HURRICANES

Author(s): R. H. Simpson
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HURRICANES

By flying through furious winds into the calm, clear "eye" of these vast storms, meteorologists are beginning to learn something of their complex origins, structure and behavior

by R. H. Simpson

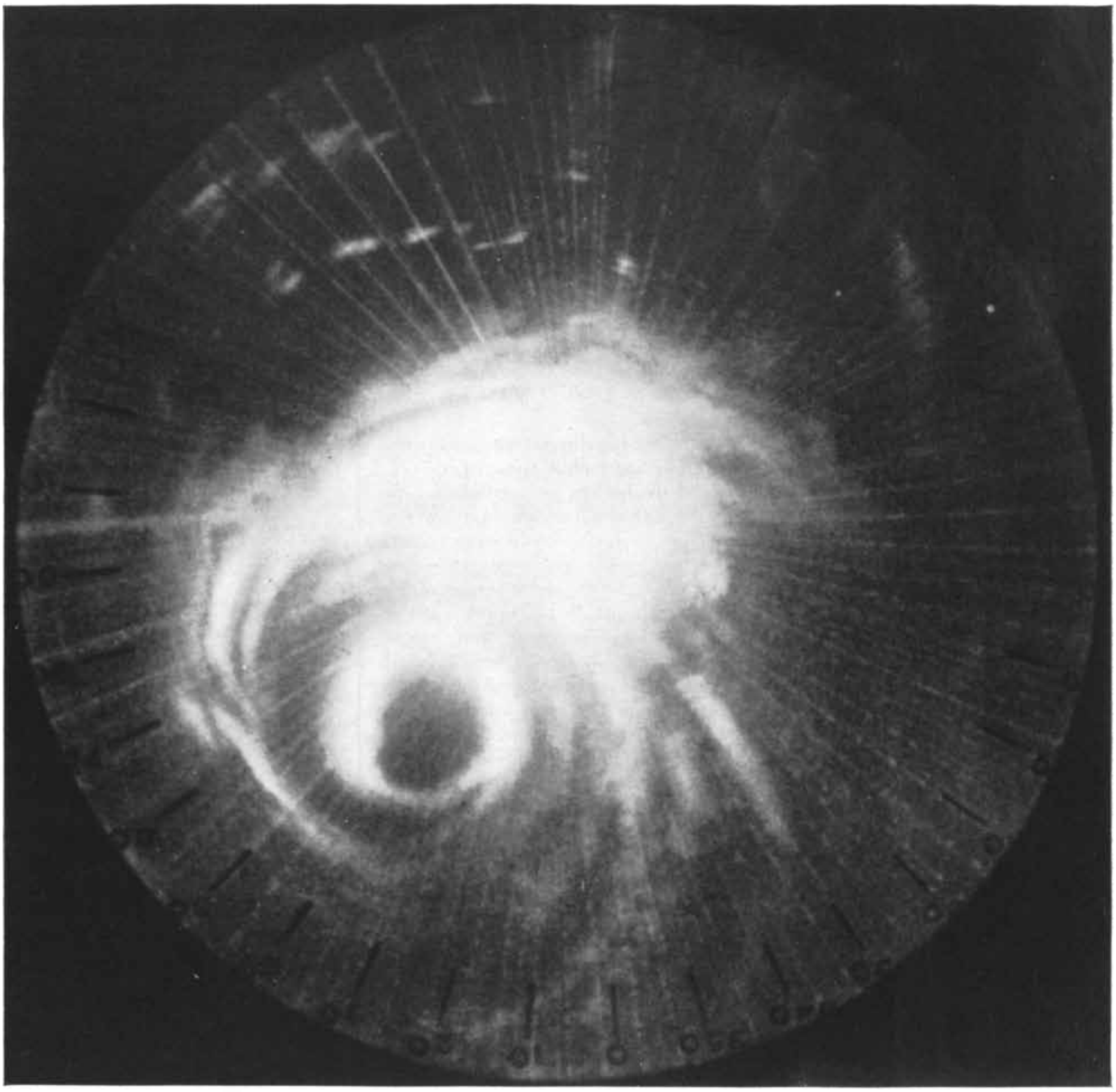
A hurricane is the most dangerous and destructive of all storms on the earth. It does not cover nearly as large an area as the ordinary storms that make our week-to-week weather, nor can it match the concentrated fury of a tornado, but it combines violence and sweep to spread devastation over a huge path. The vortex of a hurricane may cover more than half a million square miles, and its winds may reach 150 miles an hour or more. Sometimes it generates a whole rash of tornadoes on its fringes. What makes a hurricane most dangerous is not primarily the wind, however, but the great waves which it may pile up in the sea. As recently as 1935 a hurricane wave drowned or killed more than 400 persons in the Florida Keys; in 1900 the wave at Galveston drowned more than 6,000; and in India in 1876 a hurricane produced an inundation in which more than 100,000 people perished.

The hurricane phenomenon itself is known by various names: in the China seas it may be called a typhoon or baguio, in Australia a willy-willy, in India a Bengal cyclone. Except that the typhoons of the western Pacific may reach a bigger size than the others, because they sweep over vast expanses of warm water, all these phenomena are the same—cyclones which arise over tropical seas and grow to incredible energies. A mature hurricane spends kinetic energy at the rate of 500 trillion horsepower, the equivalent of several thousand atomic bombs per second! How does it develop such appalling power?

SURFACE OF THE SEA about 60 miles from the center of typhoon "Marge" was photographed from an airplane flying at 1,700 feet. The wind was from 75 to 85 miles per hour.

There used to be a rather simple theory about how cyclones developed: In the calm, moist air of the tropical doldrums an eddy of warm air begins to rise, and as it rises, air rushes in at the bottom to replace it. The air currents are given a counterclockwise motion (in the Northern Hemisphere) by the rotation of the earth—the Coriolis effect. This cyclonic circulation becomes the nucleus of a hurricane. The main shortcoming of the theory was that it failed to explain why the eddy began in the first place and why the air went on rising at an accelerating pace in the center of the cyclone. If the speed of circulation is to increase and the cyclone is to grow in intensity, the rising air must be carried rapidly away from the center to reduce the pressure so that air can rush in with increasing velocity at the bottom. How this could happen was a puzzle. We have learned, indeed, that the answer to the question holds the key to the formation and growth of hurricanes.

A decade ago meteorologists began to collect detailed information about the structure of the hurricane core—at first with radiosonde balloons and later with radar and by direct airplane flights into the "eye" of the storm as well. The first sounding was made at Tampa, Fla., in 1944; the radiosonde balloon rose to 56,000 feet in the eye of the hurricane, and its tiny radio transmitted back a continuous record of the temperature, pressure and humidity conditions at various levels of the cyclone core. In 1947 the writer, along with members of the Air Weather Service, made several reconnaissance flights into the eye of the



RADAR SCOPE shows the spiral structure of a hurricane. The eye is at lower left. The radar set picks up rain squalls, which follow closely the pattern of the winds. When this photograph was taken, the eye was 37 miles away. Visibility was an eighth of a mile.

Atlantic hurricane "George," and again in 1951 we flew into the Pacific typhoon "Marge"—the third largest hurricane on record.

For the latter flight we took off from Guam at dawn on August 15, 1951. The typhoon center was 700 miles away. Flying at 11,000 feet, we were below a dull overcast, part of the shield of high clouds with which Marge had surrounded herself. As we approached the storm, we could see long swells in the ocean coming from the hurricane's direction—remnants of the enormous waves generated at its center. There was an ominous absence of random clouds beneath the solid overcast; they had all been marshaled into great streamers or "squall lines" which, as we could see on the radar screen, were spiraling in around the eye of the typhoon.

As we came closer, the surface winds grew stronger. Two hundred miles from the center they reached hurricane force—74 miles per hour—and in another 50 miles they had increased to 100 miles per hour. From here on we could no longer see the surface, for the cloud cover now engulfed the plane completely. Only the spiral pattern of the squall lines on the radar screen enabled us to keep headed toward the storm center. Soon the edge of the rainless eye became visible on the screen. The plane flew through bursts of torrential rain and several turbulent bumps. Then, suddenly, we were in dazzling sunlight and bright, blue sky.

Around us was an awesome display. Marge's eye was a clear space 40 miles in diameter surrounded by a coliseum of clouds whose walls on one side rose vertically and on the other were banked like the galleries in a great opera house. The upper rim, about 35,000 feet high, was rounded off smoothly against a background of blue sky. Below us was a floor of low clouds rising to a dome 8,000 feet above sea level in the center. There were breaks in it which gave us glimpses of the surface of the ocean. In the vortex around the eye the sea was a scene of unimaginably violent, churning water.

For four and a half hours we cruised in the eye of the typhoon, taking observations and making photographs of the clouds. Among the most significant measurements were those of temperature. We found the air in the eye considerably warmer than that in the surrounding vortex. At 8,000 feet its temperature was some 14 degrees Fahrenheit higher; at 18,000 feet the eye temperature was more than 32 degrees higher than that of the outer fringes of the vortex. This astounding temperature gradient indicated that the storm had as great a concentration of potential energy as has ever been detected in the atmosphere.

A hurricane can be regarded as a gigantic heat engine fueled by the latent heat released by water vapor condensing in the air. Its nucleus usually springs from a turbulent eddy in the trade winds, not necessarily in the doldrums ["Trade-Wind Clouds," by Joanne Starr Malkus; Scientific American, November 1953]. The hurricane develops when the wind pattern aloft, about whose nature there is some doubt, removes the rising air at upper levels.

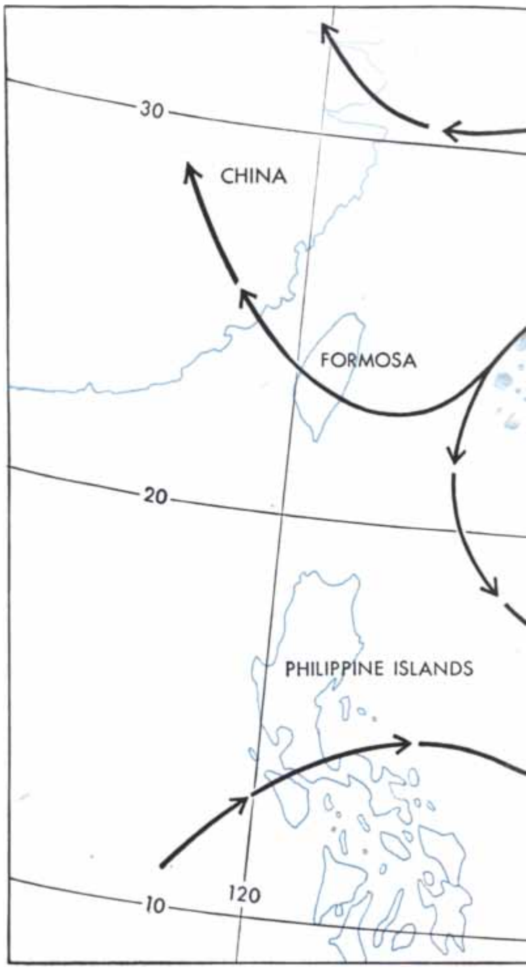
Any storm must have a low-pressure center to maintain its circulation. In a hurricane the air pressure at the center of the storm may be as much as 10 per cent lower than at the edge. Moreover, most of this pressure gradient usually occurs within 30 to 40 miles of the core. The greatest fury of the cyclonic winds is concentrated in the region near the eye; in a small but violent storm the maximum winds may be within a few hundred yards of the eye, while in a mature hurricane they are several miles away. The highest wind velocity ever measured at the surface in a hurricane was 186 miles per hour, recorded at the Mount Washington weather observatory during the New England storm of 1938.

The surface winds spiraling around the eye force moist air violently upward at a rate which may exceed a million tons per second. As this air is cooled, its moisture is condensed and wrung out in the form of rain. The condensation releases vast quantities of latent heat, raising the temperature near the eye considerably above that of surrounding areas. Pressure decreases with height less rapidly in warm air than in cool. Consequently at higher altitude the pressure gradient between the inner and outer parts of the vortex becomes smaller. As a result the spiraling currents of air, because of their centrifugal force, fly outward. This is how air leaves the center and prevents the storm from decaying. The process is reinforced by the so-called solenoid effect, which has the result of converting potential energy into kinetic energy and accelerating the outward flow of air.

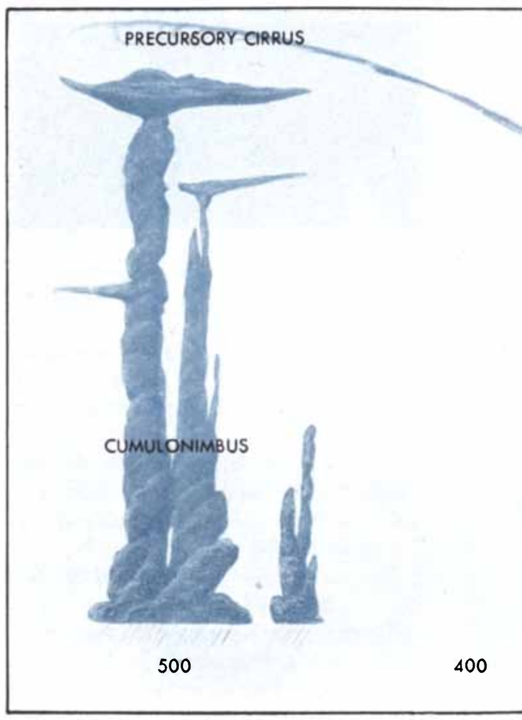
As for the primary source of the hurricane's energy—the inrushing moist air—there can be little doubt that all of it comes from near the surface of the sea. Unlike a thunderstorm or large cumulus cloud, the hurricane entrains little or no air from its surroundings at levels above 2,000 or 3,000 feet from the surface.

So far we have been considering only the lower and middle layers of the vortex. At the bottom air moves in; at intermediate levels it moves out. But at the top other air pours into the storm center. Our observations in the Marge reconnaissance flight showed that most of the air filling the middle and upper layers of the eye had descended from great heights, probably having been injected at some point near the top of the storm's cloud system. The great warmth of the eye stemmed mainly from compression of this air, brought down from high levels, rather than from the condensation of water vapor. On the other hand, the existence of the cloud floor at the bottom of the eye means that some turbulent air must seep into the eye near the water surface. If air is introduced simultaneously both at the top and the bottom of the eye, there must be outflow at intermediate levels; otherwise the pressure at the center would rise and the storm would decay. This circulation downward and outward from the eye is in exactly the opposite sense, with respect to the surfaces of equal entropy, to that of the major circulation surrounding the eye, and hence absorbs kinetic energy. It therefore tends to act as a governor, braking or retarding the fury of the storm.

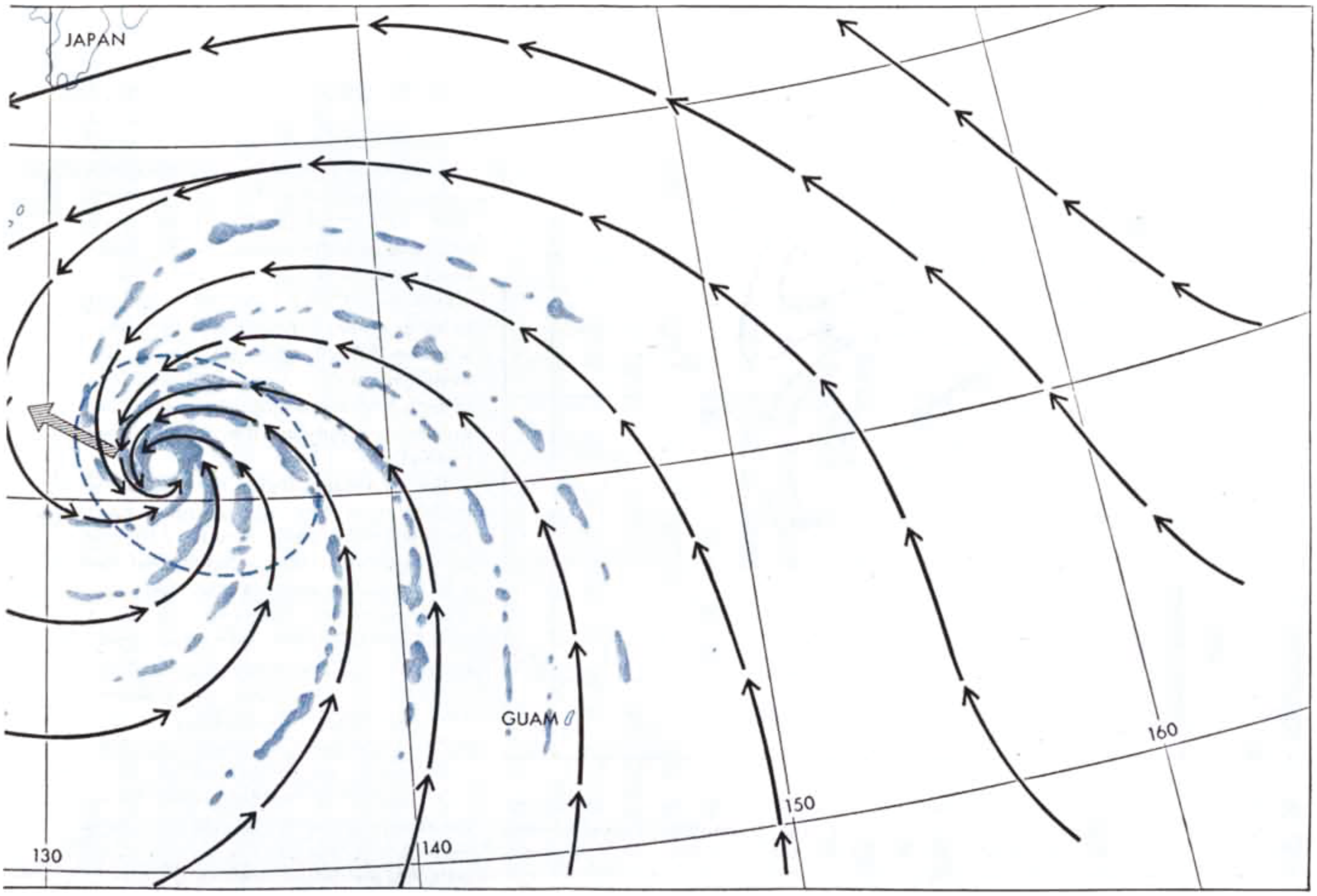
Perhaps the greatest enigma of hurricane structure is the way the heavy rains are concentrated in great spiraling squall lines. These lines were discovered by radar, which makes it possible to watch the rainbands and the storm center itself from distances up to 300 miles. A small, immature hurricane sometimes concentrates most of its rain around a single rainband, which spirals inward toward low pressure like a huge comma, entwining itself around the eye. A more mature storm contains a number of spiral



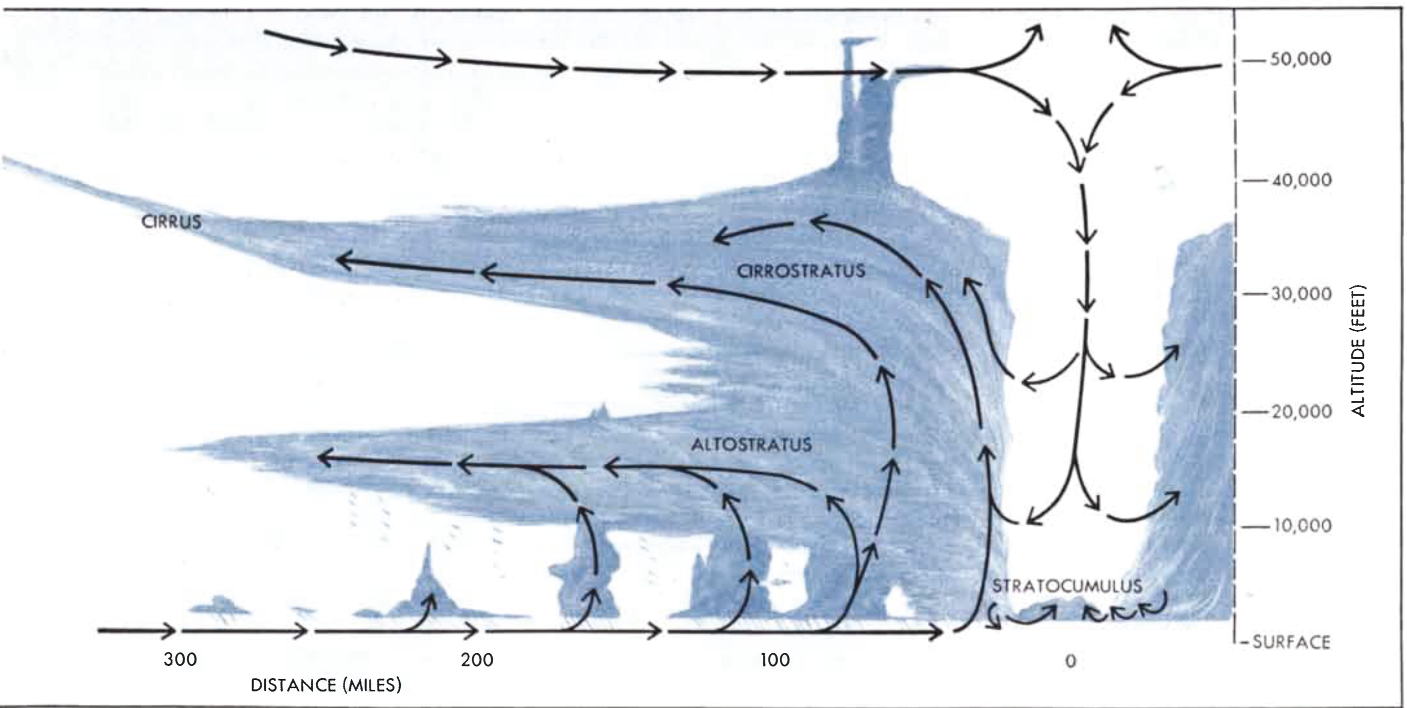
TYPHOON MARGE exhibits the typical spiral wind pattern (*black arrows*) of a ma-



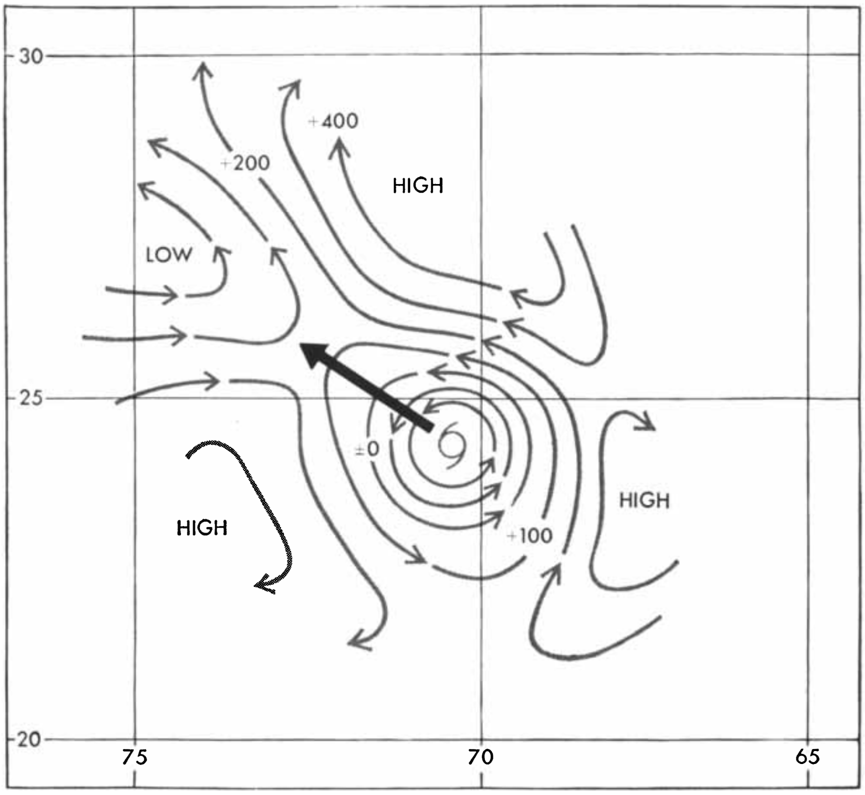
CROSS SECTION of an ideal hurricane shows the circulation of air in the vortex.



ture tropical cyclone. Almost parallel with the air currents are bands of rain clouds, converging with the winds around the small, clear eye. The rain clouds make the storm visible on radar. The large cross-hatched arrow shows where the storm center is heading.



Warm, moist surface air converges around the eye and is forced upward, releasing large amounts of heat through condensation. This heat is the storm's principal source of energy. Air also enters from the top. At intermediate heights it flows away from the vortex.



AIR CIRCULATION near the top of hurricane "George" was traced by an airplane flying through it. The contours are "D values," or altimeter corrections. The coordinates are degrees of longitude and latitude. The black arrow shows the direction of the storm.

rainbands. For example, in typhoon Marge at least six rainbands were observed. These rain clouds, often visible from an airplane, are rarely detectable from the surface in good perspective because small clouds cluster around and obscure them.

As a hurricane approaches, a succession of squalls usually occur, each associated with one of these rainbands. With each squall the gusts of wind increase in violence, and heavy bursts of rain fall. Each successive squall is more severe than the last, until finally wind and rain become continuous at a sustained peak in the last stage before the eye arrives.

Harry Wexler, Weather Bureau meteorologist, has suggested that the rainbands are, in effect, a manifestation of certain parallel lines of small cumulus clouds which are frequently observed over tropical ocean areas. He reasons that these bands are drawn into the vortex of a hurricane, where a few of them grow at the expense of others.

A mature hurricane usually thrusts forward a curious tongue of warm air in the direction of its movement. The reason for the protrusion of this tongue, first observed by the writer in 1946, is not completely clear. It probably develops in the following way. In the moving storm the greatest piling up of air, and hence the greatest release of latent heat, occurs to the right of the line of the storm's advance. As a result, the horizontal pressure gradient tends to decrease with height more rapidly in this sector than elsewhere. The spiraling streams of air rising in this sector therefore find less resistance to outward movement, and they tend to move tangentially along the line of the storm's path. The vanguard of warm air tends to reduce the pressure ahead of the storm center and contributes to its movement. The warm tongue is not always a reliable indicator of direction; even in mature storms it occasionally shows a tendency to branch into a double tongue at some distance from the center. But as we learn to understand it better, it should help considerably to predict the path a hurricane will take.

The circulation of winds at very high levels remains somewhat mysterious. This is unfortunate because the application of certain hurricane forecasting methods depends upon accurate analysis of wind circulations near the top of the storm. Grady Norton, chief forecaster at the Miami Hurricane Center, has successfully applied a theory that the speed and direction of a hurricane's forward movement can be gauged by the wind velocity at a certain high level where the cyclonic circulation shrivels to a minimum size or disappears. This level, which he calls the "steering level," varies considerably from day to day, for reasons which are not always clear. It is difficult to locate when observations of high-level winds in the storm area are lacking. The development of a more accurate model of high-level wind circulations will help greatly in applying the steering-level method.

Reconnaissance flights and radiosonde soundings at very high altitudes have disclosed two curious features of the top of a hurricane. Above 20,000 feet the relative temperature of the warm eye drops, and there is some evidence that at high levels the core may become slightly cooler than its surroundings, so that the cyclonic winds may tend to regenerate. This possibility was explored in two flights into hurricane George in 1947, and it was found that at 38,000 feet there was a small core of cyclonic winds blowing at approximately 120 miles per hour. Surrounding this core were three small cells of higher pressure which apparently were circulating in the anticyclonic sense.

The other peculiar feature is a trough of low pressure that seems to extend ahead of the storm, becoming pronounced about 300 to 500 miles in advance of it. The trough is very high—at 50,000 feet or above—and no trace of it is detectable below about 20,000 feet. It is beneath this trough that the showers and thunderstorms which herald an approaching hurricane develop. Long, silken filaments of cirrus clouds also stream out in advance of the hurricane center. This cirrus, covering a wide area ahead and to the right of the storm, is probably the best-known precursor of a hurricane. It accounts for the fiery sunset that we sometimes see during a hurricane approach.

The part that the high-level circulation features play in the development and career of a hurricane remains obscure —a real challenge to investigators. The three Rs of hurricane investigation—radiosonde, radar and reconnaissance by plane—have turned up almost as many questions as they have answered. Already, however, they have made possible more accurate, effective and timely warning of hurricanes and substantially reduced the loss of life and of property.

MARGE'S EYE is pictured from a point just west of the storm center, looking southwest, at an elevation of 17,000 feet. The walls rise to a height of almost 35,000 feet. Their upper rim is 40 miles in diameter. Below can be seen a part of the cloud floor.