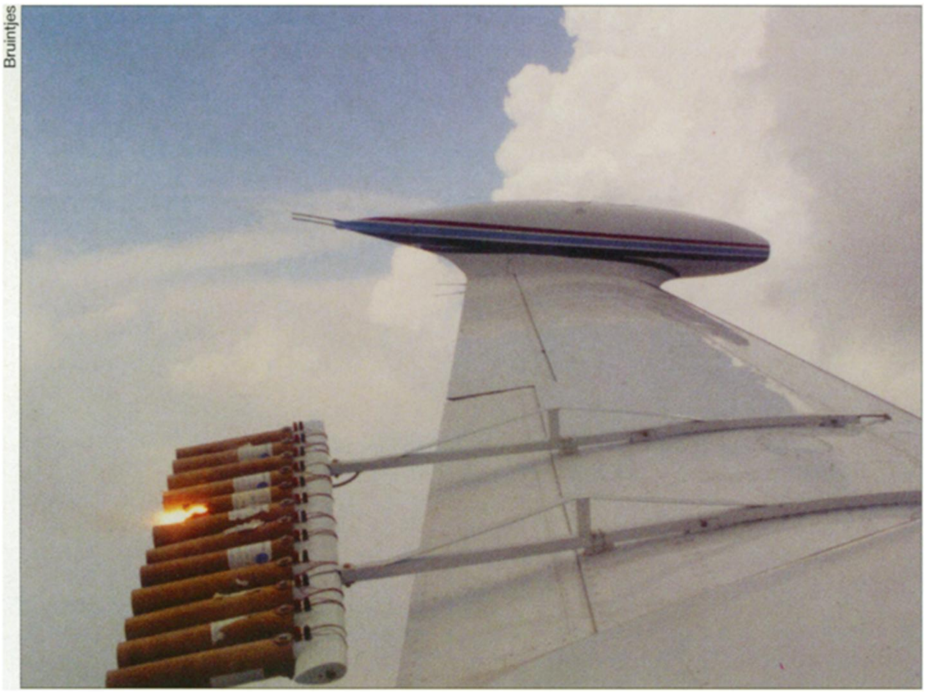
"These hygroscopic flares represent the most exciting new development in 50 years in this field," says Nico J. Kroese, deputy director of precipitation research for the South African Weather Bureau in Bethlehem. "The proof that you can actually duplicate this research in different parts of the world is quite exciting for all the water-stressed parts of the world. I'm not saying it will reduce drought completely, but it can be part of a technique that's used to tackle this problem."

Credit for the new method goes ultimately to a pollution-belching paper mill near Nelspruit, South Africa. During a research program in 1988, the late Graeme Mather was attempting to enhance rainfall by seeding clouds with dry ice. On one day, the only cloud that showed any potential for rain happened to be growing in a conspicuous location, over the paper mill. To see why, Mather and his team from Cloudquest, a research company in Nelspruit, flew through the cloud and collected samples of the tiny particles that serve as condensation points for water.

"He found that the properties of the storm over the paper mill were completely different from what we are used to over South Africa," says the weather bureau's Deon E. Terblanche.

It turned out that the paper mill was emitting tiny crystals of potassium chloride and sodium chloride, which rose with the updrafts into the cloud. Because these two salts attract moisture, they quickly formed large water droplets in the cloud. The atmosphere naturally contains particles of these salts, but the paper mill exhaust contained a higher concentration of them and larger sizes, better able to form rain.

Mather, Terblanche, and their colleagues decided to simulate the emissions from the paper mill. In 1990, South Africa dispensed with dry ice and silver iodide and switched to hygroscopic salts. The Weather Bureau and Cloudquest initi-



Smoking permitted: During a cloud-seeding experiment in Mexico, a burning flare emits particles of potassium chloride and sodium chloride in hopes of stimulating rain.

ated a 6-year experiment to test the efficacy of flares that spew out potassium chloride and sodium chloride.

At the end of their trial, which examined 127 seeded and unseeded storms, the researchers were confident that they had a winner—one that worked much better than previous methods. Radar measurements indicated that seeded clouds produced 30 percent more rainfall than unseeded clouds.

The news coming out of South Africa caught the attention of authorities in Coahuila, across the Rio Grande from Texas. In this perennially drought-stricken region, a burgeoning population had been depleting stocks of underground water.

An international team of researchers began in 1996 to test the hygroscopic flares. Their study works much like a randomized clinical drug trial, comparing the effects of a seeding agent with the meteorological equivalent of a placebo. As researchers in a plane approach a growing cumulus cloud, they open an envelope containing randomly assigned instructions on whether to seed. If they get the go-ahead, the researchers ignite the flares and fly within the updraft flowing into the cloud. The plane follows the same prescribed path even if the flares remain unlit.

Without knowing the envelope results, radar operators on the ground track the storms as they grow. By measuring the amount of microwave energy bouncing off water droplets, researchers can gauge how much precipitation is developing in the cloud.

The effects of seeding hardly stand out like a bolt of lightning. "You wouldn't see the difference with the eye," says study leader Roelof T. Bruintjes of the National Center for Atmospheric Research in Boulder, Colo.

One of the laws of meteorology is that all clouds look different, and no cloud remains the same from one minute to the next. "That is why we revert to randomized experiments, because this is the only way we could get a big enough sample set of natural and seeded clouds to compare and see if there are significant differences," says Bruintjes, who reviewed the last half century of cloud-seeding research in the May BULLETIN OF THE AMERICAN METEOROLOGICAL SOCIETY.

At a meeting of the World Meteorological Organization in Chiang Mai, Thailand, in February, the participants in the Mexican study discussed their findings thus far. Preliminary data from the first 3 years have encouraged investigators, says Kroese, who aided in the design of the Mexican trial. "The Mexican results look slightly better than the South African results," he says.

Another report at the meeting also supported the technique. The Bureau of Royal Rainmaking in Thailand conducted a randomized, controlled study of hygroscopic salts and obtained positive results.

Bruintjes acknowledges that his team's initial findings in Mexico seem promising, but he remains noncommittal. "What we have found is that it seems the South African results are going to be confirmed, although we wanted to do our last year before we really publish anything on it," he says.

Such caution serves as a reminder that the vagaries of cloud studies have doused scientists' expectations many times before.

An element of chance has dominated the business of weather modification from the moment of its birth in 1946. At that time, scientists at the General Electric Research Laboratories in Schenectady, N.Y., were working on techniques to keep aircraft wings from icing up. As part of these experiments, Vincent J. Schaefer needed to form ice on some metal pieces in a cold box.

One day while looking inside the box, Schaefer inadvertently breathed into it. When he then put a piece of dry ice into the box to make it colder, the moisture from his breath fell out as a miniature snowstorm. The scientists soon took to the sky, demonstrating that dry ice, and silver iodide, had the potential to increase snowfall and rain.

The theory behind cloud seeding rests on the observation that most clouds are stingy. A single cumulus cloud may hold millions of tons of water, but it often won't part with a single drop of precipitation. Even when clouds do produce rain or snow, they usually give up less than 30 percent of their moisture, says Bruintjes.

Blame it all on poor timing. An individual cloud has a limited life span, and it takes a certain amount of time for water droplets and ice crystals to grow to appreciable size. If a cloud dissipates too quickly, the precipitation never gets big enough to fall to the ground. For instance, in South Africa, cloud droplets need 30 minutes to reach the size of a raindrop, yet fewer than 5 percent of cumulus-type clouds last that long.

Silver iodide and dry ice are thought to mimic natural ice crystals in clouds short on frozen particles. As clouds grow, their heads often poke up high enough to reach temperatures well below freezing. In many cases, though, much of the chilled water in these clouds remains liquid—stuck in a supercooled state. The droplets, touched by seeding agents such as silver iodide or dry ice, instantly freeze into ice crystals.

In theory, moisture in the cloud then readily solidifies on these crystals, helping them grow big enough to plunge out of the cloud. In winter, these particles fall as snow. In warmer weather, they melt on the way down to form rain.

The strategy behind hygroscopic salts exploits a different way of making rain—one that occurs over the oceans. "You're actually trying to modify the continental clouds to be more maritime in character, because that is exactly what the oceans do," says Terblanche. "They seed clouds with small salt particles, and the maritime clouds are much more efficient in producing rainfall."

Maritime air is clean, with relatively few salt particles around onto which water can condense. The limited number of available droplets attract moisture in the air and quickly grow big enough to plummet from the sky.

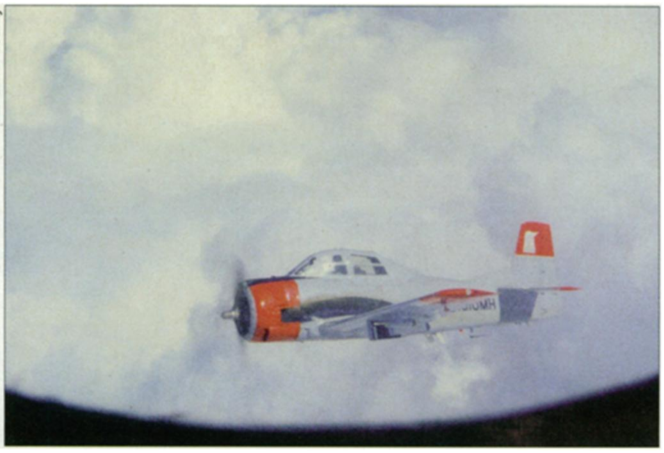
Continental clouds, however, have a dirty secret: The atmosphere over land is filled with dust specks that serve as condensation points. As a consequence, moisture in a cloud spreads out among many small droplets that fall so slowly that they evaporate long before reaching the ground.

To make rain, the tiny droplets must collide with each other and merge in order to grow. The trouble is that cloud droplets rarely crash together. They are so slight that the currents of air inside a cloud often carry these droplets skirting past each other.

"It's like when you drive a car very fast and you see a bug. Big bugs, due to inertia, will impact on the window, but some small bugs may flow with the airflow of the car over the roof," says Bruintjes.

The hygroscopic salts from flares take a shortcut around this problem. They start off bigger than natural dust particles, and the salts quickly form large droplets because they attract water.

Aside from testing cloud-seeding techniques, many of these hygroscopic-flare experiments measure storms and take air samples to see precisely what goes on inside a seeded cloud. "That's the most important part because that will scientifically let us know how this works, whether we can optimize it, and what are the criteria for transferring it from one region to another region," says Bruintjes.


William Woodley

Researchers in Texas use an armored T-28 aircraft to fly into seeded and unseeded clouds.

Even before scientists have appraised the potential of this technology, use of hygroscopic flares has started to spread.

"We have been using it operationally for 4 or 5 years. It looks pretty promising," says Thomas J. Henderson, president of Atmospherics, a cloud-seeding company in Fresno, Calif.

Henderson, who has worked in this arena since 1948, notes that such flares are not new. The U.S. Navy developed similar ones in the 1960s to clear fog from airports. It was the South African discovery that prompted people to try these salt flares for augmenting rain. He views the hygroscopic flares as complementary to silver iodide, with one or the other effective in different situations.

Despite deep scientific skepticism about the efficacy of modifying weather, cloud seeding has grown into a big business. Henderson's company has operations in Indonesia, Costa Rica, and Greece, as well as eight projects in California. In all, more than 40 countries have some cloud-seeding programs, as do many states and counties in the United States.

Texas is currently seeding clouds across one-quarter of the state, according to the program's administrator, George Bomar of the Texas Natural Resource Conservation Commission in Austin. Funded half by the state and half by local districts, the seeding costs $3.3 million per year.

Studies in Texas going back to 1985 indicate that seeding clouds with silver iodide does produce extra rainfall when averaged over a several-year period, says Bomar. Nonetheless, he acknowledges the scientific skepticism. "We're at the point where we can't prove it works. I don't know if we'll get to a point where we can prove cloud seeding works on a given day."

The uncertainty, though, doesn't deter farmers and water managers from investing in this relatively cheap technology. After all, business people never wait for the same level of certainty that scientists desire.

"If farmers in a certain area decide to invest in weather modification, I can't say that they're wrong because I have doubts. Possibly, they're wasting their money. But they may say, 'It's worth the expense to seed the clouds, and we're going to take the risk,'" says Gabriel, a member of the American Meteorological Society's committee on weather modification.

Skeptics and proponents agree that cloud seeding cannot cure droughts because the technique requires that the sky already hold enough moisture to form clouds. Instead, regions can use cloud seeding to build up water supplies in normal years or to supplement natural rainfall during moderate dry spells.

It may be that effects of cloud seeding will always remain foggy. The father of modern applied statistics, Sir Ronald Fisher, once quipped to Gabriel that weather modification "reminds me of the burnt offerings in the ancient years. There was an awful lot of fire and smoke on the ground and it was very impressive and it rose to the heavens, but you never knew whether it did anything in the heavens." □