The Origin of Hurricanes

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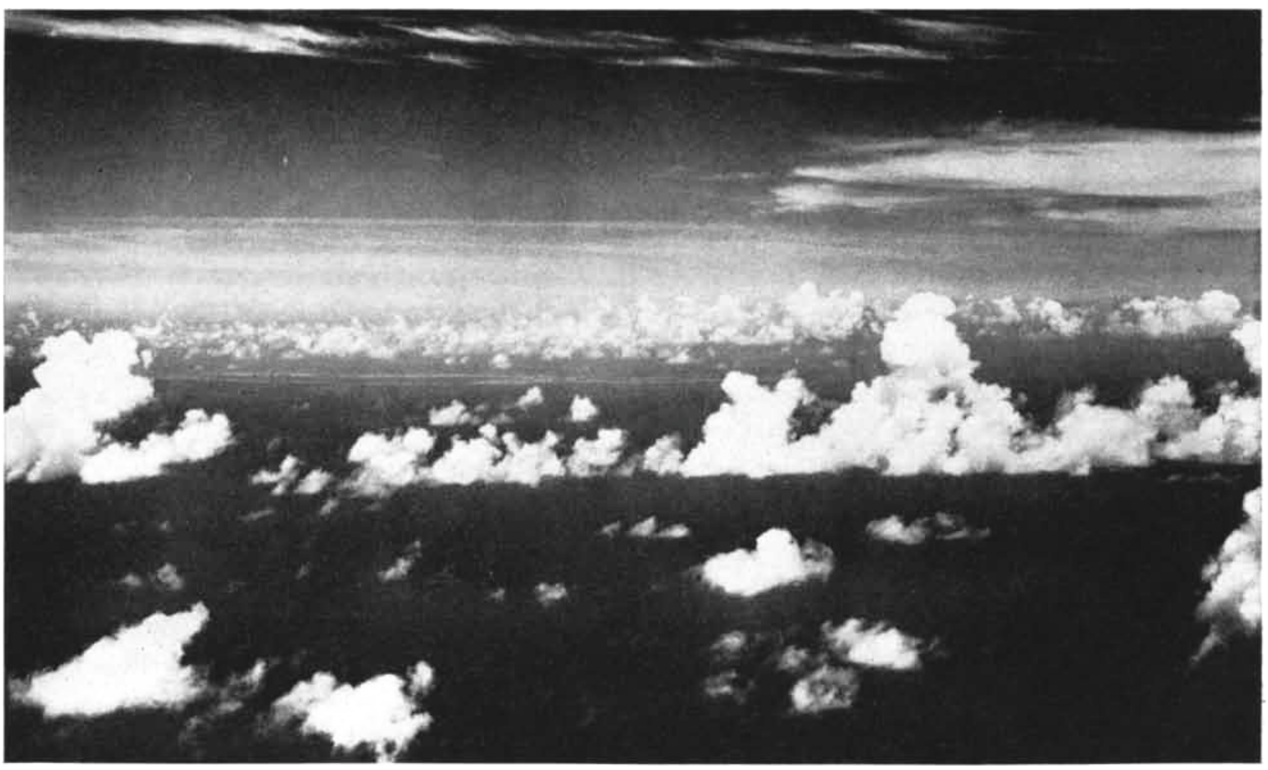
The Origin of Hurricanes

During the summer the uniform weather of the tropics is periodically disturbed. Occasionally these disturbances ripen into hurricanes. Why they do not do so more often is still a basic question of meteorology

by Joanne Starr Malkus

The weather of the tropics is notoriously monotonous. The wind always blows from the same direction, and airports need only a single runway. A daily shower, so we are told, arrives with clocklike regularity. The temperature is so even all the year round that a five-degree drop makes people shiver. A tedious climatic uniformity sits upon land and ocean alike. How is it, then, that these impassive tropics generate one of the most violent weather phenomena known to man? The fact that hurricanes are hatched in the seemingly peaceful tropical regions is one of the great paradoxes of meteorology.

Like all paradoxes, this one has a surprising answer. The atmosphere of the tropics is not as placid as it seems: its apparent tranquillity lies only on the surface. Probing into the higher levels,

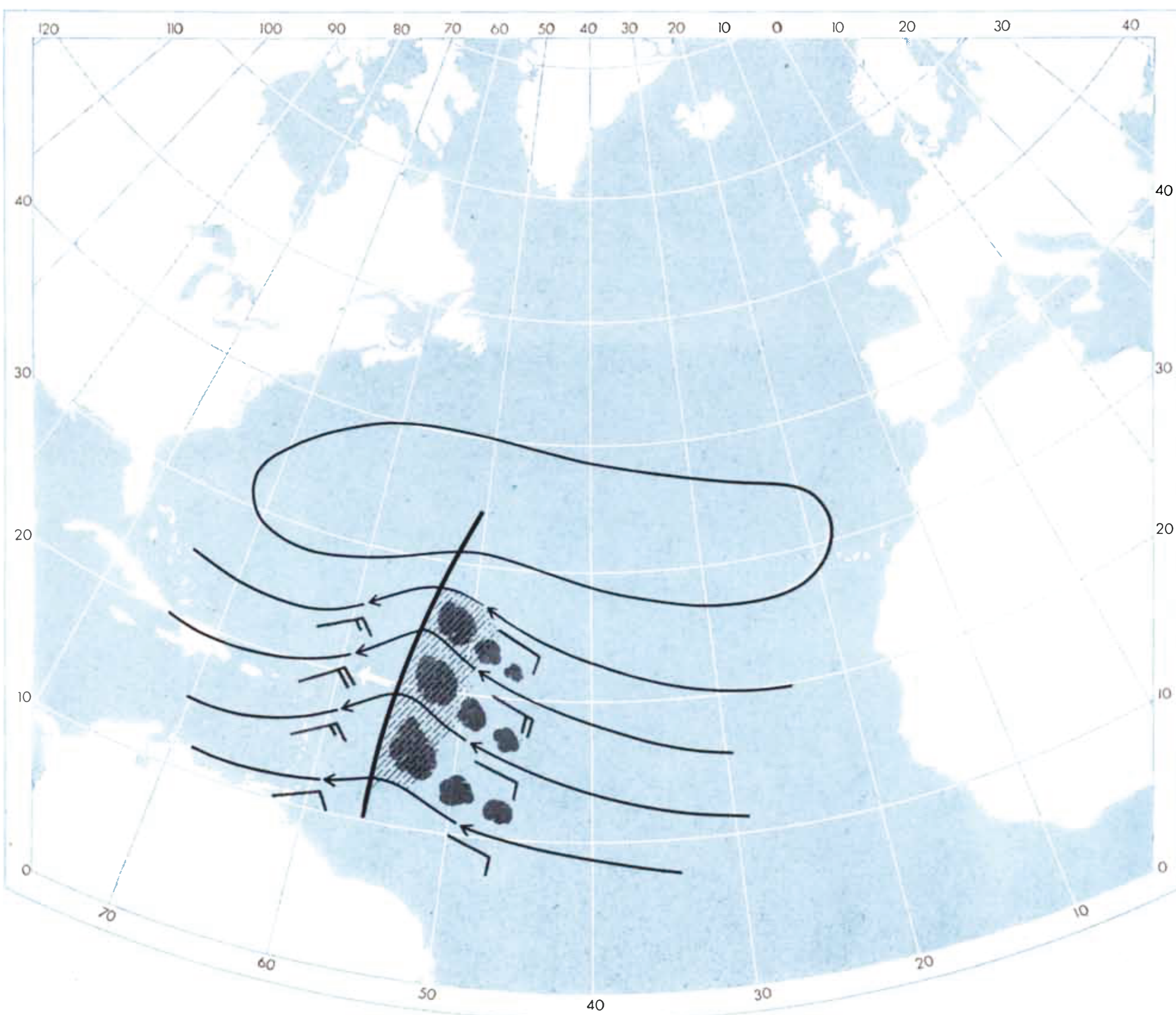


CUMULUS CLOUDS are a characteristic feature of an ordinary day in the Caribbean. In this photograph, made from a PBY aircraft of the Woods Hole Oceanographic Institution, the trade wind blows from left to right. The tallest clouds rise about 6,000 feet.

meteorologists have discovered that the air aloft is far more disturbed than one might guess at ground level. In fact, the situation in the tropical regions is just the reverse of the familiar picture in our so-called temperate zones. Our wind flow is variable near the ground and comparatively steady at high altitudes; in the tropics it is steady below and variable aloft. Storms are almost as frequent in the tropics as in our proverbially fickle climate, but they have a different character and develop in a different way.

Our middle latitudes are a battleground of cold and warm air masses. Clashes between these masses form great rotating cells of air, which bring dramatic changes of air flow and temperature at the ground when they pass over a given area. Thus in our latitudes the winds may shift suddenly and may blow from any direction. We broil or freeze or enjoy days of balmy weather—depending upon what corner of the moving battlefield we find ourselves in at a given time. At the front between contrasting air masses there may be a temperature difference of 50 degrees or more within 100 miles. It is the energy supplied by these clashes between masses of sharply different temperatures—"potential" energy released by the sinking of the cold air and the rise of the warm—that powers our storms.

In the tropics conditions are entirely different. The lower air, up to about 8,000 feet, is a single, homogeneous mass covering thousands of miles of warm ocean. The wind blows steadily and uniformly from east to west. The energy that generates storms comes not from clashes of air masses but from the evaporation of water from the warm seas, storing latent heat in vapor form [see "Trade-Wind Clouds," by Joanne Starr Malkus, SCIENTIFIC AMERICAN, November, 1953; and "Hurricanes," by R. H. Simpson, June, 1954]. The vapor is pumped high into the atmosphere in cumulus clouds. When the clouds rise to great heights—10,000 to 20,000 feet or more—the vapor may condense into heavy rains and thus re-



EASTERLY WAVE is a deflection of the trade winds. The map at left shows the deflection at the surface. The heavy black line indicates the trough of the wave; the long arrows and barbed symbols, the deflected winds. Each short barb (the long barbs consist of two

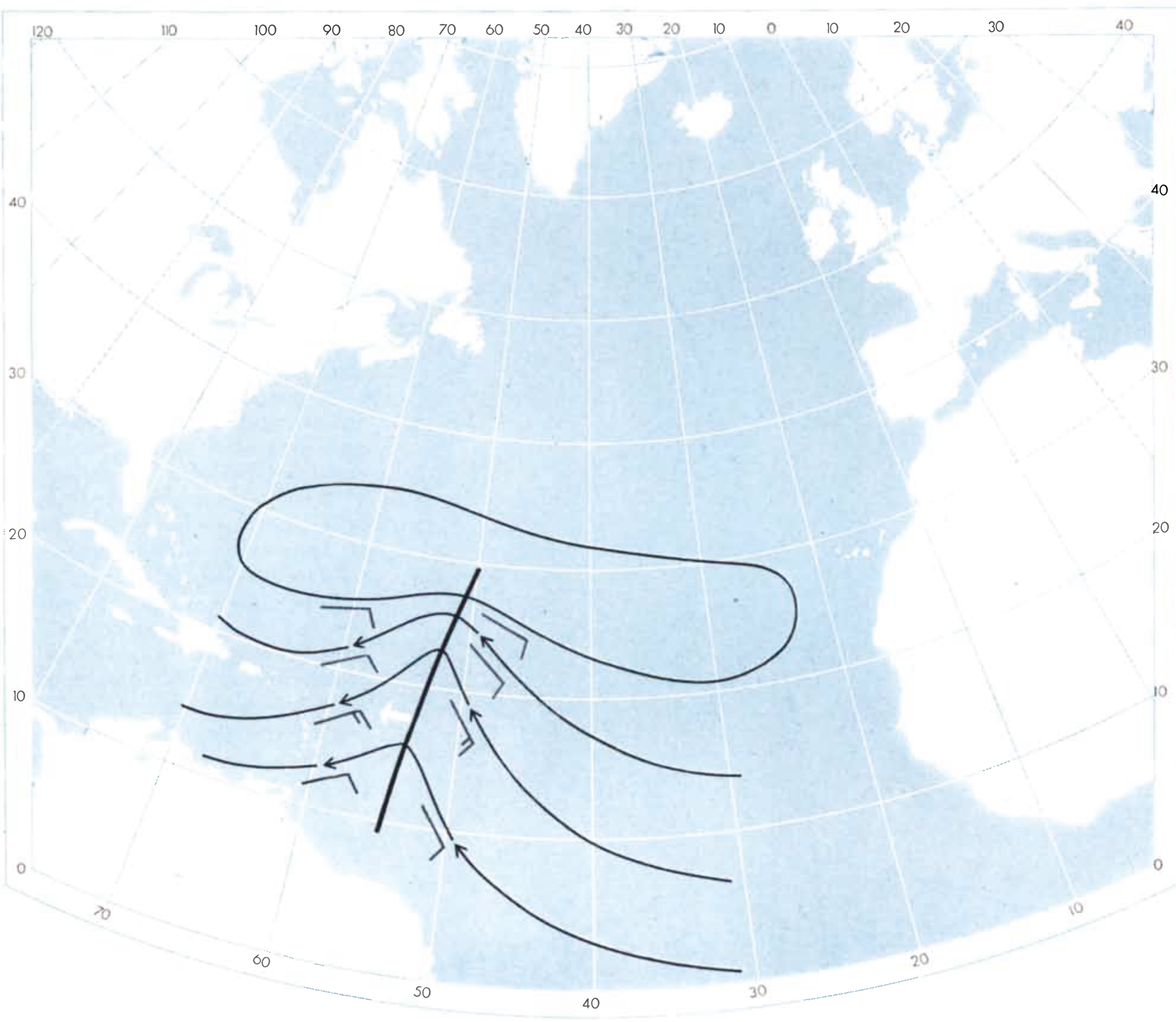
lease large amounts of the latent energy.

The upper air in tropical regions is extremely restless. Winds may blow from any direction, and often great wavelike disturbances, as much as 1,000 miles across, sweep through the trade-wind current. It is from these disturbances that hurricanes develop. However, while the wavelike disturbances occur frequently, hurricanes are comparatively rare. Thus the real puzzle for meteorologists is not why the tropical regions produce hurricanes but why they produce so *few* hurricanes!

The vast frontier of the tropical atmosphere has been explored intensively since World War II, by means of ships, aircraft, radiosonde and radiowind stations and all the apparatus of modern meteorology. The U. S. Weather Bureau, the Woods Hole Oceanographic Institution, the University of Chicago and other groups have collaborated in a big project to learn the cause and development of hurricanes. There are no final answers yet, but many of the pieces of the puzzle are beginning to fit together.

One of the first clues, discovered by careful study of weather records, is that the notion about regular rainfall in the tropics is a myth. Significant rains are not daily occurrences and are apt to be concentrated within one or two periods in a month. This suggests that the rains stem from systematic disturbances of the upper atmosphere. As I have mentioned, severe storms are fairly frequent in the tropics. During the summer one or more major disturbances is constantly brewing in the Caribbean. Yet at most only one in 10 of these grows up to be a hurricane. Why so? What is the particular set of conditions necessary to hatch a full-fledged Betsy or Diane? We can best attack the problem by considering step by step just how a tropical disturbance develops.

One of the most important types of summertime disturbances of the wind pattern in the tropics is the wavelike deflection of the trade winds, advancing on a broad front. It is a kind of dent in the trade current, producing shifts in

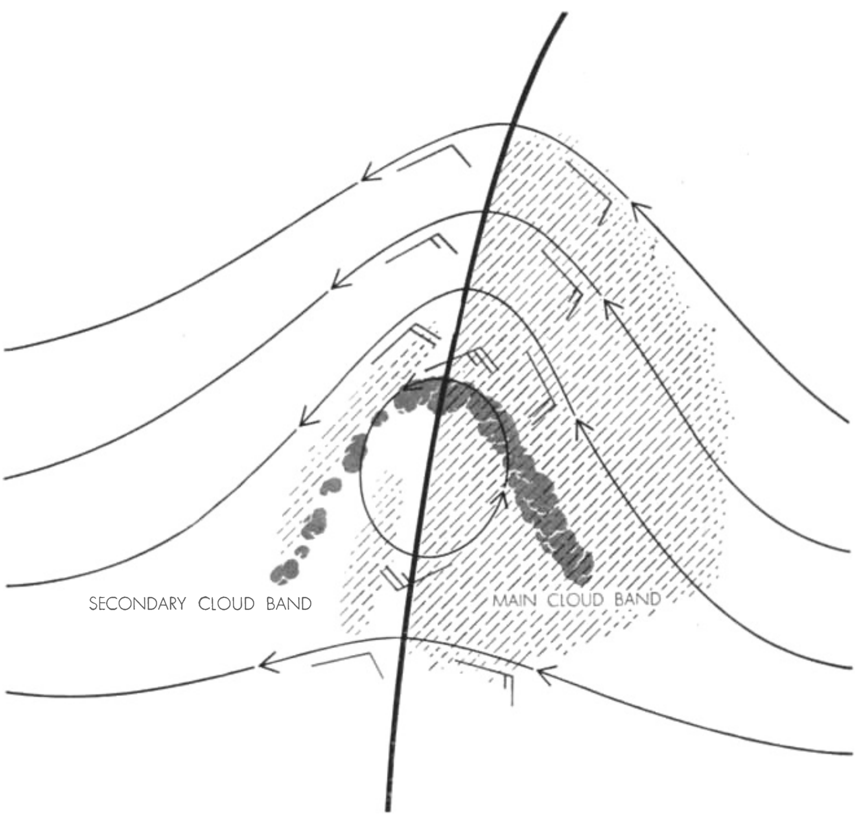


short ones) represents a wind velocity of five miles per hour. Behind the trough it is cloudy and rainy. The closed loop at the upper end of the trough is a high-pressure area. The map at right shows winds of the same disturbance at an altitude of 15,000 feet.

the wind direction: ahead of the wave the trade wind blows slightly north of east; behind it, slightly south of east [*see diagram on page 34*]. In advance of this eastward disturbance (known as the "easterly wave") the weather is unusually clear, but in its train come thick clouds and rain. The reason is that the wave wipes out the boundary (called the "trade-wind inversion") which normally divides the moist lower air from the dry upper air at a level of around 6,000 to 10,000 feet in the tropical atmosphere. Moist air therefore funnels up as high as 50,000 feet. In this moist air cumulus clouds can grow to towering heights and become raining thunderheads [*see lower diagram on opposite page*].

This suffices to account for a rainstorm, but the main ingredients of a hurricane are still missing. We need a vortex for the storm. And we find it making its entry at the next stage of intensity in tropical storms. Above about 30,000 feet the steady trade winds peter out and, as we have noted, the tropical atmosphere becomes turbulent and variable. Here we find cyclones and anticyclones—great eddies of air like those of temperate latitudes, except that in the tropics they float above instead of below the prevailing winds of the region. If an anticyclone happens to drift across an easterly wave, it begins at once to intensify the disturbance. The anticyclone pumps air outward from the eddy at high levels, and air is therefore pulled into the storm at its bottom. The pressure at the center of the cyclone drops. As a result of the inflow of air and the earth's rotation, the spin of the cyclone speeds up and it becomes a closed vortex with winds of 35 to 45 miles per hour. A large cloud band develops, extending southeast from the vortex, and often many secondary cloud bands [*see diagram below*]. Squalls and thunderheads multiply; the rain intensifies; showers break out ahead of the advancing disturbance.

The storm now has many of the features of a hurricane. Will it inevitably grow into one from this stage? The answer is no. More than half of these storms, even with the developed vortex, come to an ignominious end within a few days. Something more is necessary to make a hurricane.



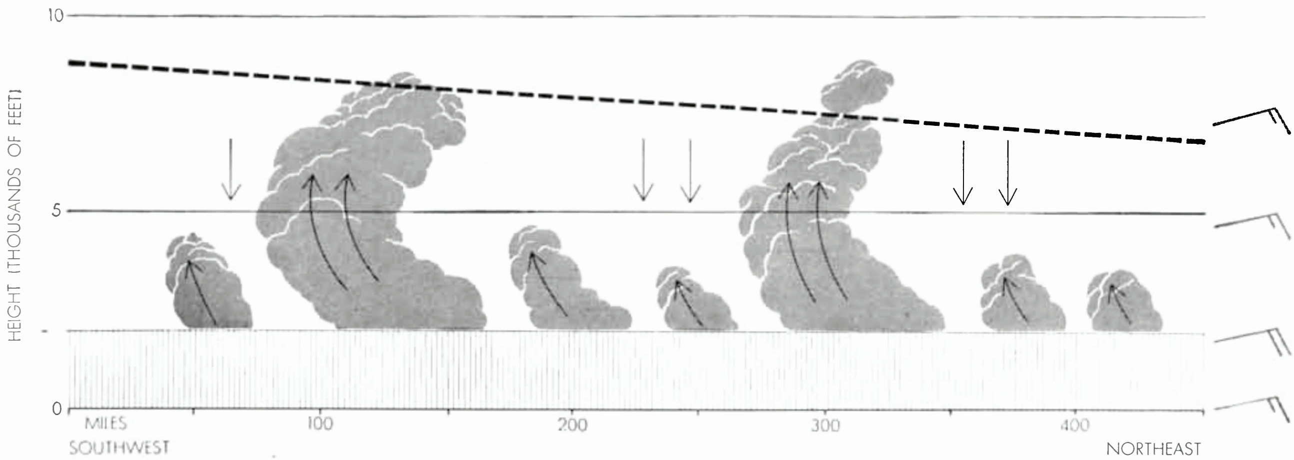
VERY DEEP EASTERLY WAVE, mapped in the same way as the wave on the preceding two pages, develops a central vortex (*closed loop*). The hatched area is cloudy and rainy.

Let us look at a hurricane itself to see if we can find any distinguishing features. We find one clear clue in the temperature of the core. In a storm of the kind just described, the core is a little colder than the surroundings; in a hurricane, on the other hand, it is warmer. The more vicious the storm, the warmer its center; some Pacific typhoons are 10 to 15 degrees F. warmer than the environs at high levels. A warm core seems to be crucial to development of a hurricane for two reasons: (1) because the inflow into this center of less dense air at the bottom permits the vortex to wind up to high speed, and (2) because at high levels the warm air of the center has a higher pressure than the surroundings and therefore flows out of the core, allowing the circulation of the vortex to continue unimpeded.

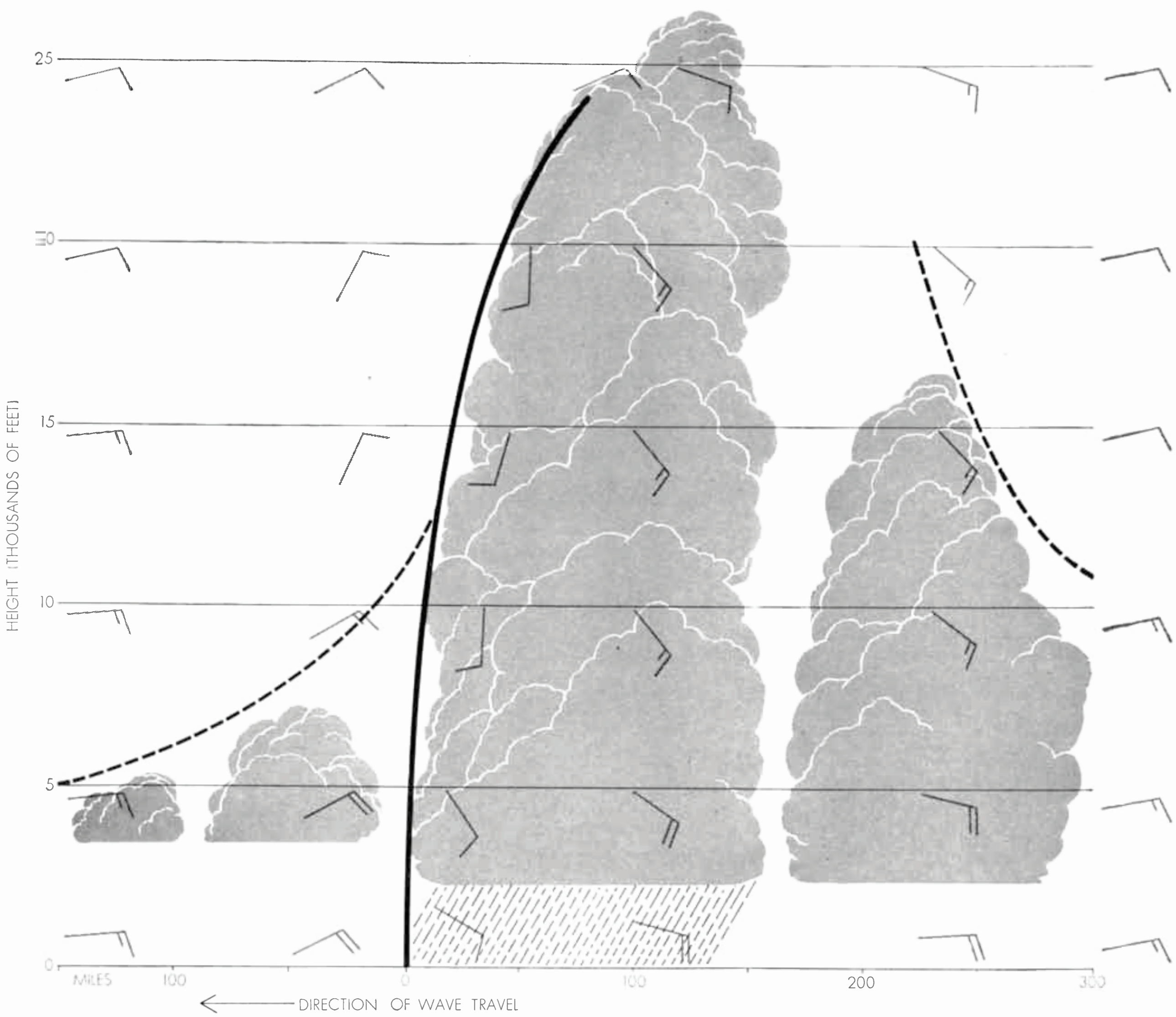
What produces a warm core? We know that the basic source of energy for tropical storms is the latent heat of water vapor, released when the vapor condenses. It seems logical to assume that this process—moist air rising from the sea and condensing into cumulus clouds—is responsible for the warming of a storm core. But the process will not go very far if the moist air is diluted with drier, cooler air as it rises. The clouds rise to great heights only when the warm, wet air is funneled upward without much mixing with dry air. A disturbance such as an easterly wave, as we have seen, raises the roof of moisture and permits the clouds to build up to towering heights. In most cases, some cool, dry air is drawn into the rising air column from the surroundings. It is only when all or nearly all of the air ascending to the cloud tops has risen from the moist base that we get a warm core.

Is the storm now ripe? Do we invariably get a hurricane under these conditions? Again the answer is, not necessarily. We have arrived at a condition which is probably necessary but not sufficient. The core is not yet warm enough: it may be five or six degrees warmer than the surroundings, but in a hurricane it is 10 to 15 degrees warmer. An additional warming mechanism seems to be required. This is probably where the famous "eye" comes in.

The eye of a hurricane is its most remarkable feature. Within the wall of towering thunderheads and raging squalls is an oasis of calm 10 to 30 miles across—often sunny and completely free of clouds. This eye plays a vital role in the formation and maintenance of a hur-



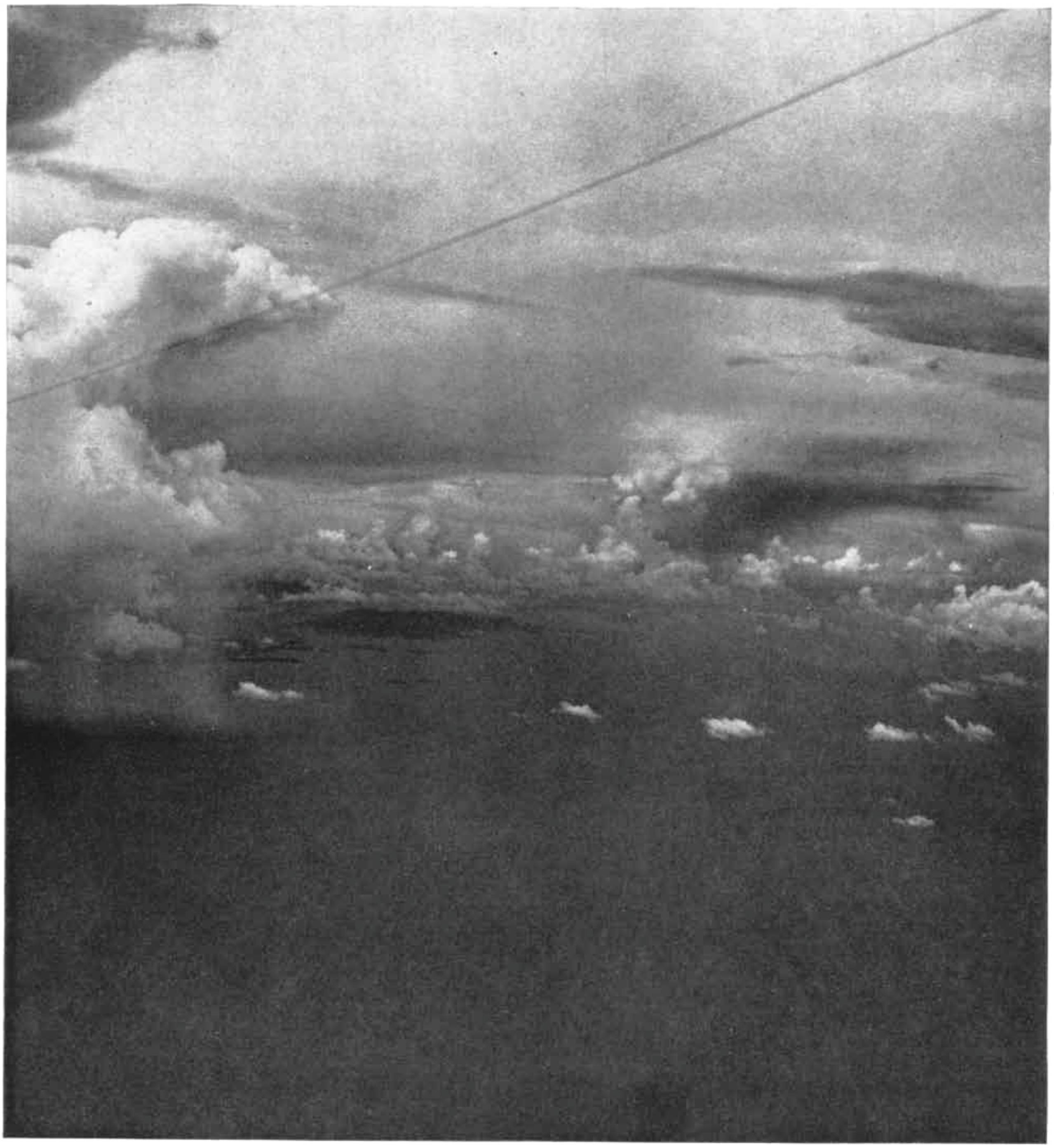
NORMAL CUMULUS CLOUDS of the tropics are shown in cross section. The broken line at the top of the clouds marks the trade-wind inversion, which divides the moist lower air from the dry upper air. Scale of clouds on this page is greatly exaggerated.



EASTERLY-WAVE CUMULUS CLOUDS are similarly represented. The trough of the wave is indicated by the heavy, curved vertical line. The wave destroys the inversion layer, permitting the clouds to ascend more than 20,000 feet and become thunderheads.

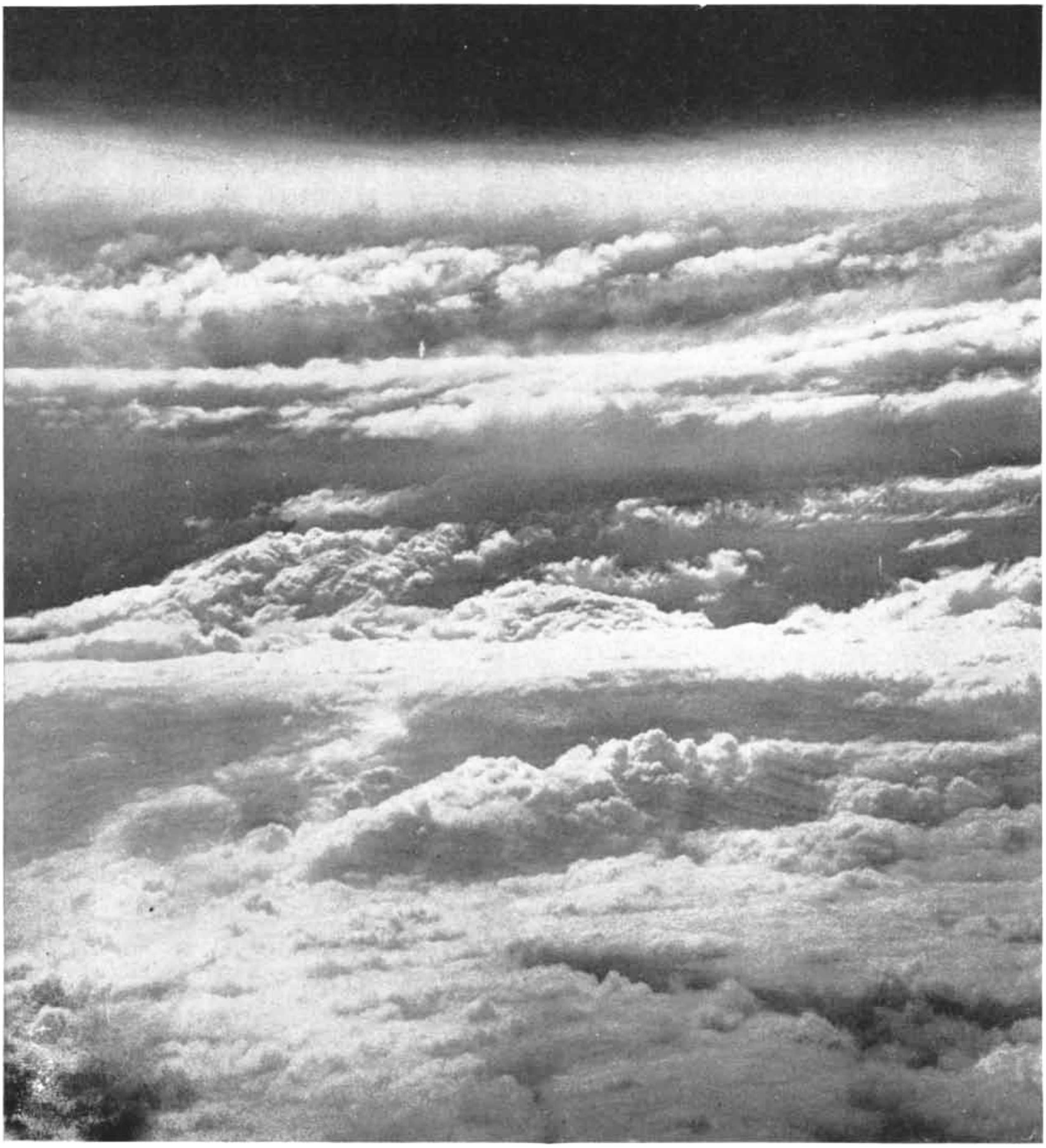
ricane. Here the air is falling instead of ascending, and, as it sinks, the increasing pressure of the surroundings squeezes and warms it. The air descending in the eye probably is thrown out again into the rain band at low levels by centrifugal force, so that more air falls in from the top. It seems that this downflow of warmed air is the ultimately essential condition for a hurricane. Without it the temperature of the core cannot reach the necessary levels and the winds cannot exceed about 45 miles per hour. But once an eye has been formed and its associated air-warming process has begun, the storm is on the way to developing the phenomenally low pressures characteristic of a hurricane. This is the "point of no return"; the storm will now start its baleful career—and acquire a girl's name. The wind velocities may rise to hurricane fury within a few hours; the closed central vortex takes over from the easterly wave as the dominant driving force of the air in its path.

Just how the eye is formed is still unknown. The question involves a whole



CENTER OF DEEP DISTURBANCE which failed to become a hurricane was photographed from the Woods Hole PBY in 1956. The clear area in the center suggested the eye of a hurricane in the process of formation. Puerto Rico lies beneath clouds on horizon.

complex of detailed studies: the structure of the air surrounding the storm, air flows, cloud formations, features of the upper atmosphere and probably many other factors. The various groups cooperating in the Weather Bureau's National Hurricane Research Project have undertaken such explorations. The Woods Hole Oceanographic Institution and the University of Chicago are jointly analyzing the entire history of an extraordinarily deep tropical disturbance of 1956 which did not develop into a hurricane. Although the research is still incomplete, preliminary results suggest that this storm kept a cold core even though it had a calm, "eyelike" central region. Apparently the moist air rising in the vortex wall flowed out of the core in a disorganized fashion and at relatively low levels. One or more of the links in the complex chain of events that makes a hurricane were missing. Just what these are we hope eventually to discover and relate in a physical model, connecting an evolving storm with the tropical atmosphere as a whole.



EYE OF PACIFIC HURRICANE Typhoon Marge was photographed in 1951 from a National Hurricane Research Project aircraft flying at 15,000 feet. The eye is surrounded by a wall of cloud which slopes away with altitude. Within the eye the sky is clear.