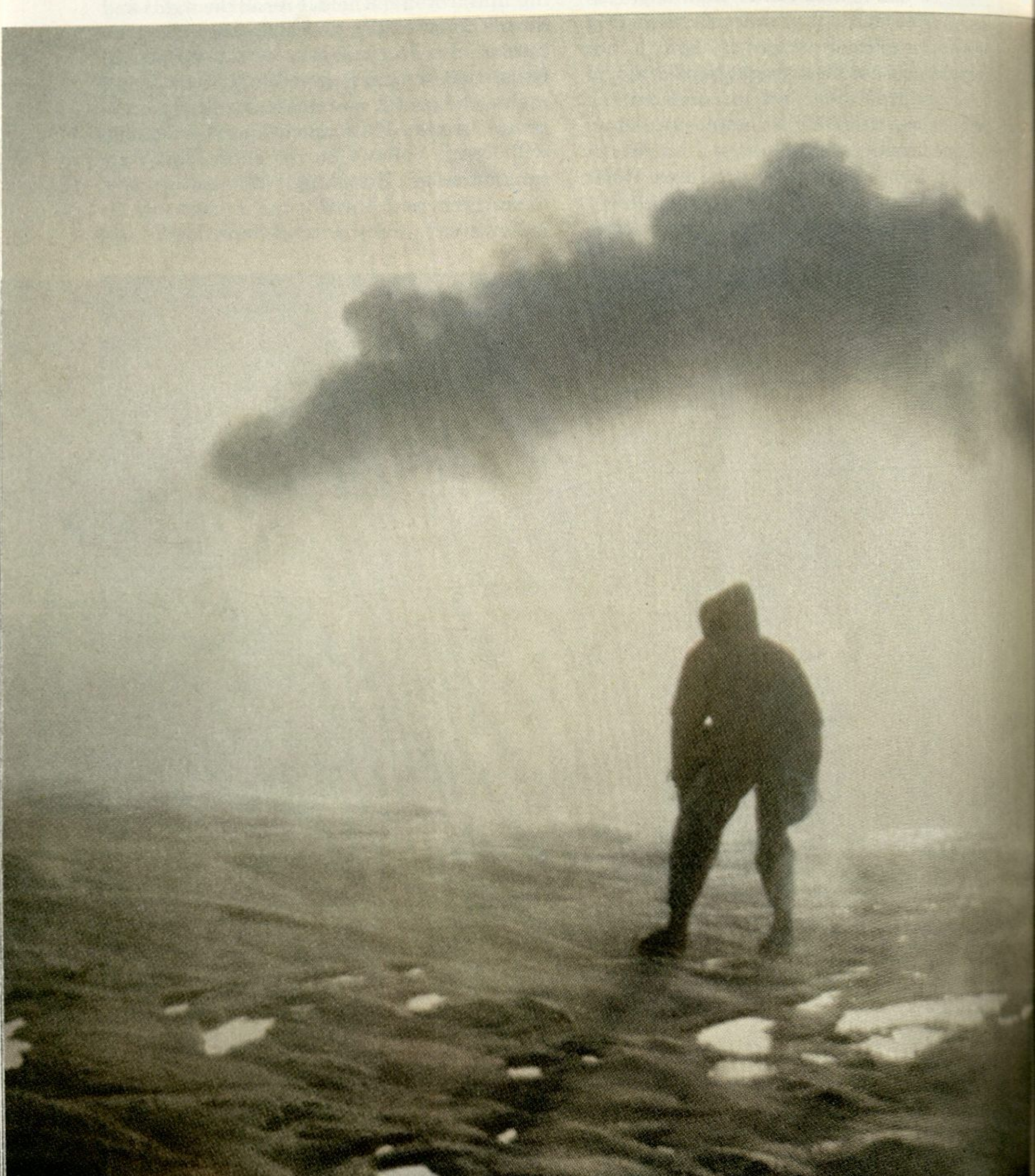
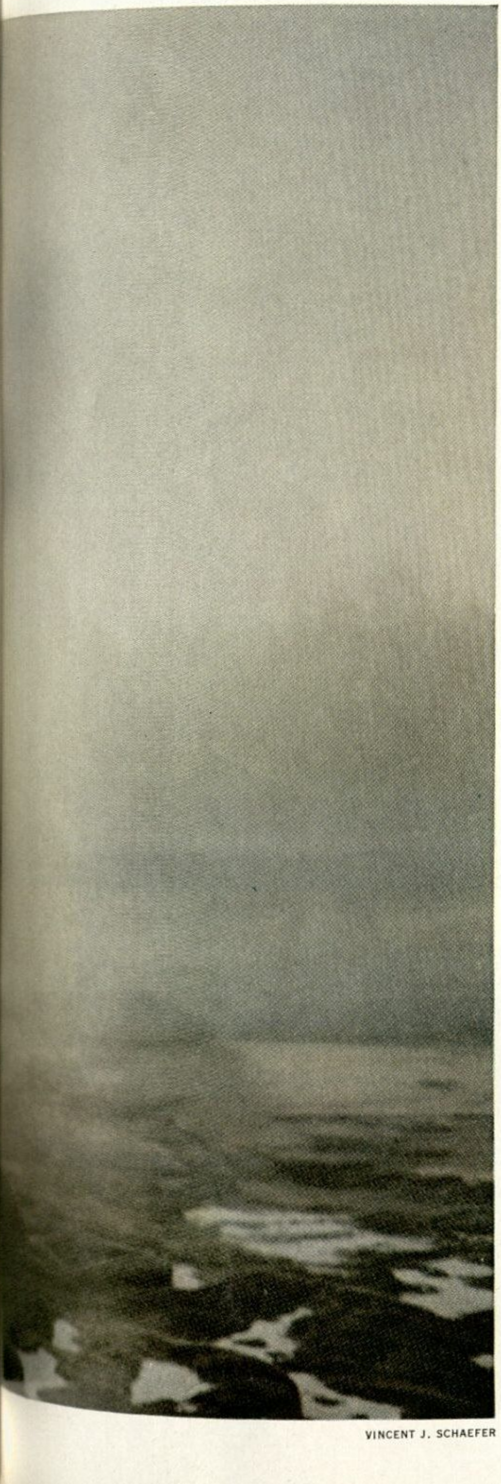
We're Doing Something

By WALTER ORR ROBERTS



About the Weather!



VINCENT J. SCHAEFER

ONE WINTRY MORNING an indignant lady telephoned Washington's most popular TV weather forecaster with this frigid blast:

"I wish you'd come out here and scoop this six inches of 'partly cloudy' off my driveway!"

Information at the disposal of the weatherman the evening before had not seemed to justify a snow forecast. Then, during the night, the essential ingredients of weather—temperature, humidity, atmospheric pressure, and winds—had changed enough to produce a snowfall. As far as the irate householder was concerned, the weatherman had goofed.

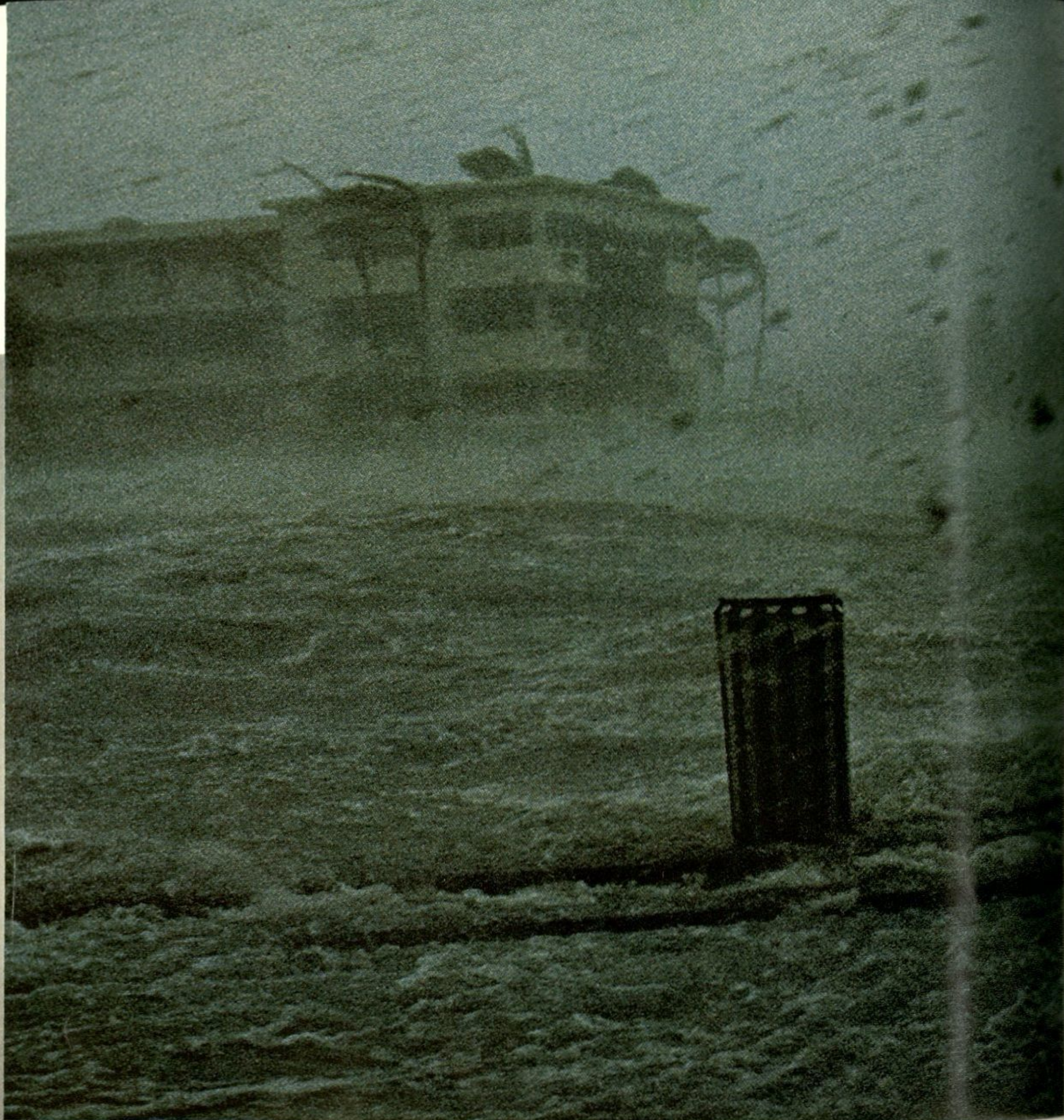
Ask the man in the street if weather reports are reliable, and he may think of all the times he has been caught without an umbrella. The truth is, however, that weather forecasting has become remarkably good. Moreover, it is going to get even better.

Behind these optimistic statements lies an exciting story of scientific developments, in some of which I have been privileged to play a role—of satellites whose unblinking eyes watch the birth of every storm around the globe; of new sensing devices that easily pierce darkness to take the temperatures of clouds; of fantastic computers that digest billions of bits of information and in minutes draw complete weather maps; and of a global study of the weather that is harnessing international effort on an unprecedented scale.

It's a story also of tragedy and violence. But the tragedy is increasingly being averted

Cloud of his own creation hovers over a scientist after he threw a can of hot water skyward in Yellowstone National Park. The numbing winter air—45° F. below zero—enables him to observe clouds as they might behave in earth's frigid upper atmosphere.

National Geographic editors spent five years searching for photographs that would best portray the power and fury of the weather and how man attempts to understand and even control it.



by swift warnings. And the day is coming when the violence of giant storms may yield to the strategies scientists are now devising.

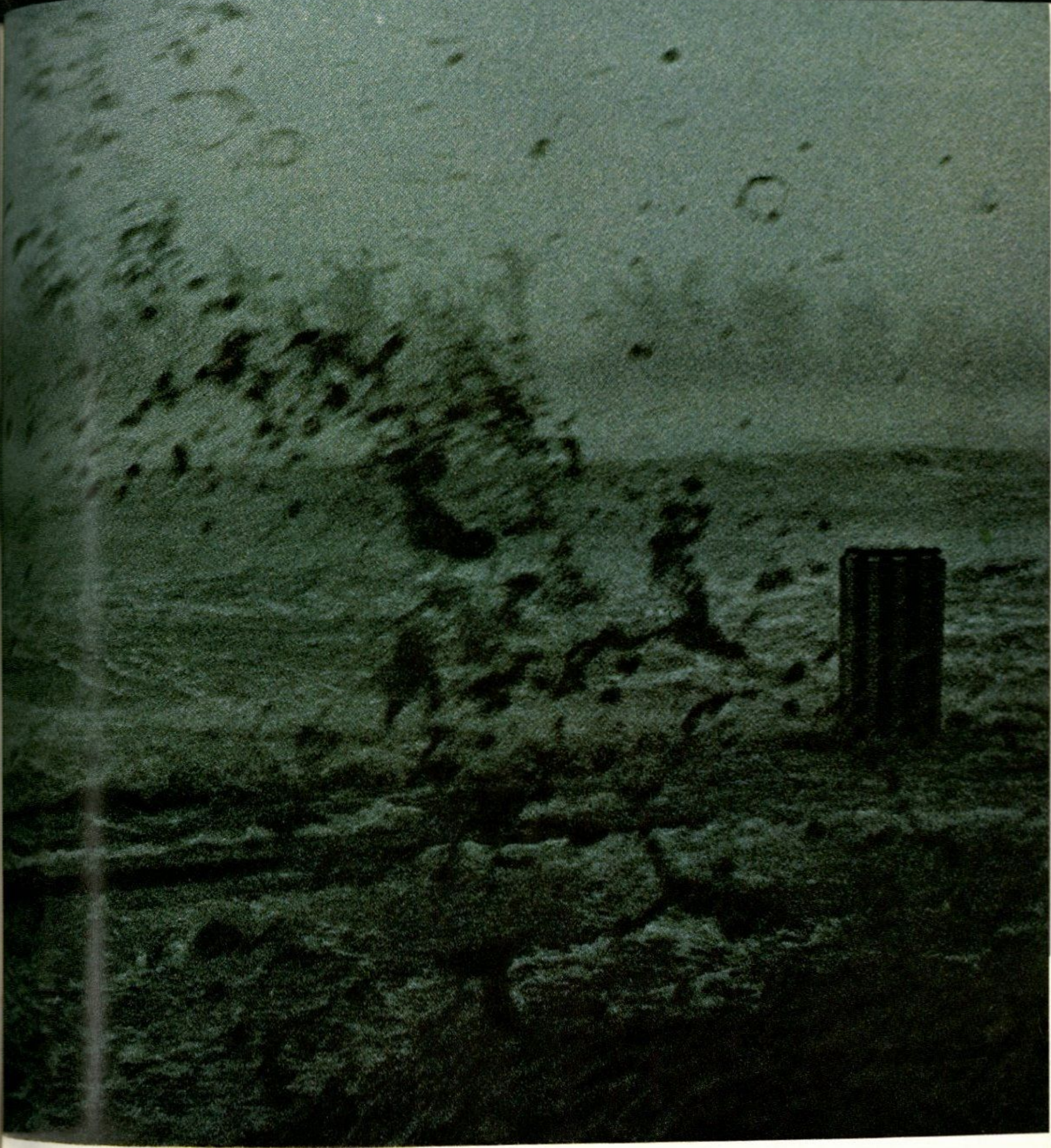
There's a strong wind blowing in weather science these days, and it will do a lot of people a lot of good. Weather hazards, by conservative estimates, cost the United States 1,200 lives and 11 billion dollars in property damage annually.

As a boy in Massachusetts, I would often go down on gray mornings to the dock at Cuttyhunk Island and watch Capt. Frank Veeder head his stubby swordfishing boat out to sea. I would wonder what kind of weather lay ahead of him on the open Atlantic.

In those days, people depended a great deal on weather lore. For clues that bad weather was coming, they paid attention to the twinges in the rheumatic joints of older folk, or watched the erratic behavior of beasts and birds. In such rhymes as "Red skies in the morning, sailor take warning; red skies at night, sailor's delight," they distilled the experience of generations.

They may not have known, incidentally, how venerable that particular bit of lore really is. Read Matthew 16:2, 3:

"When it is evening, ye say, It will be fair weather: for the sky is red. And in the morning, It will be foul weather to day: for the



Driving the sea before it, Hurricane Betsy batters Miami. The 1965 storm took 75 lives and caused damage estimated at 1.4 billion dollars.

The swirling anatomy of Hurricane Camille, the 1969 killer that snuffed out more than 320 lives, is exposed (**right**) at the National Hurricane Center in Miami. Color added to a satellite photograph charts the storm's moisture content; whitest areas indicate the fiercest downpours.

FLIP SCHULKE, BLACK STAR (TOP); RAY LUSTIG sky is red and lowring. O ye hypocrites, ye can discern the face of the sky; but can ye not discern the signs of the times?"

Today's mariners—and farmers, and resort owners, and construction men, and all the rest of us who watch the weather each day—seldom need depend on folklore. The National Weather Service (formerly the Weather Bureau) provides detailed forecasts covering two and three days ahead. Since February 9, 1970 (the 100th birthday of the Weather Service), less detailed five-day forecasts have been available daily. And for $3.50 a year the Weather Service will send you 30-day temperature and precipitation outlooks by mail twice a month.

Today's Forecasts: Bolder and Better

How accurate are today's two- and three-day predictions? Let the weathermen tell you.

Allen D. Pearson, Director of the National Severe Storms Forecast Center in Kansas City, points out that "forecasts are now much more precise than they used to be. They are couched in less cautious language."

Arthur Gustafson, who is in charge of San Francisco's forecast center, says, "Now we do better on two-day forecasts than we did for one day in the early '60's. And a decade ago, who would have dared tell you anything about Sunday's weather on Wednesday?"

Dr. George Cressman, Director of the National Weather Service, puts it explicitly: "The national average verifications show that we can forecast today's or tonight's temperature to within about 3½ degrees, and tomorrow's to within about 4½ degrees. If you count a forecast of over 50 percent chance of rain as meaning it will rain, and under 50 percent as meaning no rain, our national averages show about 87 percent hits for today, and about 80 percent hits for tomorrow."

To this Al Pearson adds a caution:

"Weather forecasts are made for wide areas, not for pinpointed spots. Suppose the prediction is for 10 percent chance of rain, yet rain falls in one corner of that area. The man who is getting drenched screams, 'Ten percent! Don't those guys see what's up there?' He may not realize that most of the forecast area is as dry as can be.

"Don't forget," says Pearson, "a prediction of only 10 percent chance of rain does not guarantee *no* rain. In fact, if we predict 10 percent chance of rain on 10 different days, by all the laws of probability it should rain on one of those days!"

So fast is weather science improving that Dr. Joseph Smagorinsky, one of today's most respected meteorologists, foresees that we can expect increased accuracy of forecasts over periods of up to several weeks, sufficient to be useful for economic planning and for weather-hazard warning.

Whether two- to three-week forecasts can ever be made with the same accuracy we now enjoy for two or three days is a matter of vigorous controversy. The answer depends on feverish research now going on with computers, mathematics, techniques of observation, and satellites. And of these, perhaps most fascinating is the weather eye in space.

Last summer as I worked on this article, a stubby object known as NOAA 1* was circling in earth orbit, passing northward over California. It resembled an oblong packing crate with three purplish blue wings attached at one end (page 525). The wings, covered with solar cells to produce electricity for the satellite, always faced the sun, and the spacecraft itself kept one side turned toward earth.

Within the next hour and 55 minutes, NOAA 1 made a complete circuit of the globe, passing near the North Pole and then sweeping south over Arabia and the Indian Ocean to Antarctica and back north again.

Multiple eyes in the spacecraft scanned the swift-moving panorama 900 miles below. Two TV camera systems caught the glint of oceans and ice fields, the white expanse of clouds, the familiar outlines of continents and islands. More important, instruments known as radiometers detected heat and light radiation from earth, cloud, and sea.

Unwinking Eye Scans the Entire Globe

As Canada passed beneath, a radio command came up from an 85-foot antenna near Fairbanks, Alaska, operated by the National Environmental Satellite Service.

"Give us your pictures," it signaled.

Like an obedient child, NOAA 1 turned on magnetic tape recorders that had stored pictures from one of its TV cameras. Electronic impulses that encode patterns of light and dark went by radio from the spacecraft to the ground station, from which they were relayed to weather stations all over the United States. In hours, forecasters had the pictures on their desks, showing storm patterns that

*NOAA takes its name from the new National Oceanic and Atmospheric Administration, which includes the National Weather Service, the National Environmental Satellite Service, and several other agencies of the Department of Commerce.

would affect you and me the following day.

NOAA 1 made such a picture every 260 seconds. Each covered a square some 2,000 miles on a side, an area of four million square miles. Cloud patterns as small as two miles across could be distinguished.

As the spacecraft made its orbit, the earth rotated nearly 29 degrees to the east. Thus each successive orbit, and each successive strip of photographs, was displaced westward. Since the strips overlapped, NOAA 1 captured a progressive portrait of the globe. It scanned every spot on earth at least twice each day.

Cloud Pictures Free for the Taking

NOAA 1's second camera system, known as APT (Automatic Picture Transmission), did not store its pictures. Instead, the electronic signals were continuously broadcast to earth, free for anyone who wanted to pick them up.

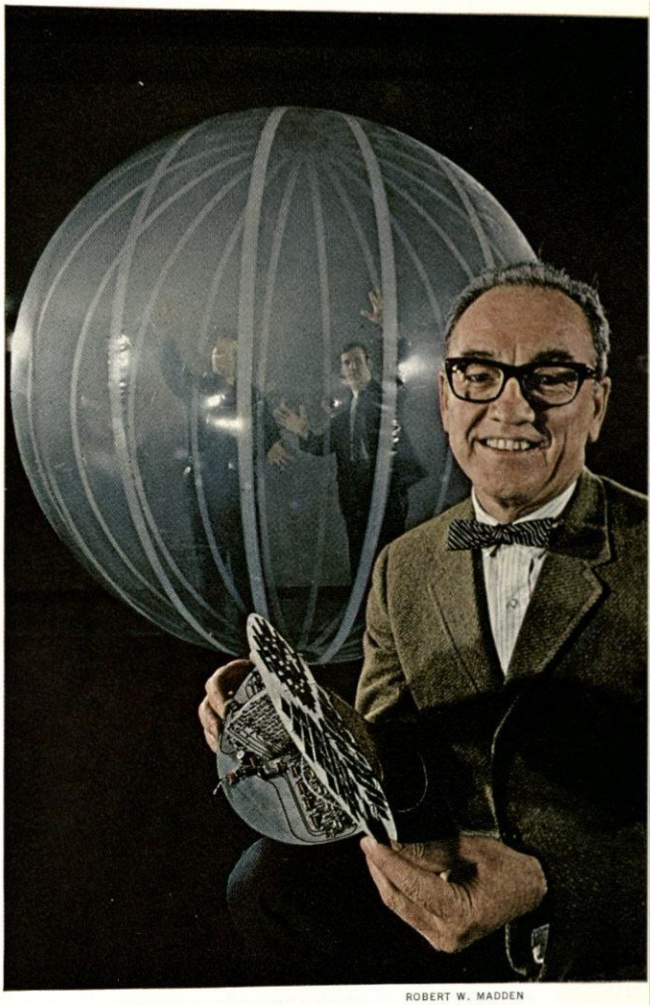
Some 550 weather stations all over the world, in 94 countries and territories, have their own APT receivers for picking up these signals and converting them to pictures. Even less advanced nations can afford them. In fact, they are so simple that in Montgomery County, Maryland, high school students put together a receiver.

I always find it impressive to watch APT pictures come in. As a wide sheet of paper slides slowly from the machine, an electric needle moves rapidly back and forth, burning a pattern of light and dark. The needle makes 600 passes in two and a half minutes to complete each picture—each pass corresponding to a scan made by the TV camera. The individual lines blend to form a continuous picture, just as on a TV screen.

The original NOAA was launched December 11, 1970, and unexpectedly went dead last July. Another is scheduled to be put in orbit sometime this spring. In the interval, other weather satellites of an earlier generation have taken over NOAA 1's tasks.

Two dozen older weathercraft—most of them smaller and less elaborate—keep the now-silent NOAA 1 company as they circle earth in space. Most are also dead; only five can still send back pictures.

In a lower orbit, for example, flies TIROS 1, which excited the world with the first useful television pictures from space in April 1960 and inaugurated a revolution in weather forecasting. More than a million and a half satellite pictures have flooded to earth since that time.



ROBERT W. MADDEN

The world is his weather station: Dr. Walter Orr Roberts spurs a global meteorological study as President of the University Corporation for Atmospheric Research in Boulder, Colorado. The corporation, supported by the National Science Foundation, manages a laboratory in which some 600 scientists and technicians investigate the atmosphere.

An astronomer, Dr. Roberts was elected president of the American Association for the Advancement of Science for 1968. Here he holds the instrument package of a ten-foot GHOST balloon (background) used for charting air movements.

Far above NOAA 1, two quite different spacecraft hang like silver spiders over the Equator. Known as ATS (Applications Technology Satellites) 1 and 3, they do not orbit the earth. Or, more properly speaking, they move just fast enough to keep up with earth's rotation. Thus each always hangs above the same spot on earth, and for this reason they are called geosynchronous or geostationary.

Although the ATS satellites belong to NASA, the Weather Service makes extensive use of their remarkable photographs. From the lofty vantage point of 22,300 miles, ATS cameras can see almost one entire side of earth. This means that at frequent intervals we can take a fresh look at cloud patterns over the United States and over the spawning grounds where much of our weather is born.

Heat Pictures Add Vital Data

Spectacular though they may be, TV pictures from space may prove less valuable in the years ahead than information from scanning radiometers. These instruments are already carried by the NOAA satellites. They detect and measure radiation not only in the form of light, but also in the form of heat—the energy of long-wave infrared radiation. Since heat is what drives the great engines of the ocean and atmosphere to produce our weather, that information can be of great value to weather scientists.

But we will not be deprived of pictures from space. Radiometer scannings can be converted to images similar to those made by TV cameras. And since the radiometers work with both infrared and visible light, they produce excellent pictures on the night side of earth as well as the daylit side, making 24-hour global coverage possible.

David S. Johnson, Director of the National Environmental Satellite Service at Suitland, Maryland, explains the remarkable things weathermen can learn from infrared:

"In addition to images, infrared sensing from satellites gives us the temperatures of earth, sea, and clouds, to an accuracy within 3° F. It helps us estimate how high the cloud tops are, and therefore what kind of clouds we are seeing. Moreover, we can interpret the readings to give us a profile of temperatures at various levels in the atmosphere. This information is absolutely essential for making longer-range forecasts than those now possible.*

"Finally, some of the new devices will even measure water vapor at different heights, and others may report on the total levels of such pollutants as dust, carbon dioxide, nitrous oxide, and sulfur dioxide.

"These infrared sensors represent a truly great leap ahead for the 1970's."

In the latter part of this year a brand-new weather satellite called GOES (Geostationary Operational Environmental Satellite) is scheduled to join the ATS spacecraft 22,300 miles above the Equator. Stationed at 100° west longitude, over the Pacific Ocean 1,350 miles south of Mexico City, it will be the first of a new series of earth-synchronous weather eyes.

Weathermen refer to GOES and ATS spacecraft as "natural-disaster satellites," because they are so useful in early detection of severe storms. After a polar-orbiting NOAA spots a potential storm, 12 hours must elapse before its spiraling path around the globe brings it back for another look. But GOES, from its steady vantage point, will take a new look every 20 minutes. If a thunderstorm developing from cumulus clouds seems likely to produce tornadoes, GOES may be able to give warning in time.

Satellite Asks Questions of Earth

GOES will do something else NOAA is not equipped to do: It will collect weather information from remote stations anywhere in its field of view. Rain and river gauges, drifting buoys, ships, and perhaps balloons and aircraft will, on command from the spacecraft, radio their findings directly to GOES, which will relay them to the computers in satellite headquarters at Suitland, Maryland.

So capable is GOES, in fact, that it could interrogate as many as 40,000 remote stations every six hours, and send back to earth pictures containing a maximum of a hundred billion bits of information each 24 hours. Handling the mathematics involved in digesting such a torrent of information challenges even the fastest modern computers.

If all this seems like a great surplus of information, listen to the late John von Neumann, the celebrated mathematician who nearly a quarter of a century ago pioneered the idea of computers for analyzing weather:

"The hydrodynamics of meteorology," said von Neumann, "presents without doubt the most complicated series of interrelated problems not only that we know of but that we can imagine."

*See "Remote Sensing: New Eyes to See the World," by Kenneth F. Weaver, GEOGRAPHIC, January 1969.

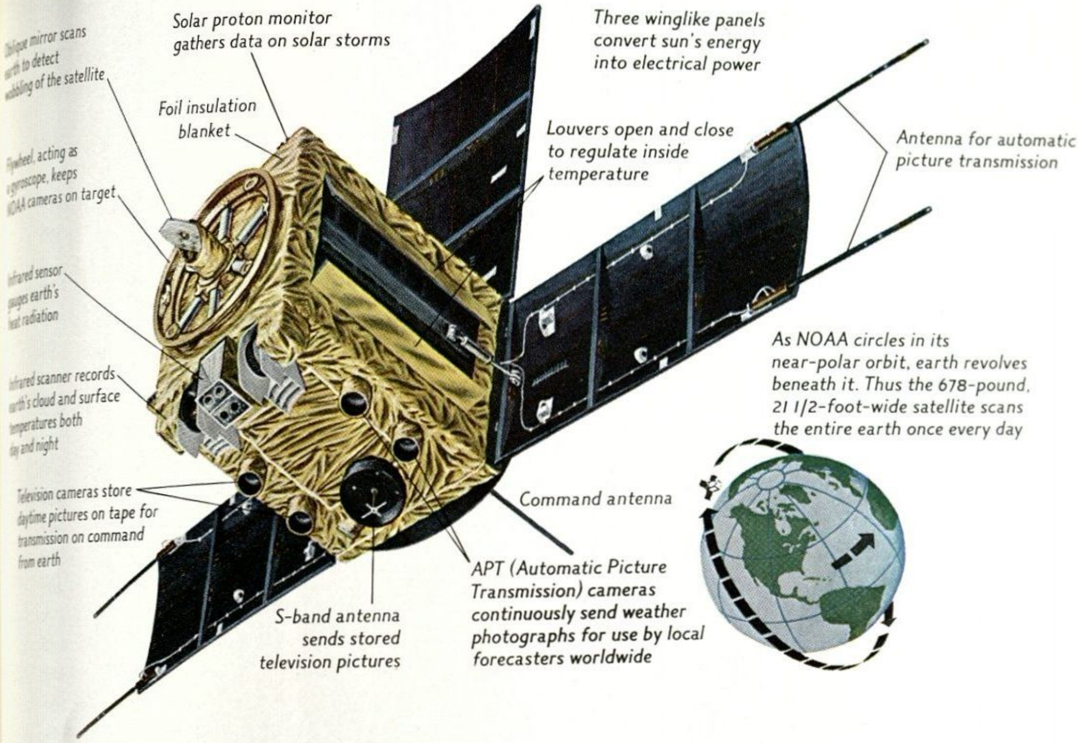
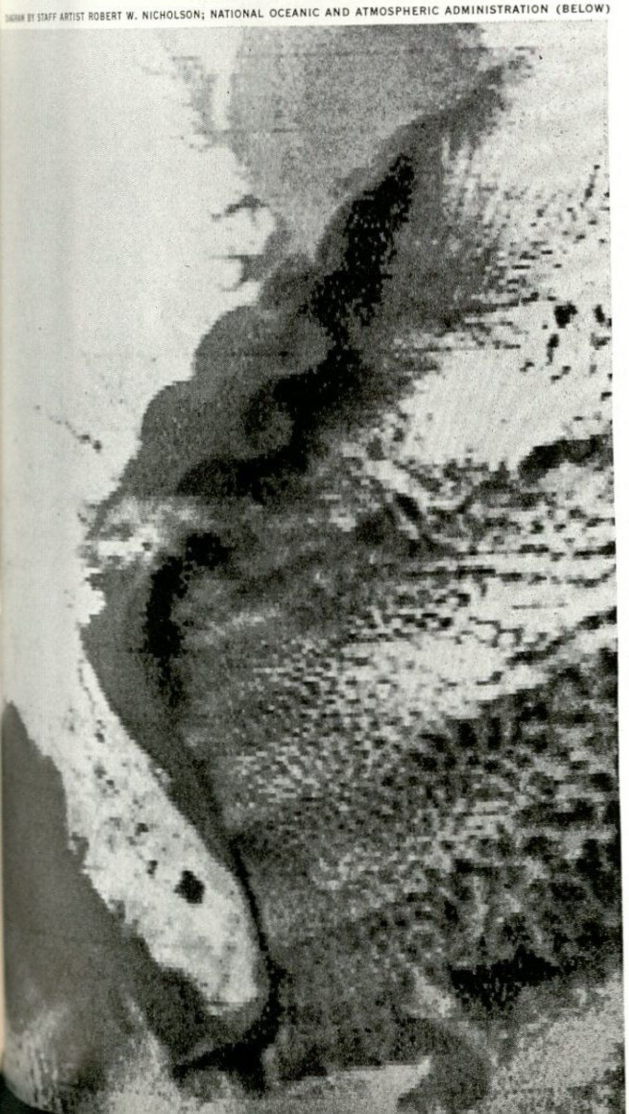


DIAGRAM BY STAFF ARTIST ROBERT W. NICHOLSON; NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION (BELOW)



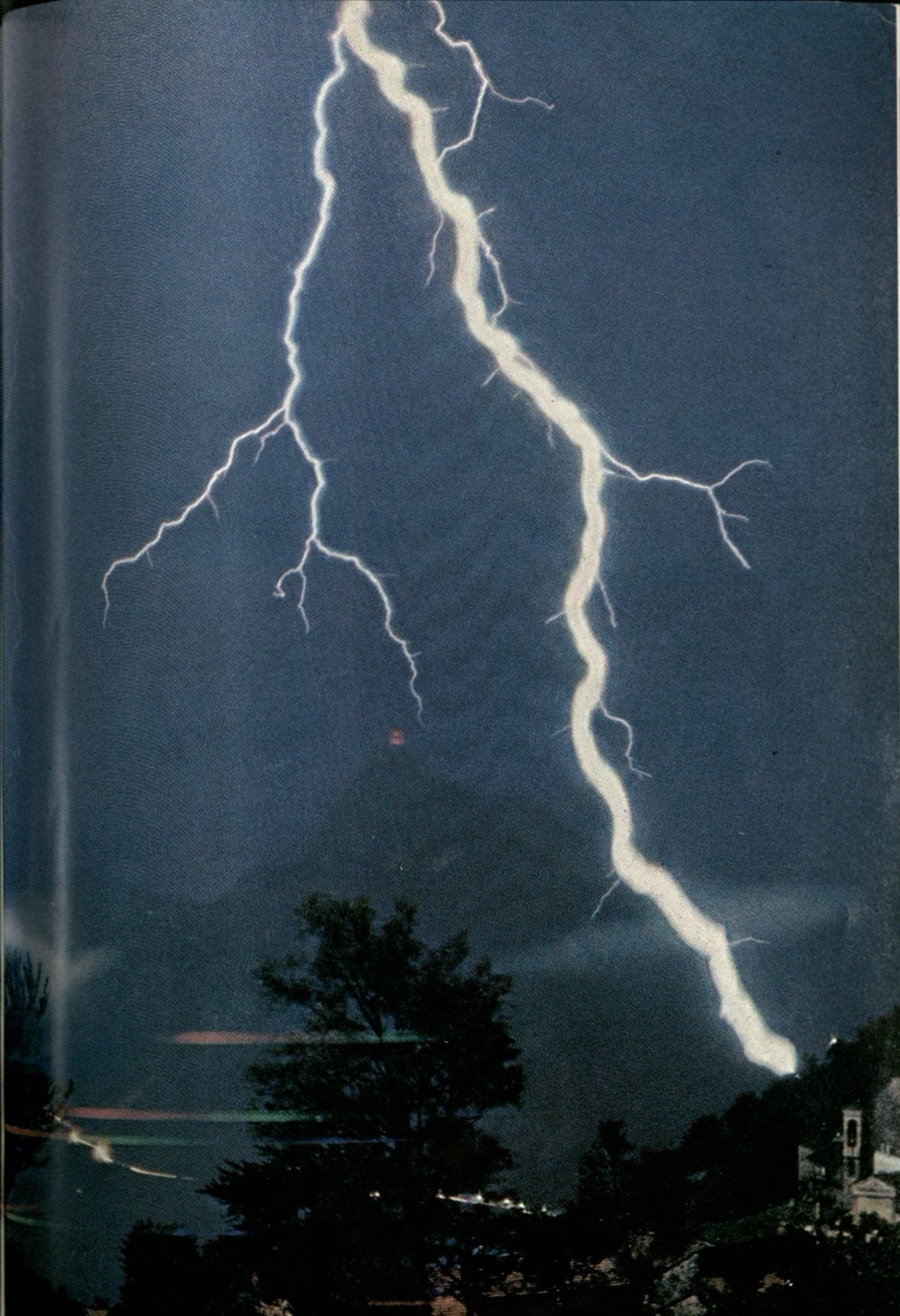
High-spying weather eye, a gleaming satellite scheduled for launch this spring carries a battery of sophisticated detection devices. Named for the National Oceanic and Atmospheric Administration, NOAA 2 will orbit every 115 minutes (small diagram), sending back overlapping views of the globe's changing weather from 900 miles in space.

Catching nature at one of her tricks, a satellite infrared image reveals massive eddies along the western edge of the Gulf Stream. The swirls occur, some oceanographers theorize, when a storm drives wedges of inshore water into the stream.

Here most of the Gulf Stream—recorded as nearly black because it is markedly warmer than surrounding water—hides beneath cool clouds that show as mottled white.

Three million volts of man-made lightning strike a model of the Concorde (**above**), the British-French supersonic transport. The fiery encounter shows where protective devices will be needed to channel lightning bolts harmlessly back into the atmosphere. Airliners are struck an average of once every 10,000 flying hours.

Forked tongue of fire jabs at a hillside near Lugano, Switzerland. Photographed through a diffraction grating, the bolt forms a spectrum; atmospheric gases radiate characteristic colors under enormous electrical potentials and temperatures five times hotter than the surface of the sun.



RICHARD E. ORVILLE; DONALD GETSUG, RAPHO GUILLUMETTE (LEFT)

To understand this assessment, you must realize how fiendishly complex is earth's atmosphere and its weather systems. The 20-mile-deep blanket holding the world's weather contains 5.6 million billion tons of air, approximately one and a half million tons for every person on earth. A gigantic witches' brew, four billion cubic miles in volume, it churns and flows in constant turmoil.

Heated by that great atomic-powered furnace the sun, the air rises in vast updrafts, especially in the tropics, sucking up the incredible quantity of more than 1,000 billion tons of sea water a day. The gigantic updrafts arc poleward, deflected to the east by the earth's rotation, then sink to earth at about 30° latitude to move back toward the Equator (diagram, pages 532-3).

At higher latitudes, where most people live, the wind circulations are even more complex, characterized by migrating cyclonic cells, thunderstorms, jet streams, and high-pressure areas a thousand miles wide—all modified by every mountain, every plateau, every body of water, every lowland.

If you think about how much heat it takes to boil away a kettle of water, you begin to get an idea of the tremendous amount of energy taken up by daily evaporation from the seas. The energy involved corresponds to 100,000 times the total electric generating capacity of the United States in 1970.

One Storm Equals a Hydrogen Bomb

Every bit of this energy—this heat of evaporation—lies stored in the vapor-laden air. When the vapor condenses again, either as cloud droplets or as falling rain, the same fantastic amount of energy is given back to the atmosphere as heat. Meanwhile, the energy may have been transported thousands of miles by the circulation of the winds. Wherever it turns up, it will markedly affect the weather.

A single thunderstorm can release to the atmosphere energy equivalent to a megaton hydrogen bomb. And since some fifty thousand thunderstorms break forth on earth every day, the daily energy released to the atmosphere equals billions of tons of TNT.

Small wonder that such energy can express itself with explosive violence, and that the large-scale movements of the atmosphere are so complex. And small wonder that science is forced to stretch itself to the utmost to describe and predict the total workings of this monstrous machine we call weather.

Prospects for success would seem dim indeed except for a great worldwide effort now under way. The United States and more than a hundred other nations have banded together, under the aegis of the World Meteorological Organization and the International Council of Scientific Unions, to develop in the 1970's a new understanding of global weather processes. It is called the Global Atmospheric Research Program (GARP). A related program, the World Weather Watch, seeks to develop an adequate worldwide observation and forecasting system.

Success will depend on three very difficult achievements:

1. Electronic computers that can efficiently perform hundreds of millions of mathematical operations per second. Best estimates indicate that these computers must have a hundred times the capacity of today's finest machines. Technology is moving so fast that we can confidently expect such capacity within a few years.

2. A fully realistic theory, or mathematical model, of the workings of the intricate processes that generate our weather. This model must include all the physical forces affecting the atmosphere. For the entire globe it must describe in numbers and in equations the oceans, landmasses, and mountains; the changes of temperature, reflectivity, and moisture; the distribution of the nuclei around which moisture condenses or freezes; the cloud patterns; the wind velocities; the temperature, pressure, humidity, and density of the atmosphere at thousands of points and at many levels. In some models it takes half a million pieces of data just to describe the atmosphere at a single instant.

The model must put all these things together in terms of numbers so the giant computer can calculate how the winds will flow, the temperatures change, and the rains come down. Such numerical models, on a promising scale, are already being used by the Weather Service in its forecasting.

3. A truly global network of stations to make weather measurements at least daily.

Already more than 10,000 people in the United States are engaged in professional weather research and forecasting, plus 13,000 volunteer observers. Around the world some 25,000 surface weather observations are made every day—and coded for global radio and telegraphic exchange. Ten thousand land stations in more than 130 countries, as well as 6,700 ships, have weather-measuring equipment. In addition, more than 1,200 daily measurements of winds and temperatures in the upper air are made from balloons.

Vast as this amount of information may seem, it is desperately incomplete. No more than 20 percent of the globe is adequately covered by weather observations. We know very little about what is happening over the oceans, and the ocean-dominated Southern Hemisphere is politely termed a "data-sparse area."

It is not enough to measure the winds near the surface. Air movements at much higher levels—in the stratosphere—influence world weather enormously.

The stratosphere air that sweeps across the central United States today may, a mere two or three days ago, have been somewhere over the mid-Pacific and quite out of range of detailed measurements. It is not unusual for a parcel of air to circumnavigate the globe in mid-latitudes in only ten to twelve days. So it is obvious that longer-range weather forecasts will require observing the air parcels in their complete circuit of the earth.

Weathermen Turn to GHOSTS for Help

The cost of covering the entire globe with ships and other conventional weather stations would be prohibitive. So we will depend heavily on satellite soundings with infrared sensors. In addition, other novel techniques are being considered, including the GHOST balloons (page 523) pioneered by Vincent E. Lally and his colleagues in Boulder, Colorado, at the National Center for Atmospheric Research (NCAR), where I have my offices.

GHOST balloons (the word stands for global horizontal sounding technique) are unusual in that they do not continue to rise through the atmosphere until they burst, as do ordinary weather balloons. Rather, they level off and drift with the wind at a predetermined altitude in the stratosphere.

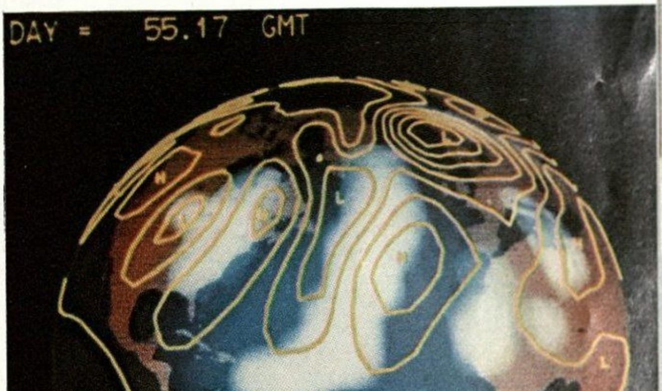
Mylar, a very thin, tough plastic almost impervious to helium, enables the balloons to maintain pressure for many months. Just enough helium is put in so the balloon will completely expand at approximately its intended altitude. When the density of the helium-filled balloon system balances the density of the outside air, the balloon floats at that altitude, rising and falling only a hundred feet or so as temperatures vary.

Simple instruments carried by the balloon measure temperature and humidity. A tiny sun-powered radio broadcasts the data and the balloon's positions, from which wind velocity can be determined. The payloads are so fragile that jet engines in ground tests have gobbled them up with no problems. The balloons, we believe, represent about one "sparrow power" of threat to a plane.

Since March 1966, NCAR has launched some 350 balloons from New Zealand and other Southern Hemisphere sites. Stations in many nations have helped us track them. Success has been sensational. One GHOST flew for 467 days, steadily radioing back useful data.

For the worldwide weather program, we

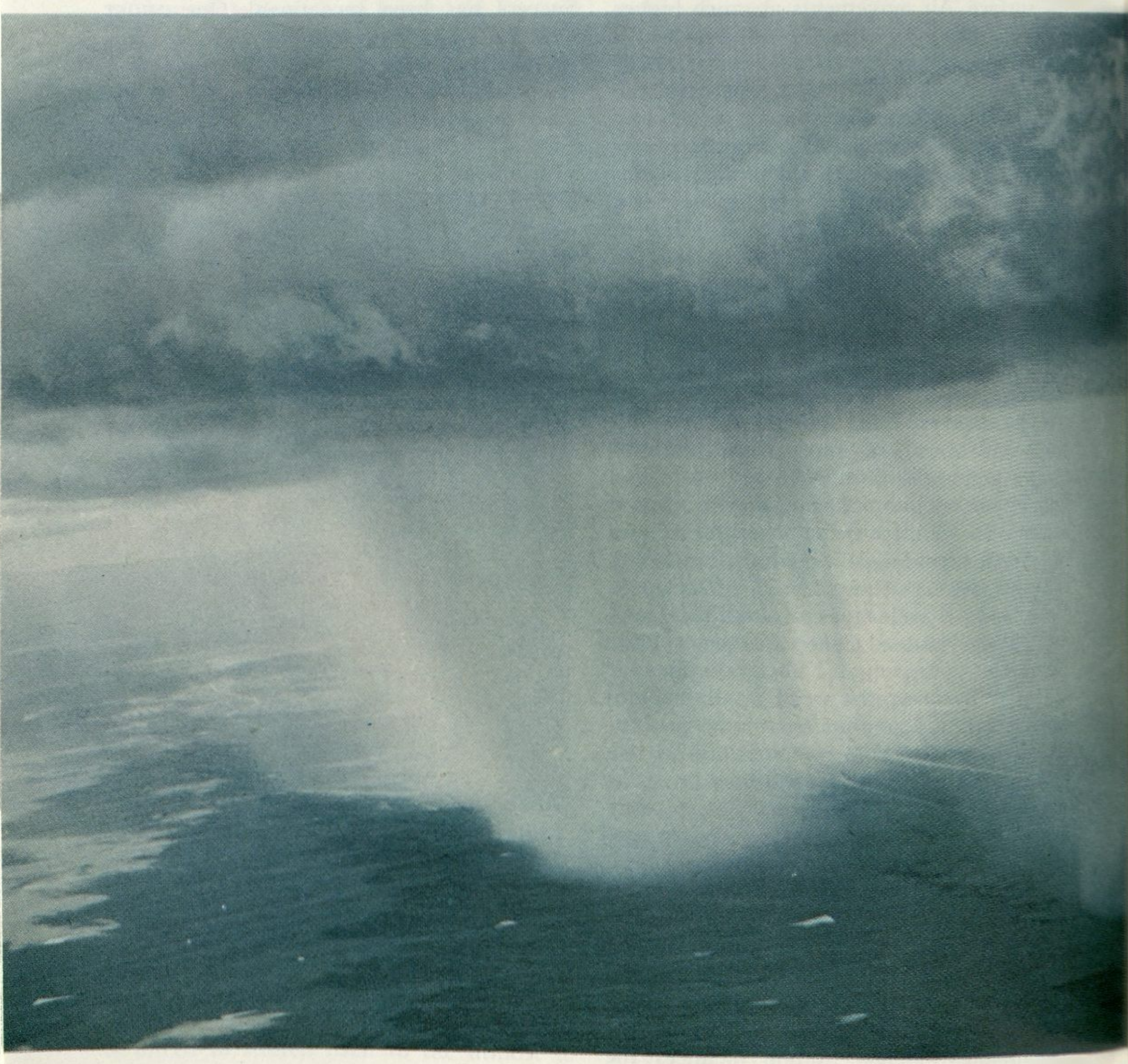
(Continued on page 534)



NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Drawn by a computer, this theoretical weather map is based on previously collected real-life data. By comparing the map with what actually happened, scientists refine a mathematical model of the atmosphere. Faster computers now in the making promise more accurate long-range forecasts.


ROLET



JAMES A. SUGAR (ABOVE AND LEFT); DONALD L. VEAL (LOWER LEFT); ATMOSPHERICS INCORPORATED

Rainmakers to the rescue: To wring out reluctant clouds, Homer F. Berry stokes a brazier of flaming charcoal impregnated with silver iodide. As he drives about the countryside trailing sparks, the fire's updraft carries smoke aloft, where its billions of minute silver iodide particles may cause the air's moisture to condense as raindrops.

Farmers of parched west Texas had offered Mr. Berry, a retired Air Force officer, $10,000 to generate five inches of rain in 30 days. But the clouds were not suitable; less than three-fourths of an inch of rain fell.

Under more favorable conditions, a downpour to gladden farmers' hearts cascades from clouds over the Dakotas (**left**). It fell after scientists flew through the clouds with silver iodide flares burning on the wing struts of their plane (**above**).

Earth's awesome weather machine

ITS FUEL is the sun's prodigious energy, striking earth with 240 trillion horsepower. Its throttle is the planet's movement—the spinning and tilting that sets the cadence of days and seasons. Its mighty engine is the atmosphere itself, a vast enveloping sea of air.

In this simplified model of earth's weather machine, prepared in close cooperation with Dr. Chester Newton of the National Center for Atmospheric Research, the sun beats directly on the Equator (lower circle). Toward the Poles, the rays pierce a greater amount of atmosphere and fall obliquely across a larger area of earth. This greatly reduces their power and creates the heat imbalance that drives the churning atmosphere.

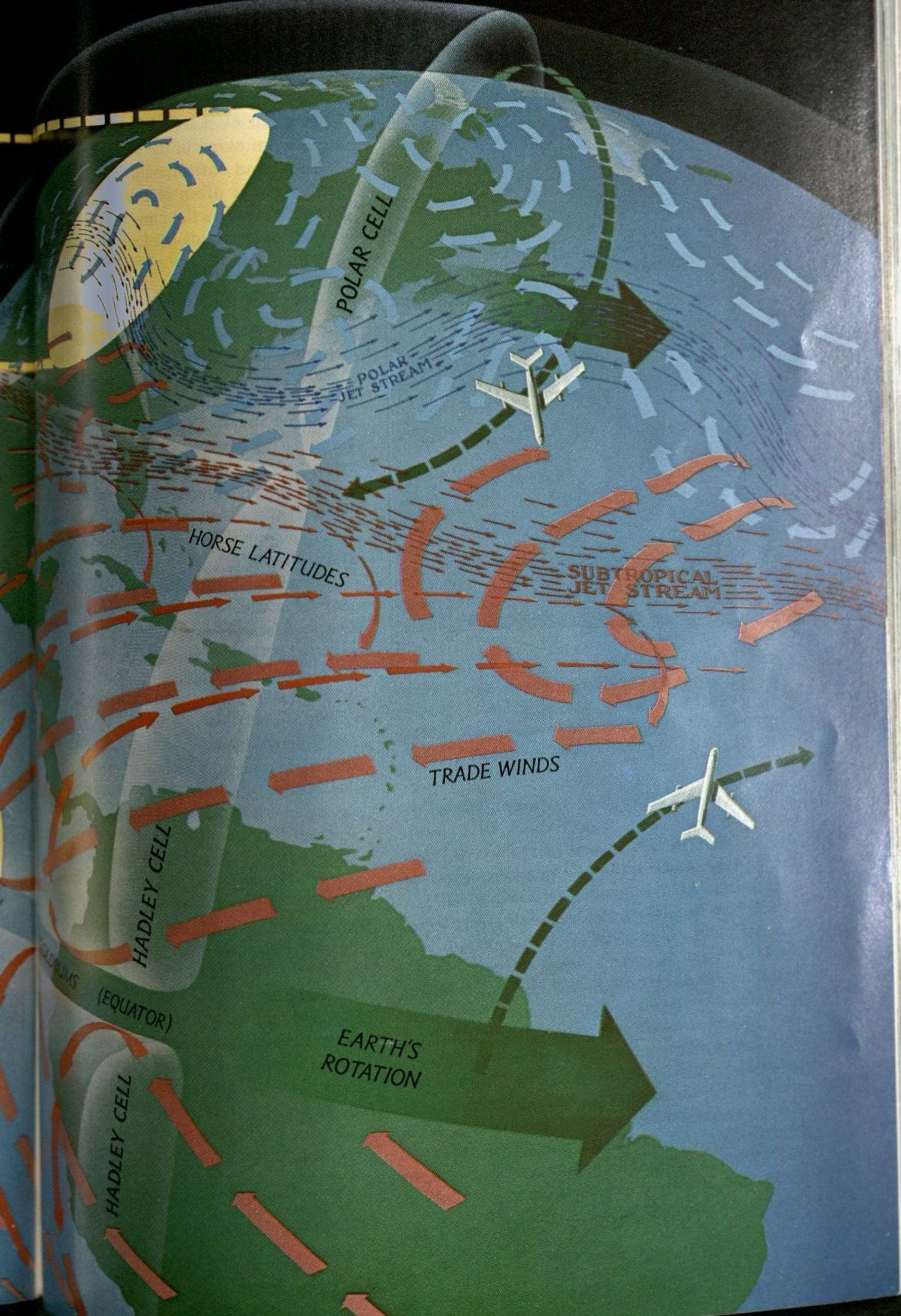
Two huge belts of moving air, the North and South Hadley Cells, girdle earth at the Equator. In the Northern Hemisphere, heated air rises near the Equator and drifts northward (red arrows). Its momentum from earth's rotation deflects it to the east—a phenomenon known as the Coriolis effect, which also influences the flight of airliners, rockets, and migrating birds.

As the high cool air approaches the latitude of Florida, some of it races on east in the subtropical jet stream. But most of it slows and descends in the horse latitudes and follows the Hadley system back southward to replace rising equatorial air. As it returns, earth's rotation deflects it westward (pink arrows)—the steady trade winds sought by ships of sail. Another part of the descending air turns northward. Earth's rotation veers this wind right to become the westerlies that prevail over middle latitudes, including the United States.

At its northern edge the Hadley Cell merges with the Polar Cell that sits atop earth like a cap. Here the circulation takes the form of huge surface eddies—the familiar high- and low-pressure cells of the weather map. In the painting a high of cool heavy air, driven clockwise by earth's rotation, swirls over New England, and another lies over the Rockies. Between them a low rotates counterclockwise over the Great Plains. Where the air currents collide, these cells breed turbulent weather, such as often roils across the U. S.

Sweeping around the planet from west to east, the powerful rivers of air known as jet streams vary in altitude from 30,000 to 40,000 feet and meander north or south. The streams reach velocities of 100 to 300 miles an hour, often speeding eastbound jetliners across the North Atlantic in an hour less time than westbound flights.

STAFF ARTIST ROBERT W. NICHOLSON


POLAR CELL
POLAR JET STREAM
HORSE LATITUDES
SUBTROPICAL JET STREAM
TRADE WINDS
HADLEY CELL
(EQUATOR)
EARTH'S ROTATION
HADLEY CELL

HENRY LANSFORD, NCAR

Wispy wake of the jet era, a contrail created by an airliner's exhaust grows into a cirrus cloud over the Colorado Rockies. Meteorologists fear such man-induced effects may disturb the earth's weather system.

may need many of these balloons, especially in the tropics, and hundreds of new buoys scattered in remote parts of the ocean. And we will need several more geostationary satellites spaced strategically around the Equator. Japan and France are both considering launching such spacecraft.

Dr. Robert M. White, head of the National Oceanic and Atmospheric Administration, estimates that this expanded weather observation system will save our nation more than a billion dollars a year. I believe Dr. White's estimates are conservative. I have seen quite genuine optimism for success among the scientists with whom I have worked for eight years in GARP's planning meetings.

While scientists in many countries seek to understand and predict the weather, others search for ways to tame, or at least alter, the severe weather conditions—the storms and droughts—that plague mankind.

In western Texas last spring a group of farmers sorely beset with drought offered a private rainmaker $10,000 if he could produce five inches of rain within 30 days. Day by day the rainmaker chased clouds across Stonewall County in an old pickup truck with a pot of charcoal and chemicals glowing and smoking in the back (pages 530-31).

At the end of the month: failure. Less than three-fourths of an inch of rain had fallen. In ancient times the unsuccessful rainmaker might have lost his head; in this case he lost only his contract.

Downpour Follows Airborne Seeding

A few weeks later Government scientists sought to ease a severe drought in southern Florida. Flying into the tops of clouds with a four-engine research plane, they dropped scores of burning flares that spewed out trillions of microscopic crystals of silver iodide.

In the six hours after this seeding, five inches of rain poured on the grateful citizens of the Miami and Everglades areas.* The drought, while not broken, had been substantially reduced.

These two examples characterize the history of rainmaking—a story of frequent failure and occasional resounding success that may or may not have been related to the deliberate interventions of man.

One early failure came in the 1890's, when Congress provided $9,000 for tests of rainmaking by sending explosives aloft with kites and balloons and by firing cannons. Perhaps the legislators had read the Greek writer Plutarch, who had noted 18 centuries before that "extraordinary rains pretty generally fall after great battles." But the experiments in 1891 and 1892 produced more smoke than rain.

Since that time a more scientific approach has been developed. We know that if air containing a good deal of water vapor is very clean, it will often drop in temperature below the level at which condensation normally takes place, yet without producing clouds. Such air is called supersaturated. Similarly, water droplets in nature are often "supercooled" well below freezing without turning to ice, if there is an absence of nuclei.

A cloud droplet cannot form without a condensation nucleus. A mote of dust, a salt

*South Florida's water problems were described in "The Imperiled Everglades," by Fred Ward, NATIONAL GEOGRAPHIC, January 1972.

crystal, or a tiny chemical droplet will do. Particles so small that 300,000 of them could line up within one inch work very well. Similarly, the formation of snow crystals can sometimes be stimulated by some kinds of nuclei.

A quarter of a century ago, Dr. Vincent J. Schaefer of the General Electric Research Laboratories was experimenting with supercooled clouds. He found that a bit of dry ice (frozen carbon dioxide) dropped into supercooled fog in a chest-type home freezer immediately filled the air with glittering ice crystals. Later, from an airplane, Schaefer seeded a supercooled cloud with several pounds of crushed dry ice. Throughout several miles of cloud, fine water droplets turned to long streamers of snow.

Shortly thereafter, Dr. Bernard Vonnegut, also then at G. E., found that microscopic particles of lead iodide and silver iodide could trigger rainfall in supersaturated clouds. The science of cloud seeding was born.

Until recently, however, scientists were cautious about claims. Often cloud seeding did not produce rain, and when it did there were gnawing doubts about whether it might have rained without the seeding.

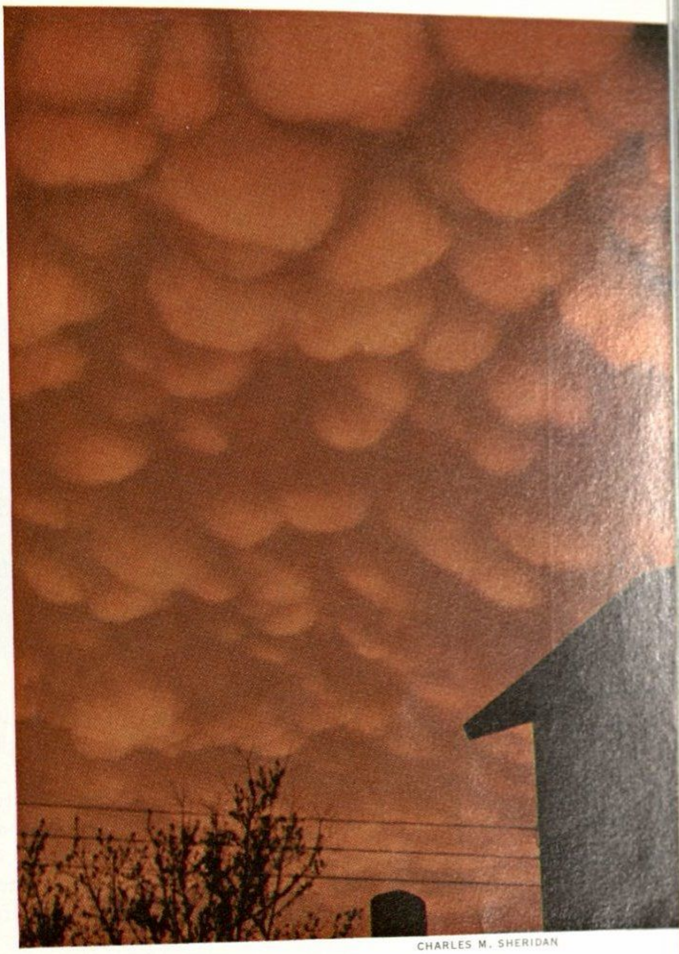
But recent work by Dr. Joanne Simpson, Director of NOAA's Experimental Meteorology Laboratory at Miami, Florida, has developed a new approach and banished much of the doubt about whether rain can be increased from tropical cumulus clouds. Dr. Simpson has used a computer to determine which clouds will respond to seeding. In repeated tests, using silver iodide smoke from planes, the rainfall has been increased by an average of 140 percent, with a probability of only about one in 200 that this difference could have occurred by chance.

And the experiments pay off. Dr. Simpson estimates that in the seeding trials in southern Florida last year benefits exceeded costs by a factor of thirty to one.

One Man's Rain, Another Man's Pain

Paradoxically, not everyone approves of cloud seeding. One economic interest may benefit from increased precipitation, but another may suffer. Some farmers or ranchers may be pleased, but how about the resort operator? And what if there are floods? Already lawsuits have resulted from weather-modification efforts, and rainmaking planes have been shot at by farmers "for interfering with God's weather."

In August 1969 the space-borne cameras



CHARLES M. SHERIDAN

Like smoke from a celestial fire, clouds linger in an evening sky after a tornado struck northern Wisconsin. The unusual formation, called mamma, often portends the approach of a hailstorm or twister.

of weather satellites revealed the embryo of a storm in the Atlantic Ocean. Succeeding satellite pictures showed the disturbance to have the whirling cloud vortex of a tropical cyclone. Since it was the season for hurricanes, the men of the National Hurricane Center (part of the Weather Service) in Miami kept a careful watch on the storm's erratic path as it swept across the Caribbean and into the Gulf of Mexico.

Additional information came from ships at sea, from hurricane reconnaissance squadrons of the U. S. Navy and Air Force, and from a weather radar fence that runs from Texas to Maine. Soon it became clear that this storm would reach hurricane force, and that it would be a killer. Hurricane warnings were flashed to Gulf Coast communities in Mississippi and

(Continued on page 541)

Long reach for the weather

WHEN BLIZZARDS HOWL across the Colorado Rockies, this gaudy 12-by-20-foot kite carries instruments nearly 20,000 feet aloft. Thus man monitors one of his most successful efforts to change the weather: the seeding of snowstorms whose melt feeds the Colorado River—life stream of the arid Southwest.

After seeding snow clouds from silver-iodide generators atop the peaks, scientists send the kite up carrying a replicator (**lower left**). It exposes coated film that records the imprints of snow crystals (**below**). These have shown that nuclei may increase snowfall by more than 50 percent.

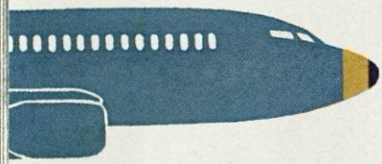
Silver iodide particles excel as cloud-seeding nuclei because their crystalline structure closely resembles that of ice.

LOWELL J. GEORGIA (OPPOSITE); EDWIN WOLFF, NCAR (ABOVE)

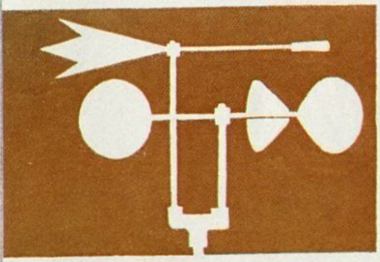
Scouts of the stratosphere, balloons take on helium at Palestine, Texas. Small pilot balloons will detect low-level winds that could disrupt the launch.

Able to drift for hours in the no-man's-land 80,000 to 135,000 feet up—too high for aircraft and too low for satellites—the balloons' instruments, parachuted to earth, yield data on the chemistry of the stratosphere. Thus scientists extend their reach ever farther into earth's ocean of air.

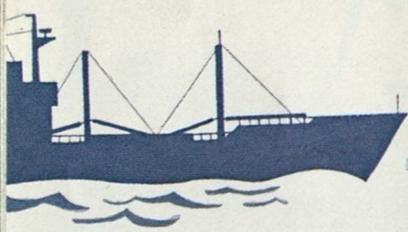
Coordinated by the World Meteorological Organization, national weather offices (white dots) collect data from a vast network of stations and dispense ever more reliable forecasts.



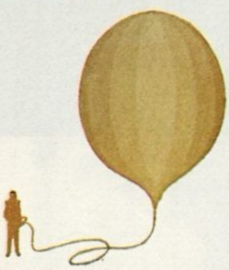
Commercial and military aircraft around the world make some 2,500 reports a day using an international shorthand code understood by weather computers.



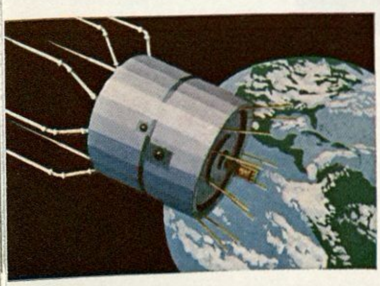
More than 1,000 U. S. surface stations daily record barometric pressures, winds, temperatures, and humidity.



Crisscrossing lonely ocean areas, where much of the world's weather originates, ships radio at least 2,500 reports a day.

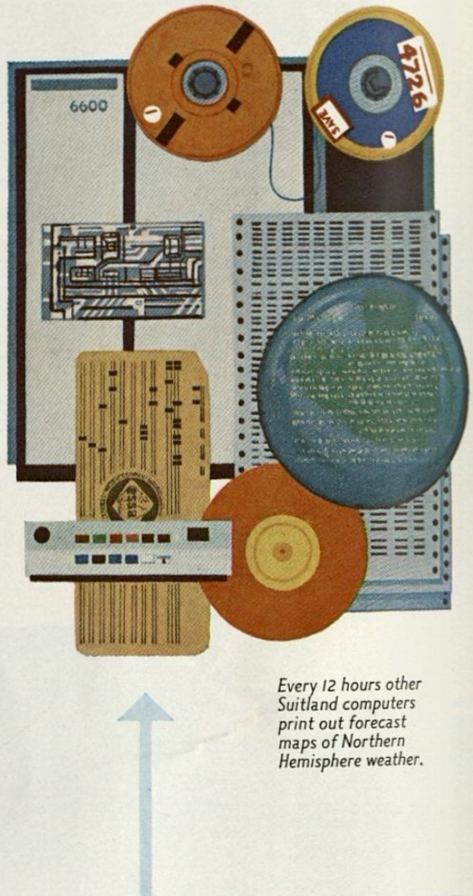


Released twice a day from U. S. weather stations, balloon-borne radiosondes record and transmit atmospheric conditions as high as 100,000 feet.

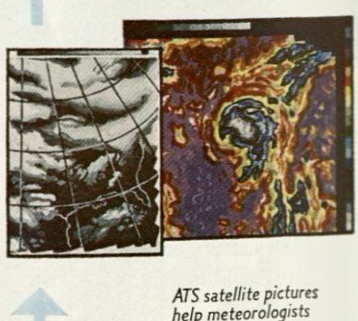


Two ATS satellites hover stationary over the Atlantic and Pacific, reporting global cloud movements.

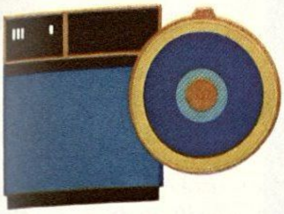
Pouring into the National Meteorological Center at Suitland, Maryland, torrents of weather data in many forms feed into three computers for storage.



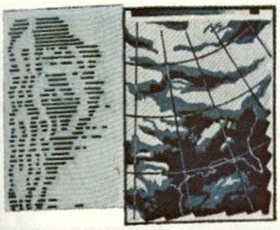
Every 12 hours other Suitland computers print out forecast maps of Northern Hemisphere weather.



ATS satellite pictures help meteorologists analyze cloud cover (left) or a swirling hurricane whose image has been color enhanced by a densitometer.



Data stored on magnetic tape permit a variety of research, such as weather's role in recent plane and ship accidents.



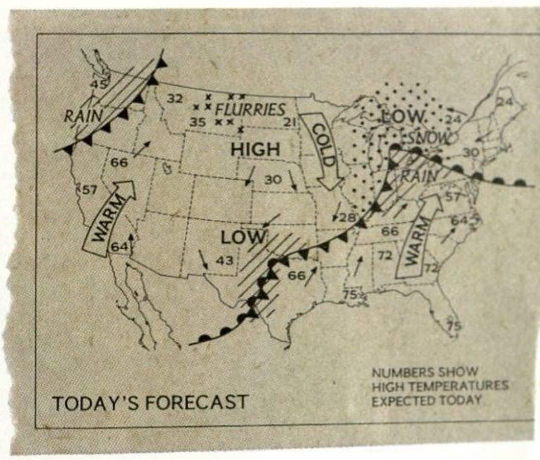
As an aid to local forecasters, a computer turns out numerical maps of wind speeds and facsimiles of satellite pictures.

Utilizing data from radar and satellites, a Weather Service meteorologist checks and refines the 24-hour and 5-day national weather forecasts.

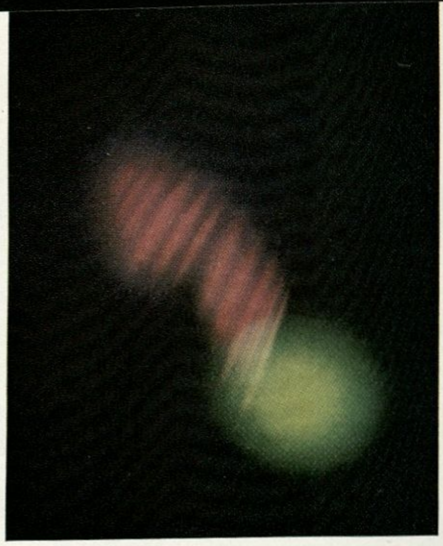
Prepared both in written and map forms, the forecasts flash from Suitland to local weather stations and then to other users, such as newspapers and TV stations.

Radar at weather stations aids local forecasters, whose observations are relayed for the national forecast.

The miracles behind your daily weather map

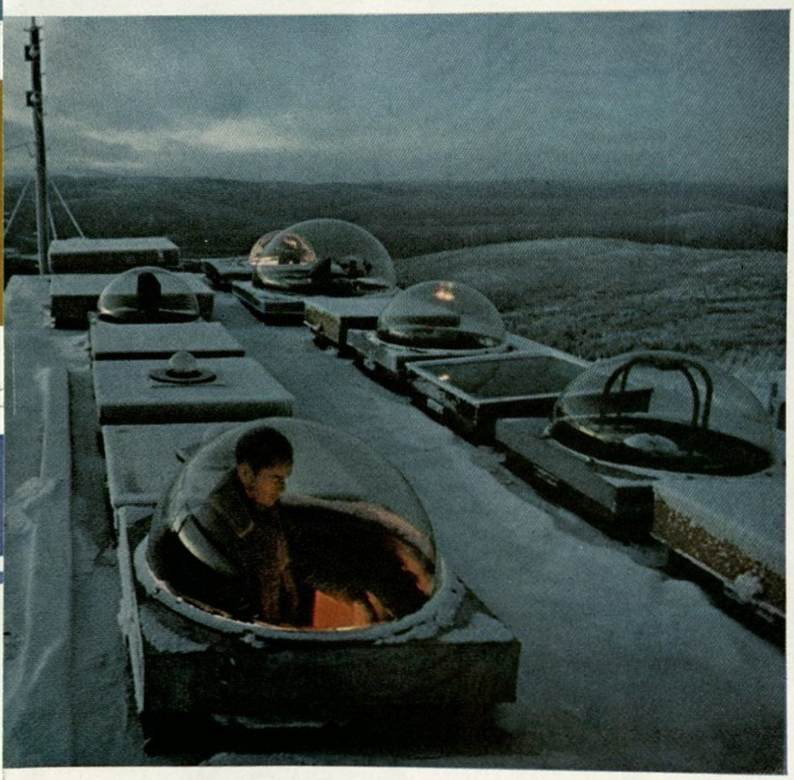


"THEY'RE calling for showers; better wear your raincoat to school," admonishes a Pittsburgh mother after reading her morning paper. Her faith in the weatherman is justified; he predicts today's weather with more than 80 percent accuracy, thanks to a worldwide network gathering raw data (**far left column**), compiling and analyzing it (**middle column**), and producing detailed forecasts for fast dissemination (**right**). Benefits are incalculable, from airline storm warnings to frost alerts for citrus growers. Evacuation broadcasts before Hurricane Camille saved an estimated 50,000 lives. STAFF ARTIST ROBERT C. MAGIS



Space Age will-o'-the-wisp, barium vapor glows 100 miles above Alaska. Ejected from a rocket-borne cannister, the cloud turns from red to green as atoms fluoresce under solar ultraviolet. The experiment enables scientists to measure ionospheric winds and other phenomena affecting the lower atmosphere.

To observe such experiments in winter's cold, University of Alaska scientists take refuge in heated viewing bubbles (**lower left**) atop the university observatory near Fairbanks.



Stuccoed with rime, Mount Washington Observatory in New Hampshire sparkles in rare December sunshine. A meteorologist clears ice from instruments atop the 6,288-foot peak. Beyond the trestle of a cog railway, chains moored in bedrock secure a building against winds that have been clocked at 231 miles an hour—strongest ever measured on earth's surface.

Louisiana that lay in the path of the storm. On the night of August 17 Hurricane Camille roared ashore. Winds exceeding 200 miles an hour and tides surging 24 feet above mean sea level smashed and leveled whole towns on the low-lying coast.

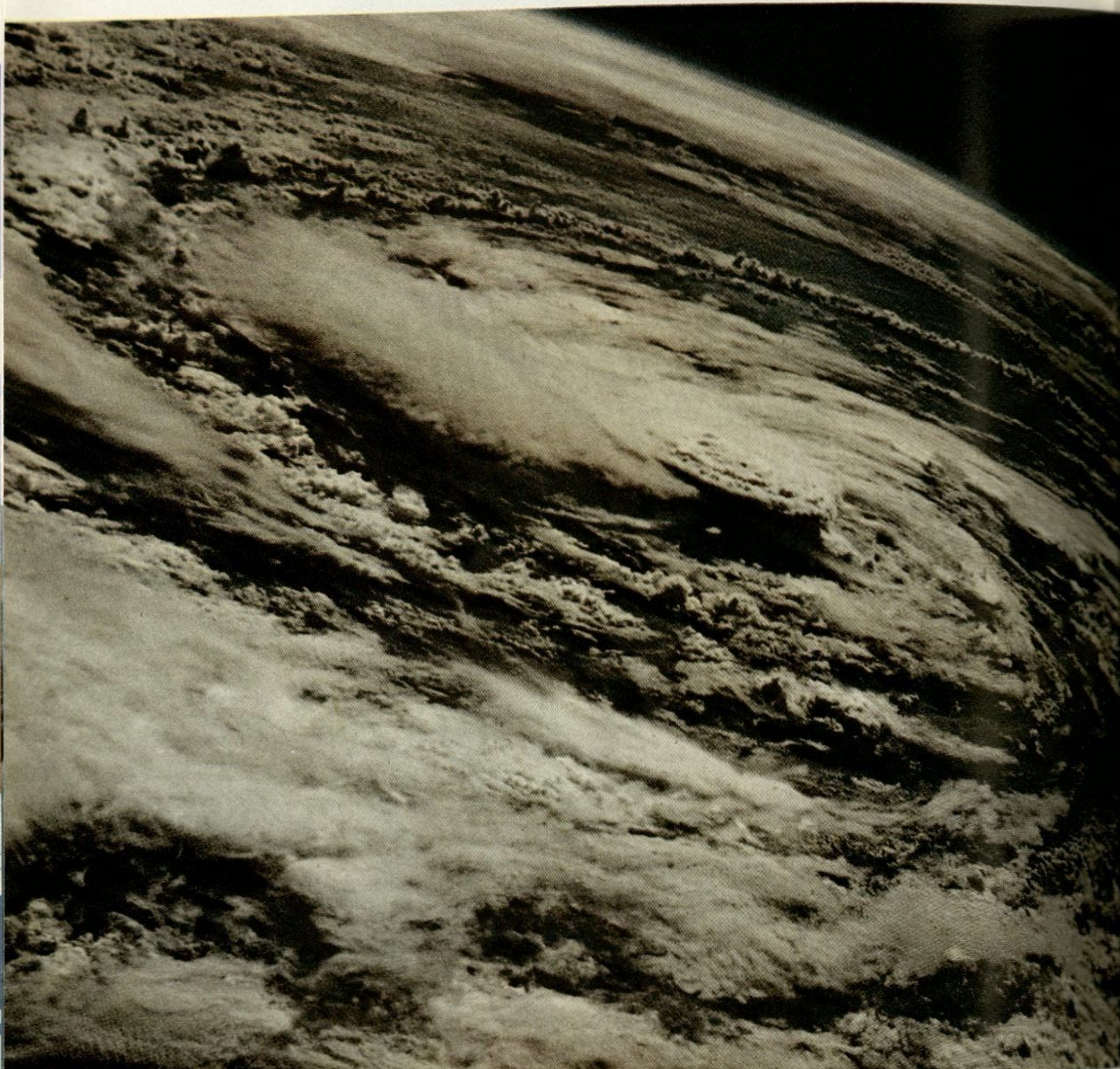
It was the most intense storm to hit North America in modern times. Property damage reached 1.42 billion dollars—a record for a single hurricane.

Relatively speaking, the loss of life was astonishingly small. The dead and missing exceeded 320, of whom more than a hundred died in floods in Virginia, where the hurricane dropped 27 inches of rain in eight hours.

Had it not been for prompt warnings from the Weather Service, the death toll might have been staggering. Because of the warnings, more than 75,000 persons fled to safety. Some 50,000 of those might have died, according to Government estimates, if they had not been warned in time.

The awesome power of rampaging weather was revealed again on November 12, 1970, when a tropical cyclone swept in from the Bay of Bengal to strike East Pakistan and leave between a quarter and a half million people dead. It was the greatest natural catastrophe of this century. Satellite pictures, received by APT stations in Pakistan, gave

GEOPHYSICAL INSTITUTE, UNIVERSITY OF ALASKA (TOP); EMORY KRISTOF (LEFT CENTER); ROBERT W. MADDEN (BELOW)



warning of the storm. But the crowded populations of the coastal islands did not get the word, and they were overwhelmed by mammoth tidal surges.

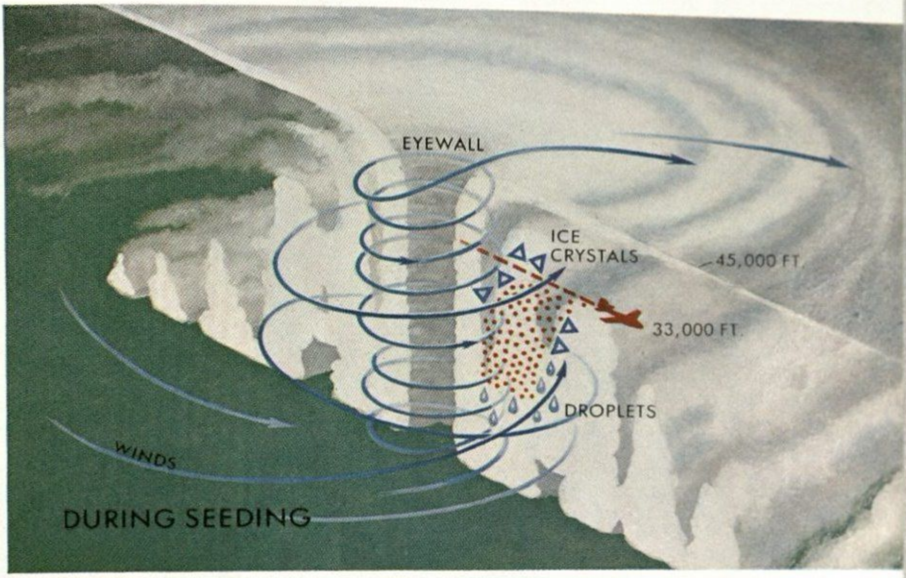
Debbie Yields to Stormfury

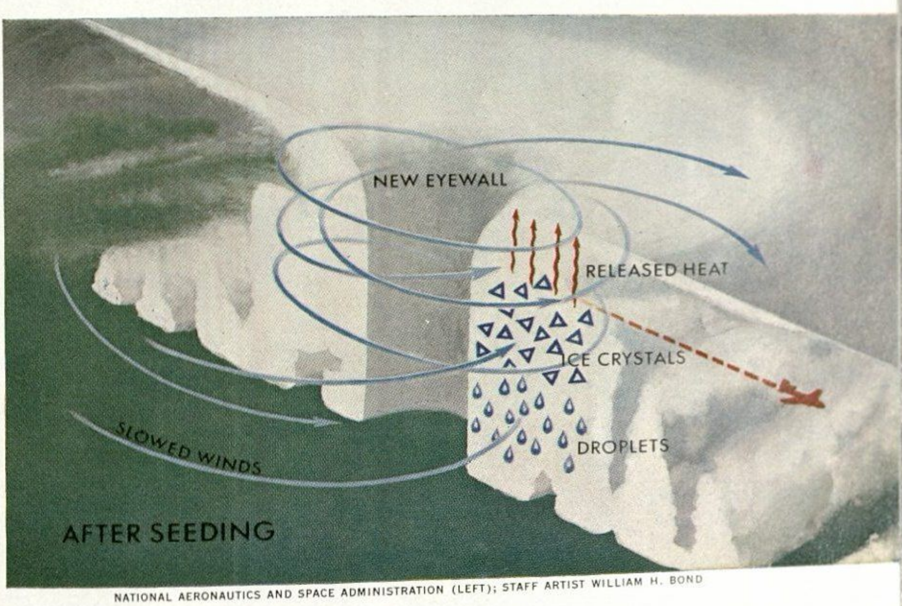
The Weather Service may properly be proud of its effective storm-warning system, which annually saves many times the total cost of the Government's weather program. But Dr. Robert H. Simpson, Director of the National Hurricane Center, believes that it may be possible to do more, that eventually we can learn how to weaken the fury of a hurricane.

A decade ago Dr. Simpson suggested that hurricanes might be altered by cloud seeding. If nuclei could be introduced into the rain clouds near the eye of the storm, transforming water droplets to ice crystals and thus releasing heat, the balance of forces in the hurricane might be upset, he reasoned.

Project Stormfury, set up in cooperation with the Department of Defense to test this theory, has seeded four hurricanes, collecting fairly convincing evidence in one case. On August 18, and again on August 20, 1969, aircraft seeded Hurricane Debbie. Five times during two eight-hour periods, specially equipped U. S. Navy planes flew through the eyewall of the hurricane, where the winds are strongest (opposite, upper), and laid down

Sparring with a hurricane





NATIONAL AERONAUTICS AND SPACE ADMINISTRATION (LEFT); STAFF ARTIST WILLIAM H. BOND

SWIRLING MAELSTROM, Hurricane Gladys spins over the Gulf of Mexico in 1968. Seen by Apollo 7 from 111 miles up, the cyclonic storm heads toward Florida.

Even as Gladys flared with 90-mile-an-hour winds, instrument-laden aircraft plunged into the seething air mass. The planes fed data to Project Stormfury, a national effort to study these weather tantrums and learn how to tame them.

Stormfury sometimes attempts to turn a hurricane against itself. Flying through a storm's eye (**upper**), an airplane seeds the turbulent eyewall clouds. The nuclei greatly increase freezing, which causes the release of tremendous amounts of heat. The heat disrupts the eyewall, causing it to rebuild outward (**lower**). This extending of the wall slows the leviathan's winds, just as a spinning skater slows himself by thrusting out his arms.

Stormfury's weather warriors shy away from claims of even partial victory, but statistics show that after their most successful assault—on Hurricane Debbie in 1969—winds slowed as much as 31 percent.

curtains of silver iodide particles 16 to 23 miles long and more than 15,000 feet deep.

Meanwhile research aircraft flew across the storm, measuring the winds. On August 18, several hours after seeding, wind velocity dropped from 98 knots to 68 knots. On August 19, with no seeding, the storm reintensified. On August 20, again after seeding, winds fell off 15 percent.

Dr. R. Cecil Gentry, Director of Project Stormfury, is cautious about these results. "It could have just happened," he admits. "However, when we analyze other storms, we conclude that wind changes this great have not occurred in any of 50 hurricanes that we have studied but not seeded."

A final answer may not be far off; Project Stormfury is continuing its experiments each hurricane season.

Desirable as all this might seem, tampering with hurricanes could also produce undesirable side results. Many parts of the world depend heavily on moisture received from these great storms. Hurricane Inez in 1966, for example, threatened the U. S. Gulf Coast with grave property damage—which fortunately did not materialize. But rains brought by the same hurricane filled the reservoirs of large portions of the Mexican altiplano with sufficient water to assure favorable crops for at least a season.

Whirlwind Poses Different Problems

The tornado—most violent of atmospheric phenomena and the most destructive over a small area—is not so easy to detect in advance as the hurricane. Space cameras cannot see tornadoes; at best, all they can make out are the types of thunderstorms most likely to produce these intense, brief, and unpredictable whirlwinds.

Yet swift warnings are essential. During the 11-year period from 1960 through 1970, 7,428 tornadoes were reported in the United States. They killed more than a thousand people, and might have killed many more except for the efficient warning system. Not a single state has been spared the lash of the tornado, although it is the special scourge of the Plains States (pages 548-9).

Oddly enough, tornadoes seem to be almost a North American specialty: They occur more often in the United States than anywhere else in the world.

In Oklahoma, in the heart of tornado country, the National Severe Storms Laboratory seeks to learn what makes tornadoes tick, and that's not easy. In Kansas City, the National Severe Storms Forecast Center maintains a ceaseless vigil, constantly analyzing atmospheric conditions across the country and coordinating the reports of hundreds of local Skywarn networks.

When an area is threatened, a tornado watch goes out via radio and television. When one of the terrifying funnels is sighted, or when radar picks up an echo with the shape of a hook or a flying eagle, characteristic of a tornado-producing cloud, every means of communication is mobilized to warn people to take shelter immediately.

Tornado Alarm All Too Successful

Allen Pearson, who for years has headed the forecast center in Kansas City, tells about an encounter with a lady who was displeased with the warning system.

"She called me up to protest that the tornado watch had kept her in her basement for five hours, and nothing happened," says Al. "I tried to explain that we didn't want to alarm her; we just wanted her to be aware. Unfortunately, the same thing happened again five months later. She was really angry that time; we had given a warning but there was no tornado.

"Two years later, we had a really big storm. The lady came up out of her shelter to find her house blown away. She got me on the phone and said, 'Now, that's more like it!' "

If anyone ever figures out how to mitigate the fury of a tornado, that man may be Dr. T. Theodore Fujita of the Department of Geophysical Sciences at the University of Chicago. His intensive studies during the past 20 years of the behavior of these devastating

Goring the earth, a tornado roars across a wheat field near Kingfisher, Oklahoma. Scooped-up debris darkens the vortex; streaks within the funnel reveal a second, inner core—a tornado feature not commonly visible. Each year hundreds of twisters wreak death and destruction on "Tornado Alley," a wide belt across the Great Plains where warm and cold air masses frequently collide. WAYNE C. CARLSON

funnels have earned him the sobriquet "Mr. Tornado."

A visit to Dr. Fujita's laboratory is a fascinating experience. With the aid of skilled machinist Vincent Ankus, he has built a wondrous tornado machine (left). A few minutes' preparation and the flick of a switch —and before your eyes miniature funnels dance and spin as do their lethal counterparts on the plains of Texas.

Wind force for the machine comes from an overlapping series of rotating cups, turning slowly at the outside but more rapidly toward the center, so that the suction is greatest in the middle.

Several feet below this apparatus sits a large tray filled with water. Dr. Fujita adds chunks of dry ice. The water bubbles like a devil's caldron, with "smoke" from the dry ice writhing and flowing above it.

Heat Tames a Man-made Twister

Mr. Ankus turns on the machine. Instantly the smoke whips into a dazzling funnel, dancing erratically about the pan as it feeds into the exhaust fan above.

Now Dr. Fujita experiments to see what will affect his miniature maelstrom. He positions a framework of electrical wires so that they extend through the funnel; nothing happens. But when he turns on the current and the wires glow red, the funnel seems bewildered and tends to break up. Heat is poison to it.

Next he pokes a ruler into the spinning cloud. If held out flat, there is little effect; if turned on edge, the funnel falters. Similarly, if suction is made uniform over the area of whirling motions, the action is damped.

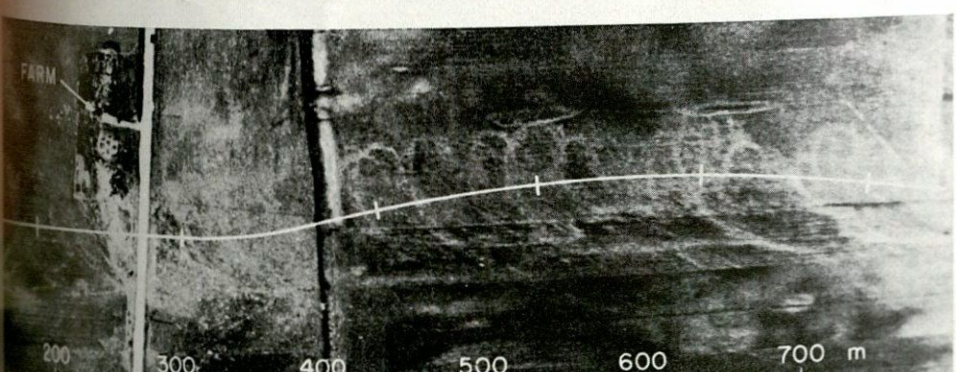
Says Dr. Fujita, "I hope that within ten years we will learn from experiments like these how to modify real tornadoes."

Suction Spots Cause Super Violence

Dr. Fujita shows visitors a picture of a tornado aftermath in which one house is totally destroyed and the next is virtually undisturbed. Such variable damage is common, supposedly because the tornado skips and jumps. That may not be the answer at all, the scientist believes. Instead, the heaviest destruction may be caused by areas called "suction spots" in the funnel wall, which Dr. Fujita was the first to explain.

"A tornado moves across country at an average speed of about 30 miles an hour," he says. "The funnel itself rotates at speeds that may vary from 50 to 200 miles an hour. But carried along in the wall are three or four, sometimes five spots, that have an additional rotation of as much as 100 miles an hour. They may measure only a twentieth of the diameter of the funnel, but the suction in that small area is much greater than within the tornado as a whole."

Dr. Fujita discovered this phenomenon when he noticed in his voluminous file of photographs of tornado destruction that the worst damage often appeared along spiral lines. Each series of loops marked the devastating track of a suction spot (below).



ANTHONY A. BOCCACCIO (LEFT); T. THEODORE FUJITA

Laboratory twister sucks up dry-ice vapor at the University of Chicago. By spinning overhead wind cups as fast as 20 revolutions a second, Dr. T. Theodore Fujita simulates the motion of the parent cloud that creates a tornado's funnel.

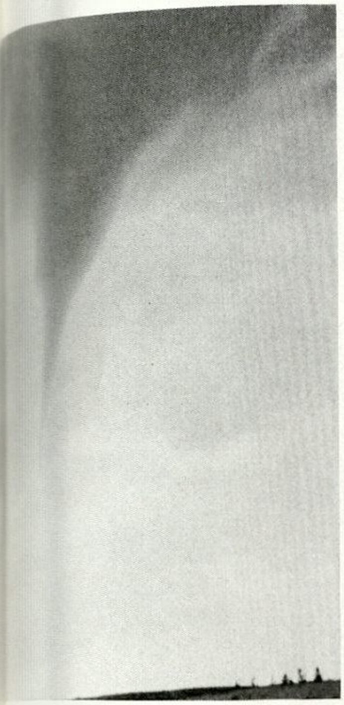
Spiral wake of an Indiana tornado (**above**) betrays the presence of hidden fangs. Dr. Fujita discovered that the pattern, common to many twisters, stems from small but incredibly violent "suction spots" that spin within the funnel wall (see text above).

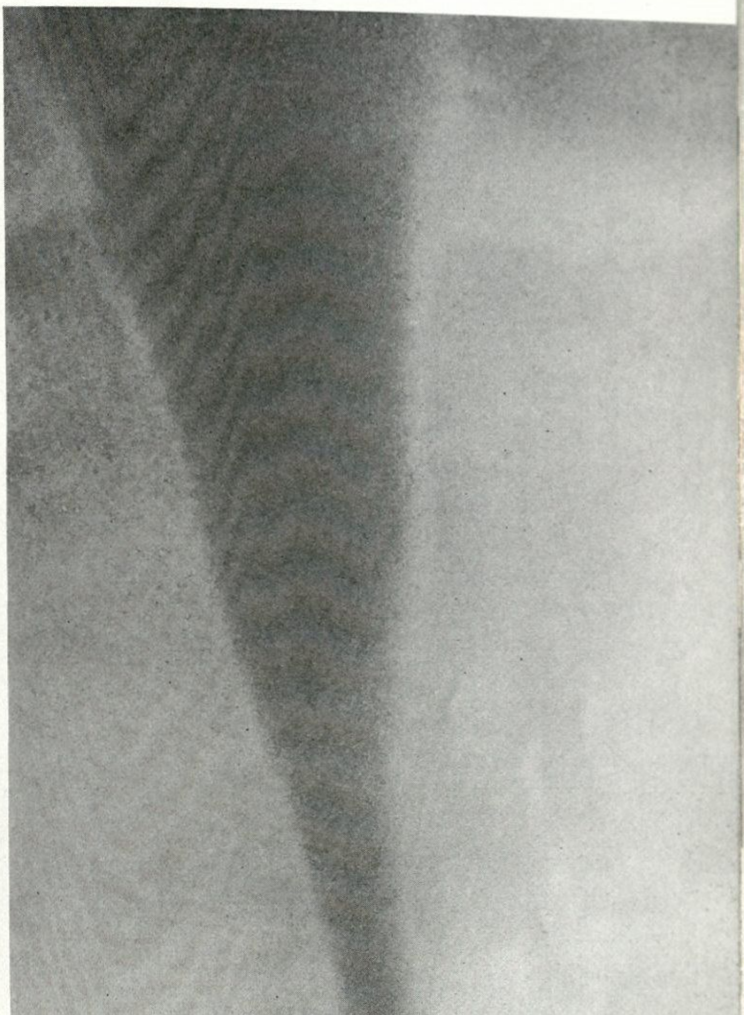
Birth of a twister: Spotting a suspicious cloud near Salina, Kansas, on May 11, 1970, two highway patrolmen radioed a warning, then leaped from their squad cars and started clicking their cameras. Seven minutes later they had recorded one of the most dramatic known sequences of a tornado's fearsome growth.

Pudgy and harmless at first, the incipient twister bulges from the cloud base two miles away. Already, winds probably coil below, perhaps even reaching the ground 3,000 feet beneath.

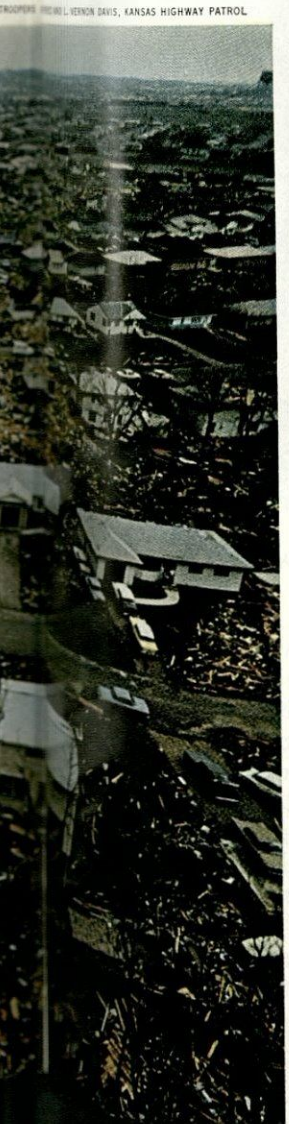
Finally the cloud elongates, tapers, and takes on its dreaded spin. Its winds probably now reach 200 miles an hour. Happily, this tornado swept across largely open land.

GERALD BRIMACOMBE (BELOW); TROOPERS

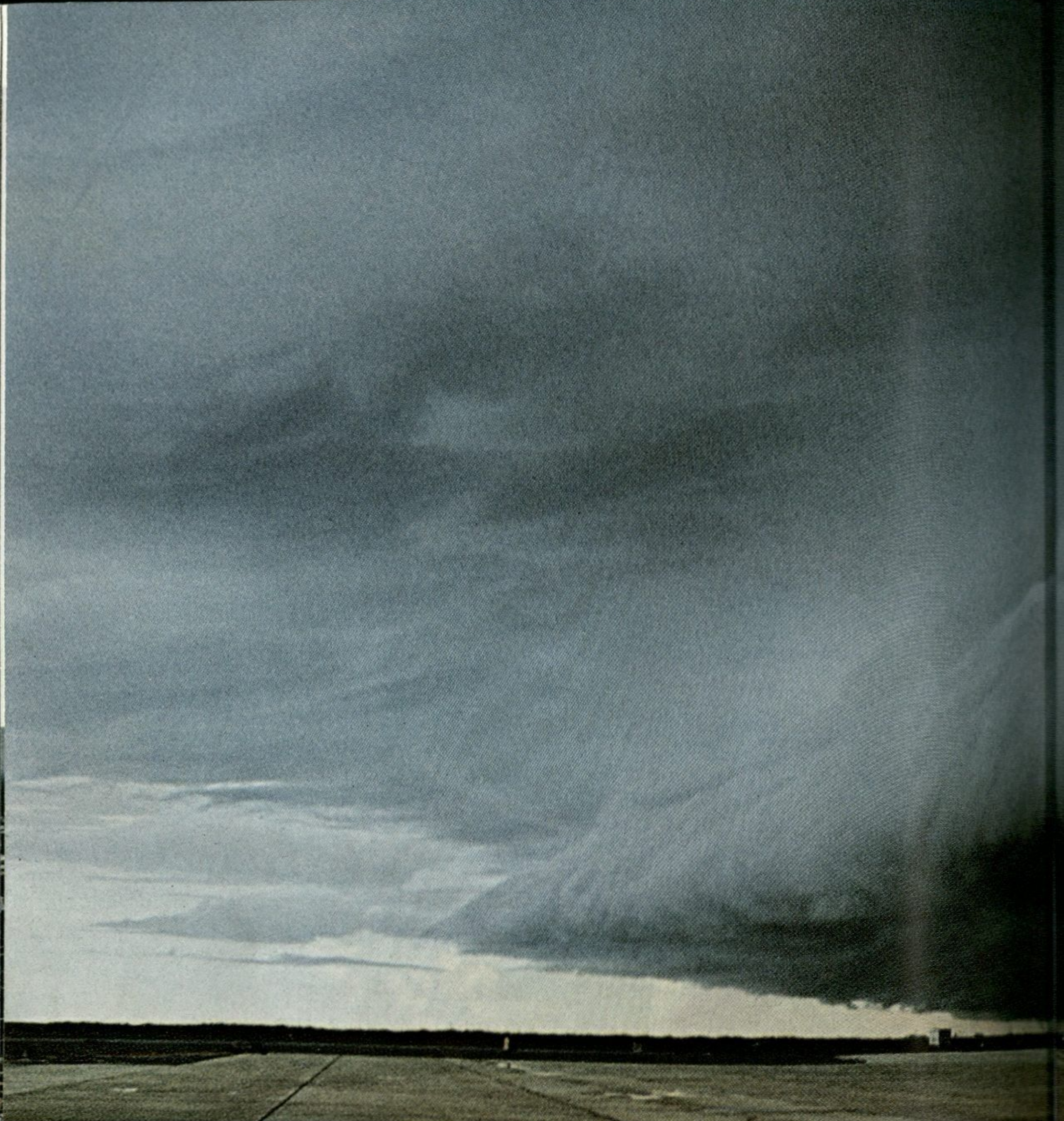




TROOPERS [illegible] L. VERNON DAVIS, KANSAS HIGHWAY PATROL



◀ **Three tornadoes in two hours** swept Fridley, Minnesota, on May 6, 1965. Winds estimated at 200 miles an hour caused only two deaths in the Minneapolis suburb but demolished 425 homes; 1,100 more were severely damaged. Houses intact amid the ruins illustrate the storm's fickle wrath.



A "roll" cloud leads a thunderstorm across Patrick Air Force Base, Florida. Warm currents,

Remarkably enough, this brilliant scientist, who has contributed so much to our knowledge of tornadoes, has yet to see one of the storms in action!

While not as dramatic as tornadoes, hailstorms cause even more economic loss. In a deep-freeze cabinet here at NCAR lie the pieces of a knobby, grapefruit-size lump of ice (page 553). It is the largest hailstone ever known to have fallen in the United States—17½ inches in circumference and 1.67 pounds in weight. It struck the earth during a severe storm at Coffeyville, Kansas, in September 1970, together with hundreds of other huge stones that crashed through roofs and put enormous dents in automobiles. A local newspaper shipped the chunk to NCAR in an insulated box packed with dry ice.

Fortunately, few thunderstorms produce such lethal missiles. Yet much smaller hailstones can do tremendous damage, smashing wheat fields flat and stripping corn to ribbons. Total losses from hail in this country run as high as 300 million dollars annually.

JAMES H. MEYER

driven upward as the cooler storm air advances, shape this usually harmless arcus cloud.

"Hail Alley"—an area extending from southeastern Wyoming to western Kansas—bears the brunt of U. S. hail damage. Here the National Hail Research Experiment, a cooperative effort involving NOAA and a number of universities as well as NCAR, will try in the next few summers to find out just what happens inside hailstorms and whether man can modify or prevent them.

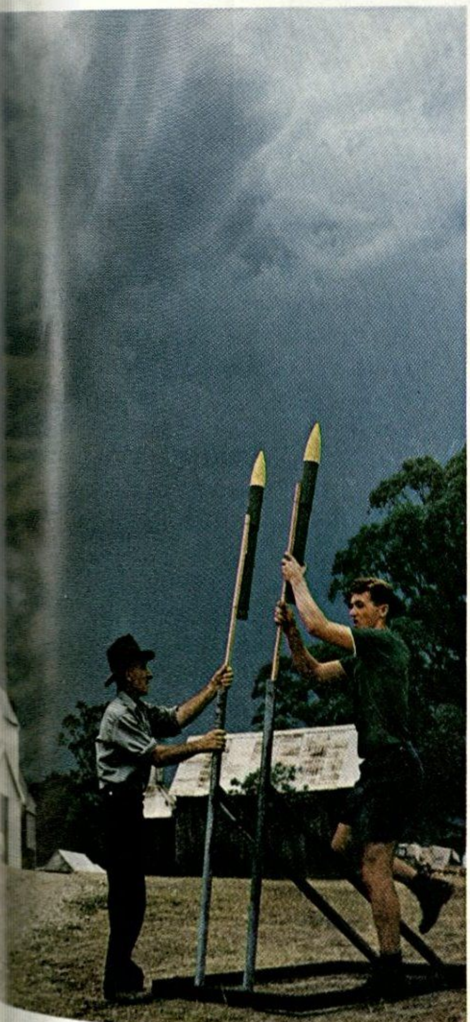
Experience in the Soviet Union already indicates that cloud seeding may be the answer. The theory on which the Russians operate, developed by Dr. G. K. Sulakvelidze, suggests that hailstones grow as they move slowly through freezing levels, buoyed by strong updrafts reaching as much as 65 miles an hour. When the weight of the ice finally exceeds the force of the updraft, the stone falls to earth. From two miles up, if it is no more than three-quarters of an inch in diameter, it may totally melt before it reaches the ground.

Guided by this theory, the Russians have set up batteries of antiaircraft guns and rockets in the wheat fields of the Caucasus.

Harvest of heartbreak: Cornstalks bow to a deluge of ice near Viroqua, Wisconsin. Hail destroys 200 to 300 million dollars' worth of crops and property each year—a greater toll than that taken by tornadoes.

Fighting back at man's ancient scourge, Australian farmers aim rockets into clouds that threaten their vineyards with hail (**below**). The missiles will explode at 4,000 feet and spew cloud-seeding chemicals, perhaps causing rain to fall instead.

In the Soviet Union, scientists claim success in hail suppression by firing chemicals into storms with rockets and batteries of antiaircraft guns.



RURAL LIFE PHOTO SERVICE (LEFT); DAVID MOORE, BLACK STAR (ABOVE); NATIONAL CENTER FOR ATMOSPHERIC RESEARCH

Record-breaking hailstone, this knobby giant weighed $1\frac{2}{3}$ pounds before being sawed into sections in a cold room at NCAR (**top**). It and other grapefruit-size missiles rained down near Coffeyville, Kansas, in 1970, crashing through buildings and pounding huge dents into cars.

Gemlike in polarized light, a thin section of the Coffeyville specimen (**above**) exhibits the crystalline structure of hailstones—a pattern that tells much about their growth. Water flowing to the top as the stone fell through supercooled clouds created the irregular knobs.

When radar pinpoints the position where hail is beginning to form, salvos of explosive charges containing silver iodide are fired high into the storm clouds. The tiny silver iodide crystals serve as freezing nuclei; they scavenge out water vapor and turn it to sleet before it can become damaging hail. The Russians say they have reduced hail damage by 85 percent in some regions, and they now apologize if hail falls in the seeded areas.

Is a New Ice Age Coming?

I have mentioned several examples of man's deliberate efforts at weather modification. In the view of some scientists, man may also be modifying the weather inadvertently through his pollution of the atmosphere, and the changes he is bringing about may be of the utmost concern.

Of course, even without man's intervention, world climate has varied considerably in historical times. Between 550 and 500 B.C., for example, about the time of Cyrus the Great of Persia, an abrupt change appears to have affected the entire Northern Hemisphere. In my opinion, it may have altered the course of Western history.

Northern Europe, before that time, had seen centuries of relatively mild and favorable weather. Then, about 500 B.C., the change for the worse seems to have shortened the growing season in Scandinavia radically. Cold, stormy weather closed Alpine passes of central Europe that had been open trade routes for at least 1,300 years. It may well be that the legend of the "Twilight of the Gods" comes from the hardships attendant upon this climatic disaster. It was nearly a thousand years before northern Europe fully recovered from this adverse period.

Later, the major part of the 11th century A.D. was warm and favorable in northern Europe, leading to Viking explorations and Leif Ericson's voyage to North America. But the 13th, 14th, and 16th centuries saw periods of worsening climate in northern Europe, with disastrous crop failures and famines. Similarly, the early part of the 1800's had increasingly bitter weather.

In the late 1880's a gradual but steady warming trend set in. In the United States it continued until about the middle of this century. Could it have been at least partly caused by man? Some scientists think so; they

blame it on the enormous increase in the industrial burning of fossil fuels—coal and oil—which pours vast amounts of carbon dioxide into the atmosphere. Since carbon dioxide permits the sun's radiation to pass through the atmosphere but tends to trap heat radiating out from earth, it might be responsible for the warming.

There were dire predictions that, if the trend continued, the world might warm up enough to melt the icecaps of Antarctica and Greenland, raising the seas and inundating all the world's great seaports.

But since about 1940 the trend has clearly reversed; we are now in a cooling phase. And again the finger may point to man. Some ecologists are convinced that man's pollution is building up a layer of particles in the atmosphere that—together with volcanic dust—blocks more and more of the sun's energy.

Airborne particle pollution has doubled in the Northern Hemisphere since 1910, from dust, smoke, and the invisible particles in automobile exhausts.* And the rate of such pollution is rapidly increasing.

*Gordon Young discussed "Pollution, Threat to Man's Only Home," in the December 1970 GEOGRAPHIC.

Could this mean a new ice age? The Russian climatologist M. I. Budyko has suggested this sobering possibility.

And only last summer a report in the journal *Science,* by Dr. S. I. Rasool and Dr. S. H. Schneider, echoed the threat: If the rate of pollution increases during the next 50 years as much as the authors expect it to, the average surface temperature of earth could well drop by about 6° F. This decrease may sound small to the layman, but to scientists it would be a large and serious change.

"Sustained over a period of a few years," says the report, "[it] is believed to be sufficient to trigger an ice age."

Fortunately, the authors hold out one bit of comfort. Within 50 years, they suggest, nuclear power may have replaced fossil fuels in energy production, and contamination of the atmosphere may have been curtailed.

Mark Twain, years ago, said that "everybody talks about the weather, but nobody does anything about it." The remark was not original with him, but no matter. If Twain were here today, I'm sure he would change his mind. Man *is* doing something about the weather, for good and for ill. □