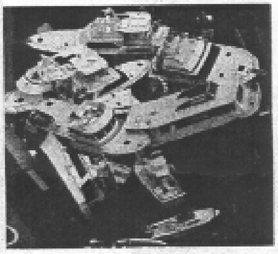
EARTH

HURRICANE OMNI:
Scenario for seeding an imaginary storm

By Carl Posey

The most promising approach to altering hurricanes now, as a generation ago, lies in turning the hurricane's own power against itself. The objective would almost certainly be to intercede—perhaps through cloud seeding—in the natural processes that cause the eye to expand and contract and to reform at greater distances from the center. Here, drawn from conversations with hurricane veterans, is the way such an experiment might unfold.



Hurricane Andrew pounded Florida with mighty winds, stacking up yachts and pleasure boats (above); Hugo hit Saint Croix in 1989 (right).

Reaching maturity about 900 nautical miles west of Puerto Rico, the storm is predicted to remain at sea for at least 24 hours. Hurricane-hunter aircraft muster at Roosevelt Roads, the military field from which they attacked hurricane Debbie in 1969. The two NOAA WP-3D Orions are on hand, both carrying state-of-the-art instrumentation that includes lidars (the laser equivalent of radar) and microwave Doppler radar, which permits them to monitor fine three-dimensional motions of water particles in the storm. They'll fly low-level missions for eight hours, at altitudes between 1,000 and 10,000 feet, before, during, and after seeding.

The four seeder aircraft—Gulfstream IV jets—carry radar and lidar equipment and cloud physics instrumentation similar to that on the Orions, permitting them to pinpoint the powerful updrafts hidden in the eye wall and primary rainband—updrafts with an abundance of supercooled water the scientists hope can pump additional heat into the storm clouds, arresting the hurricane's development when it has expanded to a broader eye.

Overhead, two geostationary satellites have been placed over the equator, 30 degrees apart, giving scientists stereo views of the storm to detect changes in structure after seeding. The entire experiment is controlled from a forward headquarters, through the Global Positioning System. But, once deployed, the aircraft will need an autonomy that matches the variability of the hurricane.

Well before dawn on the first seeding day, one of the Orions takes off into the lightening sky east of Puerto Rico, taking several hours to reach the hurricane, which it enters along the spiral rainbands, flying only 1,000 feet off the churning sea. For the next 72 hours, the hurricane will always have one of the Orions in it for ten hours at a stretch—back-breaking flying for the crews but necessary to monitor the storm and, if possible, to detect the human signal caused by seeding.

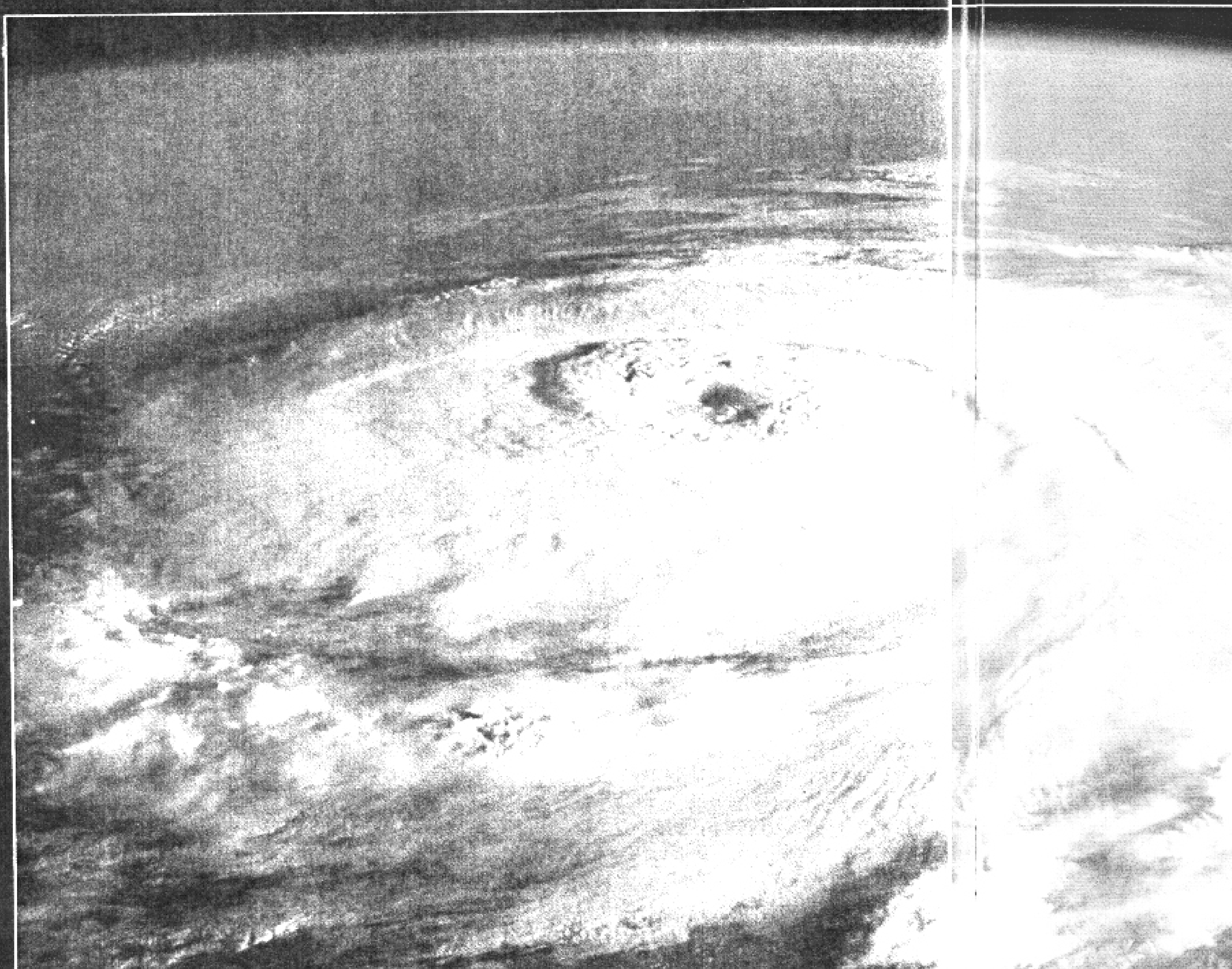
The Gulfstreams take off near midday, climbing to a cruising altitude above 40,000 feet. Two of the Gulfstreams stay high and fly some distance from the fringes of the storm, sampling the atmospheric environment for subtle disturbances that could introduce a false signal into the hurricane. The other two fly up the rainbands just above the freezing level at about 25,000 feet.

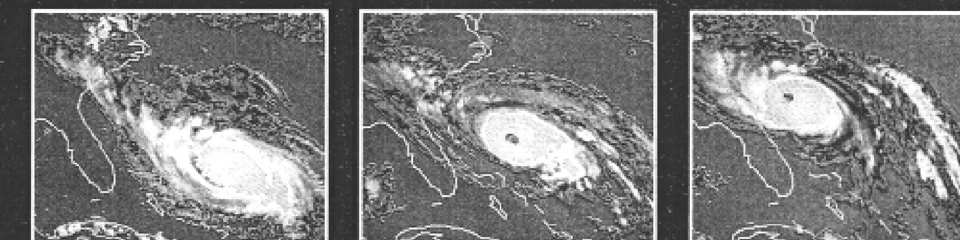
As the lead Gulfstream plows into the hard wall of rising cumulus cloud along the primary rainband, its radars tell the scientists aboard where the best seeding will be and vector the aircraft toward those turrets in the primary rainband. Once inside the hard, wing-wrenching wall of rising cumulus towers, the Gulfstream lays down a plume of smoke rich in silver iodide, spewed from wing-mounted burners. It bucks through the eye wall into the calm, sun-filled center of the storm, then returns along the rainband, seeding it again. The second seeding Gulfstream bulls into the same area and spews its plumes of silver-iodide smoke. When they've expended their silver-iodide supply, they climb out and return to Puerto Rico for fuel and a fresh crew.

No one knows, going in, whether our imaginary hurricane will turn toward shore or the northern Atlantic with a larger eye and diminished winds. Like Debbie in 1969, it is an experiment, but unlike Debbie, it could be a beginning, not an end. ∞

HURRICANES

Reaping the whirlwind





Not quite half a century ago, had you asked meteorologists whether in the 1990s a powerful hurricane could chop the communities of south Florida into matchwood, they very likely would have chuckled at your lack of vision. Everyone knew that well before the year 2000 there would be an operational technology for weakening severe storms before they made their destructive landfalls. A squadron of aircraft dedicated to hurricane suppression would stand by through each summer season. When a major storm veered toward shore, the squadron would launch an attack, seeding the central rainbands until the destabilized hurricane's winds faltered. At the turn of our century, coastal homes might still be losing shingles, but hurricanes would no

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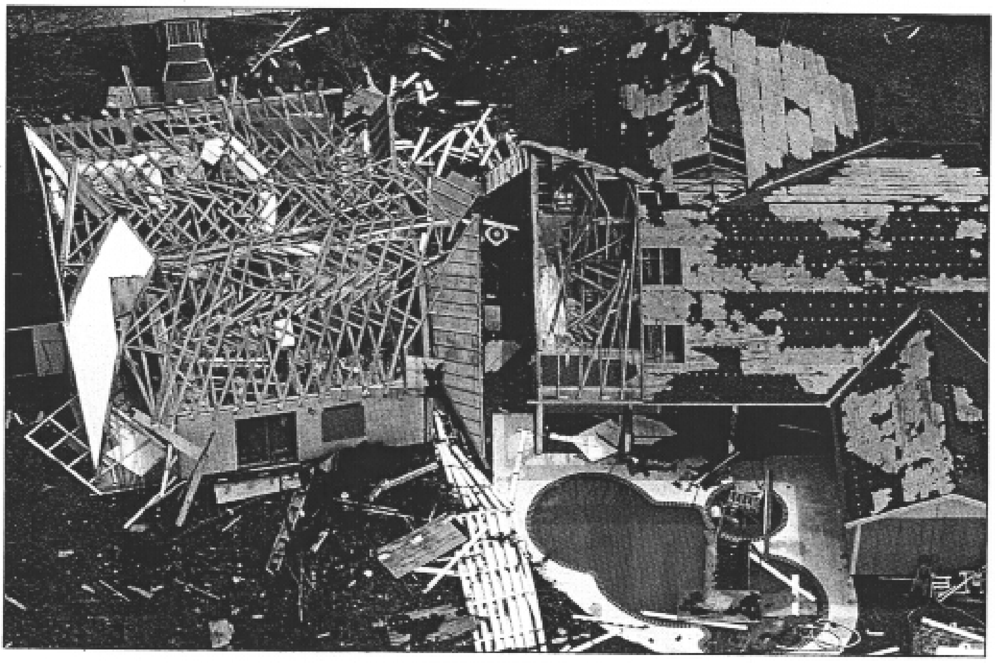
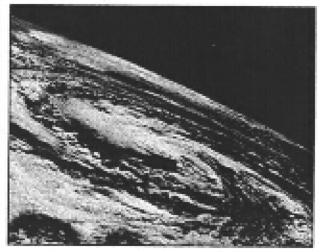


Andrew ripped through Paradise Point (left) and Fort Lauderdale (center), generating the equivalent energy of a ten-megaton bomb—not for a second, but constantly, for days. Seen from space, Gladys wallops the Caribbean (below).



longer kick their way through our towns and cities like booted giants.

Of course, the visionaries of the 1950s and 1960s were dead wrong. When hurricane Andrew ripped through south Dade County in August 1992, shredding the area's light-frame structures with its powerful winds, it arrived untouched by human hands. Radar had swept the storm during its advance, satellites had monitored it, computers had simulated the various paths it might follow on its landward run, and aircraft had probed the storm again and again. But the operational technology that everyone *knew* would be in place by now was nowhere to be seen.

Not that the notion of blunting hurricanes had been tested and found wanting, however. After a flurry of support, weather modification was simply written out of the federal agenda in the Carter and early Reagan years. Vaporous diplomats, dissent among scientists, and the elusiveness of statistically viable proofs—statisticians and their appetite for significant samples, after all, are the undertakers of daring science—combined to suffocate the idea before it could be tested in the field. Even nature played a hand. Contrary as always, she cut off the supply of seedable hurricanes and simply outwaited the truncated attention span of policy makers. Today, observes one long-time researcher, you don't even hear hurricane modification mentioned; nobody wants to think about it.

For most of human history, the idea of somehow taming the violent creatures of the atmosphere has been treated only as fantasy, as magic. A sorcerer like Shakespeare's Prospero might have "call'd forth the mutinous winds and 'twixt the green sea and the azur'd vault set roaring war," but everyone understood that such stuff was Faustian nonsense. No one knew this better than mariners. They'd gone through hurricanes, lost ships and shipmates to the big storms, and experienced the metaphorically beautiful calm of the central eye, where there might be white water aplenty but the

air was calm enough for seabirds to gather and for battered ships to rest before being overtaken by the cyclone's trailing edge. There was also something intensely personal about being thumped at sea by an Atlantic hurricane or western Pacific typhoon. The great storms were redolent with a kind of mystery—when people in the hurricane trade talk about Donna or Camille, they seem to be talking about more than just another natural phenomenon.

Radar, invented during World War II, robbed the storms of some of their imponderable qualities. On early radar screens, the storms appeared as white Rorschachlike brutes of cloud ringing an empty center, their 200-mile diameters compressed neatly into a six-inch cathode-ray display. Probing the storms with aircraft also drained away some of the mystique, despite the almost legendary roughness of the ride. These deadly spirals, it turned out, were rather easily seen.

Looking at their meteorology, you could tell at once that they were really just oversized heat engines. Warm, moist air near the ocean surface was being drawn into a spiral around a center of very low atmospheric pressure, then spun into a cylindrical wall of violent convective, vertical clouds around an eye. Adding the energy of its load of freezing water to the storm's, the air was rammed up this chimney to exhaust some ten miles above the sea in a vast shield of frozen cirrus clouds. But in that powerful, rather simple, process, there seemed to be something frail and unstable. Like the engines of Indy racers, hurricanes seemed always poised on the rim of mechanical failure. Perhaps, a few meteorologists dared think, that frailty was a handle shaped to the human hand—a way for us to tinker with the enormous energies of the hurricane.

Robert Simpson, a rangy physicist from Corpus Christi, Texas, was one of the first to see the possibilities. Working as a tropical meteorologist and hurricane forecaster in New Orleans and the Caribbean, he'd followed the progress of early cloud-seeding experiments in New England, where dropping silver iodide into stratiform clouds filled with supercooled water—water chilled below freezing but still in liquid form—had permitted General Electric researchers to carve a big "GE" in a winter cloud deck. Supercooled water waited only for a microscopic crystalline particle—a nucleus—to freeze on before it turned to ice. Silver iodide provided the nuclei. "It was heralded all over the world as the birth of a new age of weather modification," Simpson recalls today.

The people in power also began to think about hurricanes. During the 1950s, the tropical Atlantic sent one major storm after another pinwheeling toward the United States. In just two years, six severe hurricanes—Carol, Edna, and Hazel in 1954, and Connie, Diane, and Ione in 1955—caused what would today be some $10 billion in damage and took some 400 lives from Georgia to New England. Its attention grabbed, the government ordered the Weather Bureau to do something, and Simpson was given the task of creating the National Hurricane Research Project, which began working from its Palm Beach, Florida, base in 1956. "I built in some experimental seeding," he says—"not to modify the storms, but just to see what would happen."

At first, very little happened. The airborne burner designed to produce a plume of silver-iodide-enriched smoke was hard to light in the hurricane. "We had several abortive missions in 1957," Simpson says. "It was all sub rosa. In 1958, we got the instrument to light and seeded Daisy on two days." A small, strong storm, Daisy showed no detectable effects. In fact, the researchers would have been able to see only the most obvious changes. Radars of the day could discern the spiral of rainbands and define the eye, but nothing on the aircraft permitted realtime readings of the winds or the proportions of water and ice in the clouds. Simpson and his colleagues were, in a sense, the alchemists of meteorology, following instinct and intuition more than the well-defined track of a mature science.

In 1959, Simpson returned to the University of Chicago to finish his Ph.D., which had been interrupted by the war, and there he experienced the epiphany that shaped all subsequent attempts to modify hurricanes. "My friend and dissertation adviser was Herbert Riehl," he says now. "On his own, Riehl came

DOING SOMETHING

Whenever a hurricane like Andrew savages an American community, ideas pour in for hitting back at the devastating storms. Some offer recipes for homemade bombs or, most often, ask why hurricanes can't be handled like a certain maternal alien and nuked from orbit. Others wonder why the superb accuracies of smart weapons in Desert Storm can't be applied to knocking out hurricanes. Radioactivity aside, the violent energies of these great storms make anything humans can hand out trivial in the extreme.

Hurricane Andrew, for example, generated the equivalent energy of a ten-megaton bomb continuously during its passage—not for a split second, as in a bomb explosion, but all the time, for days. According to one hurricane researcher, such enormous energy represents a large fraction of global energy consumption. Would such a powerhouse even feel a nuke? Probably not.

More tempting suggestions involve tinkering with the heat-engine side of the hurricane, either by chilling its warm core—some propose bombing the eye with liquid-nitrogen bombs, others with tons of dry ice—or altering the temperatures of the warm ocean from which hurricanes draw their vast energy. Laying down a sheet of carbon black or impermeable monomolecular film, according to some scientists, might retard evaporation—the mechanism by which the storms suck heat from the sea—to weaken the winds. Of course, such schemes also pose problems of cleaning up. A one-molecule-thick film tough enough to hold together under hurricane conditions might not be easy to get rid of once the storm is past.

Alternative proposals look at ways to bring the colder waters at depth up to the surface, again in an effort to make the hurricane chill out. This kind of attempt would seed the ocean ahead of the advancing storm with such devices as wind-driven underwater corkscrews and bubble generators that would force cold water to well upward.

These ideas have merit but still underestimate the size of the storms. A major hurricane might be ten miles high with a core some 50 miles across, wound with rainbands going out more than 100 miles. To make a difference, dropping coolants in from the top would require thousands of aerial tankers. Changing water temperatures ahead of the storm would likewise require millions of expendable devices; deploying them would be a daunting task, to say the least, and very expensive.

Thus far, there is still no human technology known that can counterpunch with hurricanes—the volume and energies of the storms are just too much for us. As scientist Hugh Willoughby puts it, "At the energies of interstellar flight, direct intervention becomes possible." But he also sees a ray of sunshine—a literal one. Eventually, he believes, humankind will have to go to space for its energy, perhaps using vast mirrors to collect solar energy and beam it, in the form of microwave radio waves, to the surface. Such mirrors, he muses, might be used to shoot a blast of solar radiation into the heart of a hurricane as it forms, defusing it at birth.

down to Norfolk and asked the Navy to fly him through Donna," a 1960 hurricane. "So they took a jet and flew him back and forth over the top of Donna as she approached Florida. He took pictures—pictures of what the radar saw. Donna was a very steady storm. It had this chimney in the right front quadrant. Riehl said the effluent from this chimney created the entire cirrus shield over the storm. He came back all excited. We got together. I said, 'Did you get any icing?' He said that every time they went through the front quadrant, the plane got ice all over it." No one cried eureka, but a hypothesis was born.

Simpson had been looking for some trigger, some trick, with which to take advantage of what he regarded as the storm's inherent instability. The presence of supercooled water offered one. Water gives off enormous quantities of stored, or latent, heat when it changes phase from liquid to ice. If by seeding you could coax the supercooled water to freeze, you'd release huge quantities of heat into the heart of the hurricane—perhaps enough to make a difference. "I developed the hypothesis that you'd release more heat," Simpson explains, "and change the surface pressure gradient that controlled the flow of wind." Because the pressure drop would not be so steep, surface winds would not coil quite so tightly around the center of low pressure; the built-in instability of the storm would then cause the eye wall to wander outward, reforming at a greater radius from the center. And, like a whirling Sonja Henie sticking out her arms, the hurricane's winds would drop.

Back in Palm Beach, Simpson soon tried his hypothesis in the field. On September 16, 1961, a mixed squadron of Navy and Weather Bureau aircraft converged on hurricane Esther and dropped eight silver-iodide canisters into clouds around the eye—the annulus of towering clouds called the eye wall. Esther, which had been intensifying, leveled off, and the winds near the eye wall weakened significantly. The next day, the planes tried again, but this time the canisters missed the eye wall and no changes were observed. No cigar, perhaps, but on the whole, an encouraging start. In fact, Esther's behavior was encouraging enough for hurricane modification to move into the light. In 1962, the U.S. Navy and Department of Commerce established Project Stormfury—and Simpson's idea hardened into the Stormfury Hypothesis.

By now, however, cloud seeding had acquired some scientific trappings—it was more than just the introduction of a seeding agent like silver iodide. A technique called "dynamic seeding" had emerged, in which seeders sought to alter the very structure and wind flow in cumulus clouds. By causing supercooled water to freeze and release latent heat into the cloud, they could force the cumuli to grow, drawing increased quantities of surface air in at the cloud bases and exhaling greater quantities of frozen effluent at high altitudes. Simpson and his wife Joanne, an experimental meteorologist, incorporated dynamic seeding into Stormfury: Seeding, they postulated, would

OUT OF AFRICA

Some hurricane seasons are more equal than others. A map of the tracks of severe Atlantic hurricanes—those with winds greater than 110 miles per hour—from the end of World War II through 1969, the year that gave Stormfury Debbie to seed, is a tangle of destructive strands. From 1970 through much of the 1980s, only one severe hurricane was observed. Now, meteorologists believe, storm activity may be edging back toward a reprise of the destructive 1940s and 1950s, with the difference being that the empty marshes of half a century ago are now densely populated coastal communities like south Dade County. The potential damage is incalculable.

No one can say for sure that hurricanes are actually on the increase. To some scientists, the rise and fall in the incidence of destructive storms is merely a random flexing of the conditions over the tropical Atlantic that spawn hurricanes. Other observers, however, see an ominously predictable cycle of activity linked to forces somewhere else.

To many meteorologists, "somewhere else" is western Africa. Decades of watching the seeds of hurricanes flow westward from that continent and blossom into hurricanes over the warm ocean have led experts to look for connections between Africa and the frequency of hurricanes, but the actual mechanism has proved elusive. Some have postulated that African dust in the trade winds suppresses the formation of hurricanes by blocking solar radiation; others suggest that the grains seed the moist tropical atmosphere, abetting the growth of young storms.

According to William Gray, a meteorology professor at Colorado State University, the key factor appears to be the amount of rainfall in west Africa. The years of frequent severe Atlantic hurricanes coincided with years of abundant rainfall over west Africa. The continental storms that produced the heavy rains, in Gray's view, may have set up conditions in the easterly trade winds that fostered the formation of hurricanes. Conversely, the hurricane famine that lasted from 1970 through 1987 coincided with a relentless drought in western Africa—a stormless interval that sent no hurricane-spawning pulses out over the Atlantic.

Now, Gray reports, the African drought shows signs of ending. If it is, and if Gray's correlation is true, the American side of the Atlantic is in for it. There are already ominous signs of an increase. Gray notes that there have been ten severe hurricanes since 1987: Gilbert, Helene, and Joan in 1988; Gabrielle and Hugo in 1989; Gustav in 1990; Bob and Claudette in 1991; Andrew in 1992; and Emily in 1993. While Gray acknowledges that the signal remains far from clear, that violent cohort of storms may be the harbinger of hurricane seasons to come.

cause the inner rainband clouds to grow at the expense of clouds forming the eye wall, creating a new eye wall with a larger diameter and a concomitant reduction in maximum winds.

Like all experiments conducted in a natural laboratory, nothing about Stormfury was easy. The storms had to be within range of the research planes but predicted not to touch any populated island or coast for at least 24 hours after seeding. The 1962 season brought no candidates. The next summer, after obtaining strongly positive results in cumulus seeding runs, Stormfury turned to hurricane Beulah, which had steamed into range. On August 23, the ill-formed storm was still a marginal candidate for modification, and the seeding material fell short of the eye wall's cloud turrets. Nothing happened.

The next day, however, the storm had intensified and formed a well-developed eye. This time, the seeding canisters were on the mark. The original eye wall disintegrated, and a new, broader eye wall replaced it. And, as predicted, the maximum winds decreased by about 14 percent and moved farther from the center of the storm.

Nature not only abhors a vacuum, but she is more than a little testy about success in trying to tame her. In 1964, the Stormfury airplanes were kept down because their instrumentation wasn't ready. The next year, the planes flew into hurricane Betsy, which was too close to land to seed. Elena, a second 1965 candidate, tiptoed just out of range. In 1966, Faith sidestepped toward the northeast, short of the seeding area. No hurricanes offered themselves during the rather fallow 1967 and 1968 seasons. In almost a decade, Stormfury had "treated" only one storm.

And then along came Debbie.

On August 18, 1969, thirteen Stormfury aircraft staging out of Puerto Rico seeded the hurricane, using Navy A-6 Intruders to drop hundreds of silver-iodide-producing pyrotechnics along a line through the eye wall. Debbie's winds dropped 31 percent after seeding. A couple of days later, with the storm once more spooled up to its original strength, a second seeding run was followed by a 15-percent reduction in maximum winds. Curiously, while massive resources worked the cooperative Debbie, hurricane Camille—one of the most intense storms ever to strike the United States—was taking aim at the Mississippi Gulf coast.

Anxious to replicate their success with Debbie, the Stormfury team waited for a second opportunity. But, again, nature intervened. No candidate appeared in 1970. The only eligible storm in 1971 was Ginger, a poor thing of a late-season hurricane, ill formed and diffuse; predictably, the ensuing desperate seeding of Ginger did nothing to the storm but cast a pall on the experiment. During the 1972 season, hurricanes stayed out of reach of the airplanes. Although no one knew it, Stormfury was over.

"We entered a period when the hurricane tracks we needed just didn't materialize," recalls Peter Black, a hurricane researcher with the National Oceanic and Atmospheric Administration in Miami. He'd been present more or less at the creation and had shared the high good feelings after Debbie. But those feelings soon began to fray. "Each year, permissions from Caribbean countries became more difficult to obtain—Cuba, Mexico. The State Department made our guidelines tighter. Finally, we had only a narrow zone north of Puerto Rico and twenty-four hours to landfall, then thirty-six hours." The rules of the Stormfury game changed yearly, each change placing storms a little bit farther out of reach. "When I was first there," Black says, "there was always this idealistic attitude. We were going to do something significant—a mission to help the quality of life. That's seen as a fantasy now."

Project Stormfury lived on for another decade, however, fueled by the Debbie results—and tainted by the impotent try with Ginger. In the early 1970s, the Navy pulled out of its Stormfury partnership, and the Weather Bureau—now NOAA—aircraft began to wheeze. Until then, Stormfury had flown in DC-6s, topped by a high-flying B-57 jet bomber; the Navy had contributed its WC-121 Super Constellation hurricane hunters and the A-6 seeders. Without the flotilla of Navy planes, researchers had either to abandon Stormfury—and the promising start with Debbie—or give it a new shape that matched reality. The government chose to go with the experiment. Two specially built WP-3D Orion aircraft were purchased for about $10 million each, and the tempo began to build in NOAA's hurricane research. Planners began looking for the natural laboratories offered by other oceans—the frequent hurricanes that spin up the coast west of Mexico, away from people; the huge, intense typhoons of the western Pacific that occur, from an experimental standpoint, at least, with heartening frequency.

"They couldn't find an ocean that would have them," says Stanley Rosenthal, recently retired former director of NOAA's hurricane research lab in Miami. The problem of liability switched off interest among politicians in Australia and at home as well: Towns might sue you for seeding—or for not seeding, if you knew it would help—a storm on its way to trash them. "The Japanese killed any hope of taking the experiment to the Pacific. They had political reasons: No country wanted to be hit by storms that were made in the USA. The eastern Pacific was scotched by the Mexicans. We tried to see what we could do in the Atlantic." Rosenthal had inherited Stormfury and dutifully pursued it. "I was not an enthusiastic supporter, not a true believer in weather modification, and never became one," he says now.

Constrained to a small trapezoid of open ocean north of Puerto Rico, the Stormfury squadron—now two NOAA WP-3Ds; a NOAA C-130; a borrowed Air Force C-130; and NASA's Convair 990, *Galileo II*—waited for an alert each year through the last half of the 1970s. It never came. "My thoughts were to go all out, make every effort to seed a few storms," says Rosenthal, "show that there wasn't a great deal in the idea. It never occurred to me that politicians could get ahead of me." But they did. "Politics took over. The cuts were in the Carter budget." Including the aircraft, Stormfury had cost about $30 million in all—roughly the price of two space toilet prototypes.

In 1981, hurricane Floyd and hurricane Harvey pranced through the Stormfury area, as did another Debbie, a marginal target, in 1982. In 1989, Gabrielle and perhaps Dean were eligible, as was Gustaf in 1990. But, from 1980 onward, there were no Stormfury planes waiting to seed them.

Although the new aircraft were not seeding, these remarkable flying laboratories still probed each season's storms, taking into the swirling maw of the hurricane all the tools that Bob Simpson never had. Knollenberg imaging probes permitted scientists to tell liquid water from ice. New cloud-physics gear let them measure drop sizes and the distribution of nuclei. Digital—and, later, Doppler—radars could monitor three-dimensional wind fields inside the storms, giving researchers their first detailed look at the hurricane's interior structure. On-board computer workstations allowed realtime analysis of what the sensors picked up from the roaring gales outside. And the WP-3Ds, these starships of atmospheric research, possessed bone-rattling endurance: They could spend ten hours or more buzzing around inside a hurricane.

For the first time, measurements taken in hurricanes were not points of data along a hurried line through the storm; they were consecutive data taken by a continuous relay of the two P-3s that for days could keep one airplane always in the hurricane. Gradually, the simple brute envisioned in the 1960s became an atmospheric creature of stunning complexity and more; the aircraft showed that hurricanes, like everything else in the atmosphere, ultimately descend into the magnificent disorder known as chaos.

"About 1977," Black recalls, "we began getting a few measurements." The weakening process Stormfury wished to induce, the scientists began to realize, happened quite naturally. "In the 1960s, we thought the air came in, up, and out. We didn't appreciate the impact of environmental flow. Mother Nature sneezes a thousand miles away and the storm changes. Sea-surface temperature alters the storm's track and intensity." Hardly anything about hurricanes was what it had once seemed.

AFTER A FLURRY OF SUPPORT, WEATHER MODIFICATION WAS SIMPLY WRITTEN OUT OF THE FEDERAL AGENDA. DISSENT AMONG SCIENTISTS HELPED SUFFOCATE THE IDEA BEFORE IT COULD BE TESTED IN THE FIELD.

Nothing was less so, however, than the eye wall—the central cylinder of towering clouds and maximum winds, which is really what a hurricane is all about. It once seemed to be a straightforward chimneylike apparatus for sucking heat from moist air as it rises, spewing it out at high altitudes. In fact, the eye wall is more like the revolving breech of a colossally complicated six-shooter, in which each chamber may contain a powerful round of updrafts and supercooled water—or a dud of descending, glaciated air.

"The center of circulation is offset," explains Black—"asymmetric." And this asymmetry, hurricane researchers now believe, is important to the way the storms move and intensify. These tilted convective turrets—the live rounds of updrafts in the revolving breech—are short-lived, lasting only 10 to 20 minutes. They are matched by regions of what Black calls forced descent caused by factors outside the storm. In Andrew, he says, the updraft turrets and areas of forced descent slowly rotated around the center of low pressure at about 50 miles an hour, embedded in the eye wall clouds.

Critics of the Stormfury hypothesis, like hurricane researcher Hugh Willoughby, believe there isn't enough supercooled water even in the updraft chambers to make much difference. "If water is freezing anyway, what are you changing?" he asks. "If we were all-knowing, perhaps we could say yes, this is being caused by seeding. I can think of no way to collect data to tell you whether you've done that. You might be able to intervene and provoke something . . . but you'd never know."

Not surprisingly, Bob Simpson differs. "The bone of contention is not whether there is a way to modify hurricanes if you have supercooled water in them. The question is, do you have enough supercooled water to make a difference?" Just back from a 1993 experiment in the Coral Sea, where he had a chance to look for supercooled water in a Pacific storm called Oliver, Simpson says, "With more sensitive instruments, we found much liquid water at below –40 degrees. You can't take bits and pieces and put them together and draw conclusions." Referring to Willoughby's objections, he says, "They didn't look for liquid water where we'd expect to find it. Our experience has shown that abundance of liquid water was only in the eye wall itself. Only where you had the convective maximum did water have trouble freezing. Now it's debatable whether seeding in the eye wall is a viable hypothesis; that's still subject to argument."

But the presence or absence of supercooled water at seeding altitudes—from about 20,000 to about 30,000 feet—is not easy to verify. The heavily loaded P-3s must labor mightily to get up above the freezing level in hurricanes—something over 20,000 feet—until late in their mission, when they've burned off much of their fuel. It's a bad level for flying. "There's a lot of lightning," Willoughby says. "You get hit a lot. You become a flying hailstone." And de-icers, he adds, take a lot of energy from the engines. Because icing makes this stratum dangerous flying, nothing like a systematic inventory of supercooled water there has been made.

As Stormfury foundered at the end of the 1970s, starved of storms and perhaps of supercooled water, nature played another prank. Flights into 1980's hurricane Allen while it spun across the Gulf of Mexico revealed precisely the kind of wind variations that Stormfury scientists had measured in Debbie after seeding. The intended effect of seeding, it was suddenly apparent, happened all the time, naturally. In a kind of respiration, the eye expands outward and maximum winds diminish; then the eye tightens and winds rise. Moreover, hurricanes evidently sprout concentric eye walls all the time—1969's Camille had two, for example. Again, the desired effect of seeding was seen to be a frequent feature of unseeded storms.

Such news meant different things to different scientists, depending on whether they were Stormfury believers or infidels. To the latter, the results from Allen proved that the changes seen in a seeded Debbie—and in the earlier storms as well—were merely an illusion of human intervention, a natural coincidence. To believers, the evidence points just the other way. The variations seen in Allen show that the structural changes Stormfury hoped to achieve are inherent in hurricane behavior—ready, as Simpson postulated, to be triggered by some human agent.

Robert Sheets, director of the National Hurricane Center in Coral Gables, Florida, directed Stormfury during the 1970s and until its demise early in the 1980s. A scientist who has spent a long research career flying around inside hurricanes, Sheets remains a true believer. "I was converted by the Debbie results," he says. He himself analyzed the data, and it convinced him that the hypothesis is correct. "What we can't verify is that we caused the change," he says. "The magnitude of the system sort of overwhelms what can and cannot be done." Sheets has worked with hurricanes since 1965, when he joined the hurricane lab. "There's no question that there's supercooled water," he says. "Airplanes get covered with ice, but it seems to occur in limited areas. Tremendous updrafts in nature are also seeding the storm perhaps." He adds, "There's still the question of whether there is enough supercooled water that can be utilized to modify the storm. Some say eye wall fluctuations show seeding does no good. To me, that says the hypothesis is correct."

To believers, those pulsations, the alternate filling and deepening, dwindling and revving up, of the eye wall are a modern corollary to the frailty inferred by Robert Simpson nearly half a century ago. Those natural oscillations of the eye wall may be the wished-for handle shaped for the human hand—"if one could inhibit that cycle when it reformed an eye at its larger size," speculates Peter Black. He grins: "But this isn't even hypothesized—no hallway conversation or even bad jokes."

In normal times, there the matter would rest. But while such storms as Hugo and Andrew spin landward from the tropical sea, causing the hardships of a war along American coasts, some scientists have begun to see a cyclic increase in the incidence of severe hurricanes. The dearth of storms that helped throttle Project Stormfury may soon be replaced by a flurry of them (see "Out of Africa," page 42). But the search for a technology that might have mitigated their terrible winds was abandoned more than a decade ago. "An unfinished symphony in a sense," reflects Stan Rosenthal. "Stormfury was premature. A lot of the things that were being done in weather modification were being done without proper tools. We go into the next century with Doppler radars, atmospheric profilers. We're just now getting the tools in hand."

Yet no one today believes those modern tools will be used to blunt the fury of the hurricane. As things stand now, what nature sends spinning from the warm sea, we must meekly accept—as always.