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THE HURRICANE

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THE HURRICANE

By I. R. TANNEHILL, *associate meteorologist, Forecast Division, Weather Bureau*

INTRODUCTION

The word "hurricane", signifying "big wind", is of Carib Indian origin. It has come into general use as the name for any tropical cyclone of the Atlantic Ocean, Gulf of Mexico, Caribbean Sea, Eastern Pacific (off Central America and Mexico), and Southern Pacific. It is identical with the typhoon of the China Sea, the baguio of the Philippines, and the cyclone of the Bay of Bengal and other portions of the Indian Ocean. One must avoid, however, confusing this name of an entire storm with the term "hurricane wind" (12 on the Beaufort scale), almost universally used at sea to designate any wind, from whatever cause of 75 miles or more an hour.

Tropical storms vary greatly in intensity, but to most people the word "hurricane" implies destructive winds. Therefore it is customary for the Weather Bureau in its hurricane-warning service to use the word hurricane only when the storm is of great violence. Less severe storms of the same regions are described as "tropical disturbances", with appropriate modifying words, such as slight, moderate, considerable, etc., to indicate the intensity.

In the discussion which follows, the word "hurricane" is employed in its technical sense to mean a storm of tropical origin with cyclonic wind circulation, and refers more specifically to those which occur in the

North Atlantic Ocean, the Gulf of Mexico, and the Caribbean Sea.

The principal world regions of tropical cyclones are indicated in figure 1.

HISTORY

Although the history of these storms extends back to the time of the voyages of Columbus to America, the earlier records are fragmentary. As the islands of the West Indies, the shores of the Gulf of Mexico, and the South Atlantic coast of the United States became more densely populated, hurricanes were more often mentioned. A study of these early accounts leads to the conclusion that the frequency of hurricanes, their intensities, and movements, while variable from year to year, have not undergone any pronounced changes within the period of record.

Definite information as to the paths followed by storms of the West Indies and contiguous regions was first obtained in the early part of the nineteenth century. William Redfield plotted the paths of many of them. Also William Reid, who became interested in tropical storms in 1831, after examining the ruins on the island of Barbados caused by the hurricane of that year, secured numerous observations and determined the courses followed by a number of such storms. The earliest hurricane studied by Reid occurred in

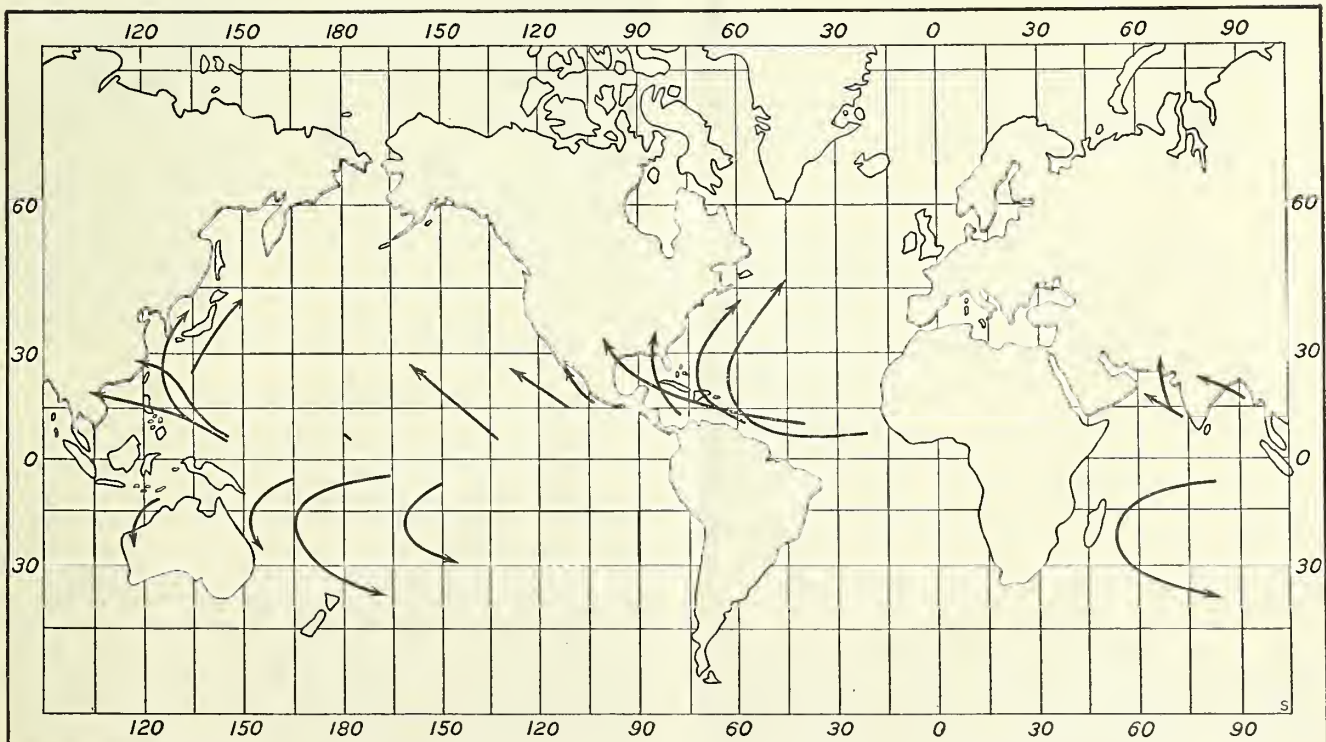


FIGURE 1.—Arrows indicate the principal world regions of tropical cyclones and, roughly, their direction of movement.

1780, and therefore our definite records as to the movements of individual storms of this kind cover more than 150 years. The course of the "Great Hurricane" of 1780 as plotted by Reid is shown in figure 2.

With the establishment of meteorological stations in the West Indies during the Spanish-American War and the development shortly thereafter of wireless communication with ships at sea, there was considerable improvement in the work of charting tropical storms for forecasting purposes. Coastal and island stations obviously afforded meager information when the storm was located some distance from land, though when the mail reports from ships arrived, it then was possible to trace a storm's path with considerable accuracy. Hence, our hurricane records may be considered fairly complete for a period of nearly 50 years.



FIGURE 2.—Track of the "Great Hurricane" of October 1780. Small circles indicate approximate noon positions on dates near circles. (After Reid.)

CAUSES

Aside from the information gotten by observations at the earth's surface, not much is definitely known of the structure of a hurricane, though a good deal may reasonably be inferred. Certain conditions which exist almost universally at the surface during the formative period of a hurricane, namely, frequent showers, light winds, and warm, moist air, are thought to be necessary for its development. The heat liberated in heavy convectional showers is generally believed to be the energy that starts the storm. Once the ascending currents are established on an extensive scale with the attendant inflow of warm, moist air, condensation takes place in amounts sufficient to account for the maintenance of a storm of great intensity.

FORMATIVE STAGES

While the causes of hurricane development are largely theoretical, the weather conditions existing at the earth's surface during the genesis of a hurricane are fairly well known, at least for the western Caribbean.

Coincident with the establishment of convectional showers over the given region, atmospheric pressure there begins to fall, and a very gradual inflow of air takes place. Because of the effect of the earth's rotation, the winds, which otherwise would blow directly toward the storm center, are deflected to the right, in the Northern Hemisphere. A cyclonic system, with winds directed around but inclined inward, is thus established. This takes place over a considerable area, usually involving thousands of square miles, and not in the form of a small whirlwind or water spout, as many persons seem to believe. Observations during formation of a hurricane are shown in figures 3, 4, 5, and 6.

Some of these cyclonic disturbances develop quickly into violent tropical storms; others increase in force much more slowly; while many become no more than mild wind systems with unsettled weather.

On the daily weather map the incipient tropical storm sometimes appears first as a deflection of the wind from its prevailing direction for the season, or a slight lowering of atmospheric pressure which causes a loop or other irregularity in the isobars, or lines joining places with the same atmospheric pressure.

PLACES OF ORIGIN

Hurricanes are known to develop in the belt of doldrums in the southern North Atlantic Ocean and also in the western Caribbean Sea when the Pacific doldrum belt extends northward and eastward into that area. However, many tropical storms of the Gulf, Caribbean, and southern North Atlantic have not with certainty been traced to a place of origin, and it cannot be said with assurance that they do not develop occasionally in other areas.

The belt of doldrums in the southern North Atlantic is farthest north in August and September, extending from the region south of the Cape Verde Islands west-southwestward to the South American coast. Nearly all the hurricanes of the Cape Verde region develop during those 2 months. The Pacific doldrum belt extends into the western Caribbean Sea in the early and latter parts of the hurricane season, June to November, and the tropical storms of that region develop principally in June and October.

The Atlantic belt of doldrums does not extend south of the Equator, and no tropical cyclones have been known to develop in the South Atlantic Ocean. These facts support the theory that such storms originate almost exclusively in the belt of equatorial calms, or doldrums. The prevailing winds and the doldrums of the Atlantic Ocean are shown in figure 7.

PROGRESSIVE MOVEMENT

Soon after the cyclonic circulation is established and the winds begin increasing in force, the disturbance, as a whole, starts to move. Thus there are two movements to be considered, (1) the winds directed around and inward toward the center of the cyclone, and (2) the forward movement of the entire wind system. The circulatory movement in the fully developed hurricane is violent, the velocities of the wind approaching and sometimes considerably exceeding 100 miles an hour. The progressive movement of the entire system while in the Tropics averages only about 12 miles an hour. If the progressive movement is, say, 10 miles an hour, it will require 5 days for the storm to move forward

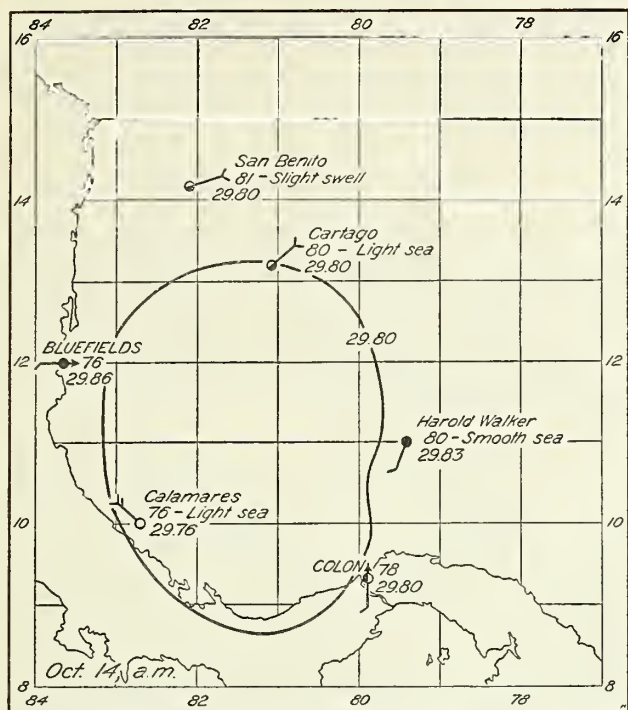


FIGURE 3.—Pressure and wind conditions at 7 a.m. October 14, 1926, showing gentle cyclonic (counterclockwise) wind circulation of incipient disturbance. Arrows fly with the wind, e.g., the *Cartago* reported wind from the northeast. The number of bars on arrow indicates wind force, Beaufort scale. Small circle at head of arrow indicates state of weather; open, clear; half black, partly cloudy; black, cloudy; two dots beside circle, raining.

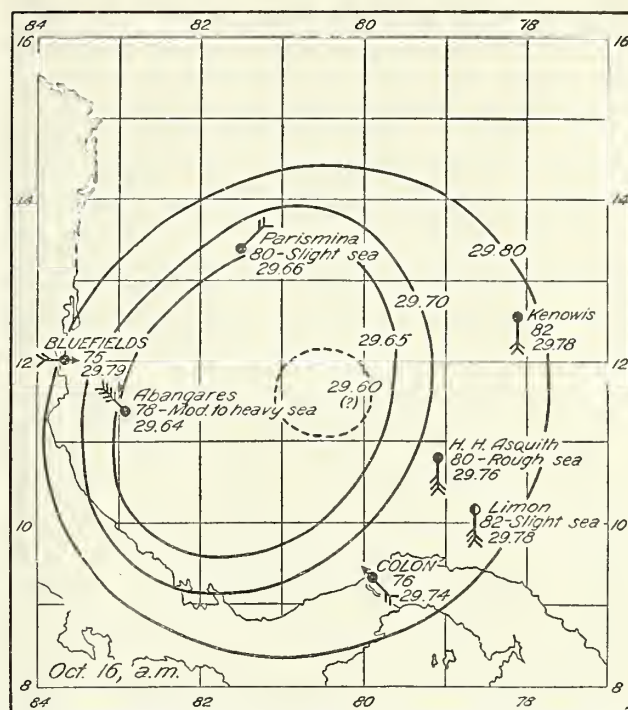


FIGURE 5.—Pressure and wind conditions at 7 a.m. October 16, 1926. The winds have increased in force and barometric pressure has fallen. The center of the storm is indicated by the broken circle. On that day the *S.S. Parismina* passed directly through the disturbance, with lowest barometer reading 29.53 inches at approximately latitude 12° north and longitude 81° west.

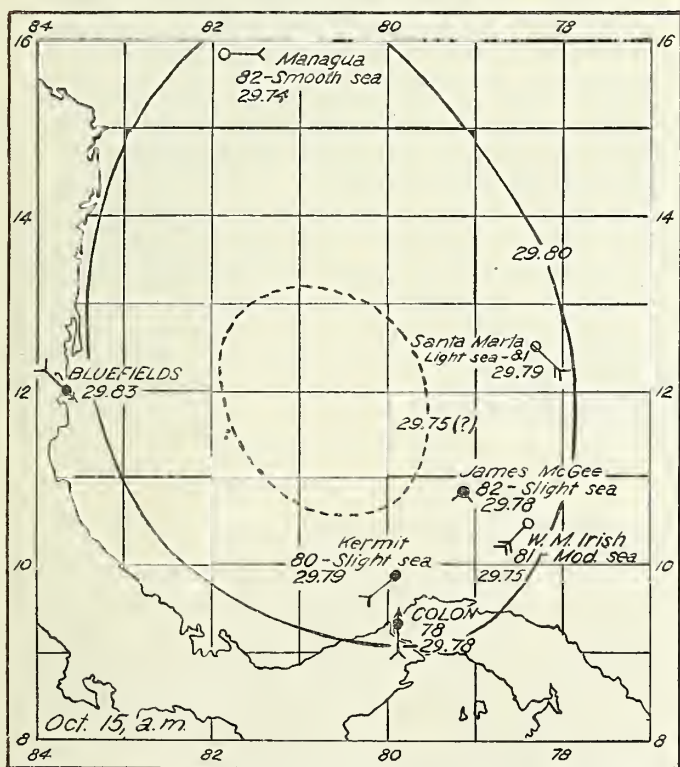


FIGURE 4.—Pressure and wind conditions at 7 a.m. October 15, 1926. Somewhat lower barometric pressure and slightly more vigorous wind circulation are in evidence. Probable central area is indicated by dotted line. Effect of the winds on the sea is shown on this and succeeding maps. Wind of force 4 is reported by the *W. M. Irish*, and the wind is steadily increasing at Colon and Bluefields.

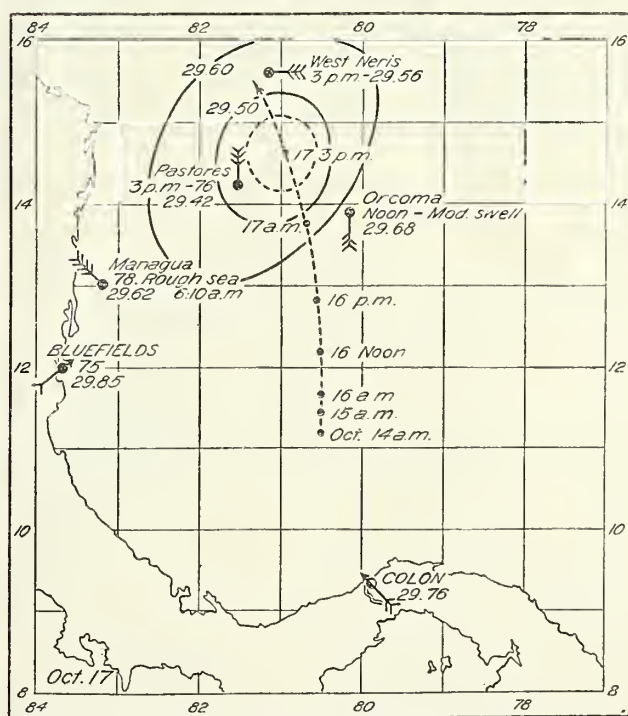


FIGURE 6.—Wind and pressure conditions on October 17, 1926, and track of the center of the disturbance. Black dots in track indicate positions of the center at the time given. The disturbance thereafter increased rapidly in intensity and passed over Habana and Bermuda with winds of full hurricane force. (Fig. 3, 4, 5, and 6 after F. G. Tingley.)

1,200 miles, even though the winds about the center have velocities of 100 miles an hour.

Nearly all of the storms which originate in the Cape Verde region first move in a westerly direction over the Atlantic and later recurve in a northerly or northeasterly direction. Some of them reach the West Indies or southern coasts of the United States before changing to a more northerly course. Others, which have been first observed in the Atlantic between the West Indies and the African coast, and a few definitely known to have formed in the Cape Verde region, continue westward to the coasts of the United States or Mexico, pass into the interior, and finally dissipate without recurving. Examples of tracks with and without recurve are shown in figure 8.

Hurricanes which form in the western Caribbean Sea in June and July generally pass northward or northwestward into the Gulf of Mexico and reach the coasts of the United States or Mexico. In September and early October they are likely to take much the same course, but in late October and November the majority recurve rather sharply, passing out to the northeastward over southern Florida or the Greater Antilles. Average movements vary somewhat with the season, as will be seen by an examination of the accompanying charts.

During the recurve, many tropical storms move very slowly, and some remain almost stationary for a day or more. After the recurve, which usually takes place at or a little south of 30° north latitude, the storm generally moves off in a direction between north and east with increasing speed, sometimes at a rate of 40 to 50 miles an hour in higher latitudes.

The generally accepted explanation of these movements is that the storms drift with the air masses in which they lie. At the surface of the earth the general circulation of the winds is from an easterly direction in the Tropics and, roughly, from west to east in middle and higher latitudes. South of about 30° north latitude the prevailing direction of storm movement is toward the west or northwest, but as the

storm progresses to about that latitude it comes under the influence of the prevailing circulation from west to east and usually recurves, its movement thereafter being toward the north, northeast, or east. There are, however, many exceptions, as will be seen from an examination of the track charts.

IRREGULAR MOVEMENTS

The characteristic curved path followed by many hurricanes has been described as parabolic. However, there are no fixed or average paths, and many courses followed by hurricanes have been quite irregular. Probably abrupt changes in their directions of movement are due mainly to the influence of anticyclones passing to the northward of the hurricane belt.

On the daily weather map two general classes of wind systems are shown, the anticyclonic or "high" and the cyclonic or "low." The hurricane, as stated above, belongs to the latter general class. In the Northern Hemisphere the winds of the anticyclone are directed clockwise about the center of the isobars, or place of highest pressure, and those of the cyclone counterclockwise about the place of lowest pressure.

When an anticyclone, or "high", comes into the region toward which the hurricane is moving, or into adjacent areas, its wind system affects the general circulation at the surface and for an indefinite distance above the surface. These effects extend into subtropical latitudes at times when hurricanes are in progress and deflect them from the course which would normally be anticipated. Likewise, the passage of low-pressure systems or extratropical cyclones to the northward is believed to influence the direction of the hurricane's movement, especially if low pressure extends well to the southward. Such occurrences explain a considerable number of the loops, abrupt turns, and unusual movements of hurricanes (fig. 9) as shown on the track charts.

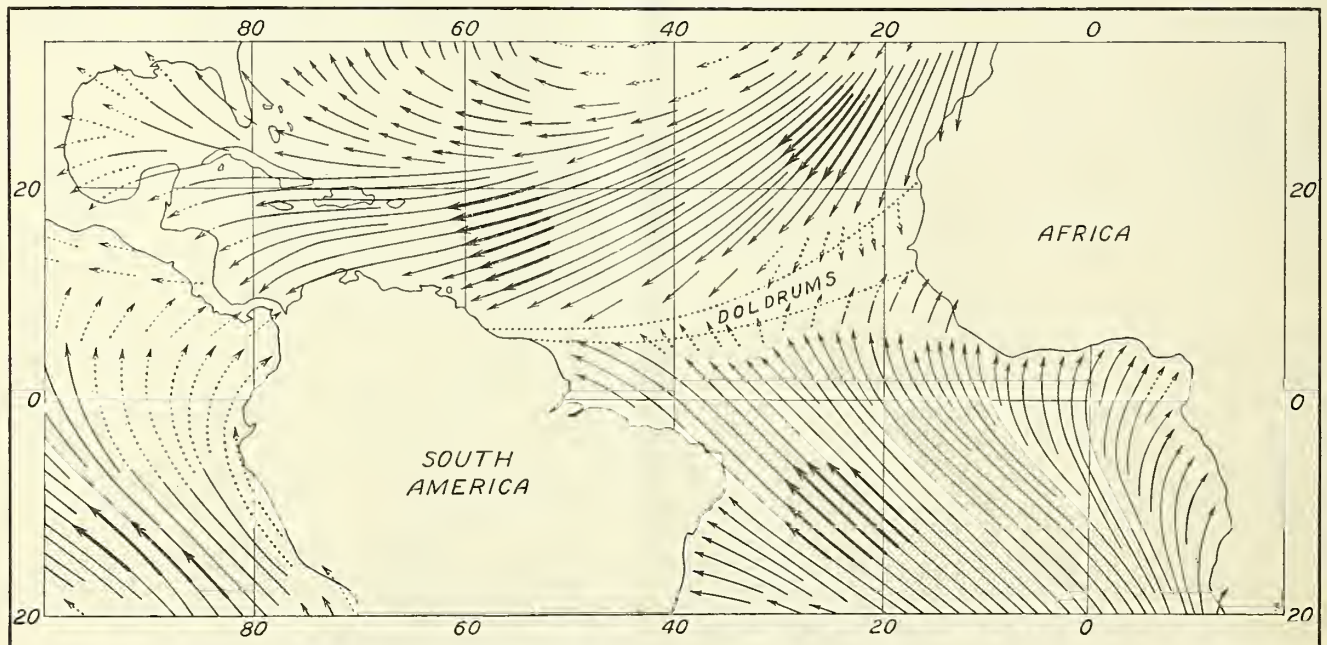


FIGURE 7.—Winds over the Atlantic Ocean in July and August, showing belt of doldrums. (After Bartholomew.)

HURRICANE WINDS

The wind system of the hurricane is more or less circular. When it passes over a given locality, the winds do not begin abruptly, but increase gradually.

At the outer limits of the hurricane the winds are only moderate breezes, though characteristically gusty and fitful. They increase in force as the center approaches, though the highest winds are not at the exact center but generally from 5 to 15 miles, and sometimes even farther, therefrom. Records indicate that these strongest winds often reach and, for 5 minutes or more, maintain velocities of 75 to 100 miles per hour, and occasionally even 125 to 150 miles per hour, with gusts of still greater velocities. The measurement of such winds obviously is attended with great difficulties. In many instances the anemometers have been destroyed by the winds and flying debris, or the towers or supports have been blown down before the highest wind occurred.

At the center of a tropical cyclone there is an area known as the "eye of the storm", where there is little or no wind. In this central area the sky sometimes clears so that the sun is visible by day and stars by night. The temperature in some cases rises and the air becomes drier. At sea the waves in the "eye of the storm" commonly are described as mountainous and confused. Birds, exhausted in the battle with hurricane winds, reach the center of the storm and alight or fall upon the decks of ships. All around this relative calm is the encircling wall of hurricane winds, which produce a rumbling or roaring sound. The diameter of the relatively calm center is not the same in all storms and may be as little as 7 miles, or less, but is rarely more than 20. It averages about 14 miles.

When the calm center, or "eye", of the storm passes over a place, the calm is *preceded* by winds of great violence from one direction and is *followed* by winds nearly equally violent from the opposite direction. Thus, if the hurricane approaches from the east, the wind blows first from a northerly direction and, after the passage of the calm center, hurricane winds come from a southerly direction. This calm center gives rise to the belief that the "storm came back", whereas it was only the opposite side of the whirl. Ignorance of the calm-center characteristics has resulted in death or injury to many people, because, believing the storm over, they left places of protection and thus exposed themselves to violent winds which began abruptly after the calm center passed.

BAROMETRIC PRESSURE

Normally, in tropical and subtropical regions frequented by West Indian hurricanes, the barometer reads about 30 inches at sea level. As the hurricane approaches, the barometer falls, slowly at first and then more rapidly as the center draws near. The rate of fall depends upon the depth of the barometric depression in the storm and the rate at which it approaches. In fully developed hurricanes the barometer nearly always falls below 29 inches (sea level), and there are many records of readings below 28 inches. There are a few records of barometric pressure at the center of tropical cyclones of about 27 inches, and one instance, the lowest of record, on board a ship in a typhoon, as low as 26.19 inches (886.8 millibars). In the United States the lowest

pressure recorded in a hurricane at a regular Weather Bureau station was 27.61 inches at Miami, Fla., in September 1926. A lower pressure, 27.43 inches, was recorded at West Palm Beach, Fla., in September 1928, on a correctly verified barometer which was not the property of the Weather Bureau. Changes in barometric pressure and other meteorological conditions at San Juan, P.R., in a hurricane, are shown in figure 10.

The difference in barometric pressure between two places is known as the "gradient," and the force of the wind is directly proportional to the steepness of the gradient. The rate of fall in pressure as the storm approaches is dependent upon the steepness of the gradient and the rate of approach.

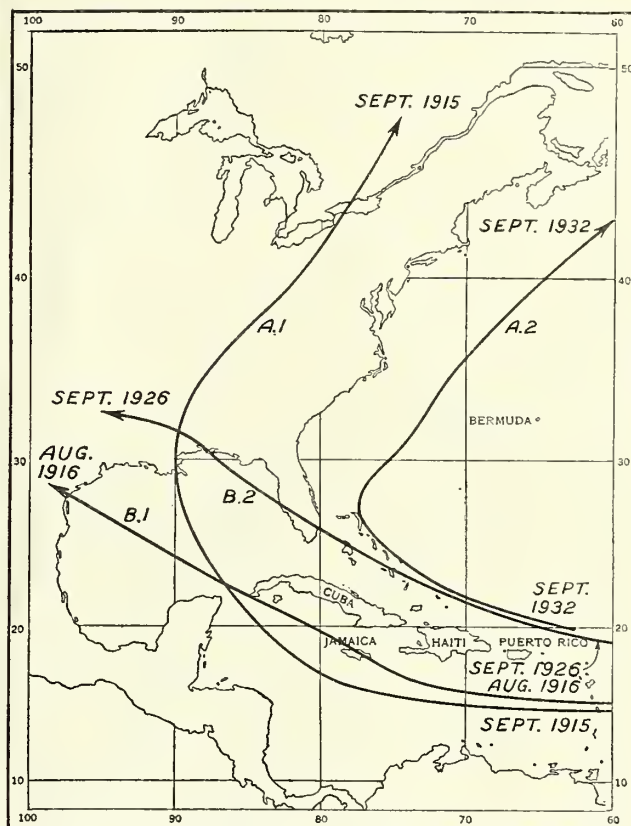


FIGURE 8.—Tracks of centers of hurricanes (A-1 and A-2) with recurve and (B-1 and B-2) without recurve.

RAINFALL

At the outer limits of the storm, rainfall is in the form of showers. As the center approaches, the characteristic squalls of the hurricane begin, that is, the showers increase in frequency and intensity. Nearer the center the rain is heavy to excessive and continuous. Frequently the total amount of rainfall which occurs at any one place during the passage of a hurricane is quite large. Amounts exceeding 30 inches are not uncommon.

In the United States the fall attending a tropical storm has exceeded 20 inches in a 24-hour period. The greatest amount of record, 23.11 inches, fell at Taylor, Tex., in September 1921, within 24 hours. When a tropical storm moves inland it is likely to die out, though in some cases much rain occurs before the storm is wholly dissipated. The record fall at Taylor, Tex., was one of this type.

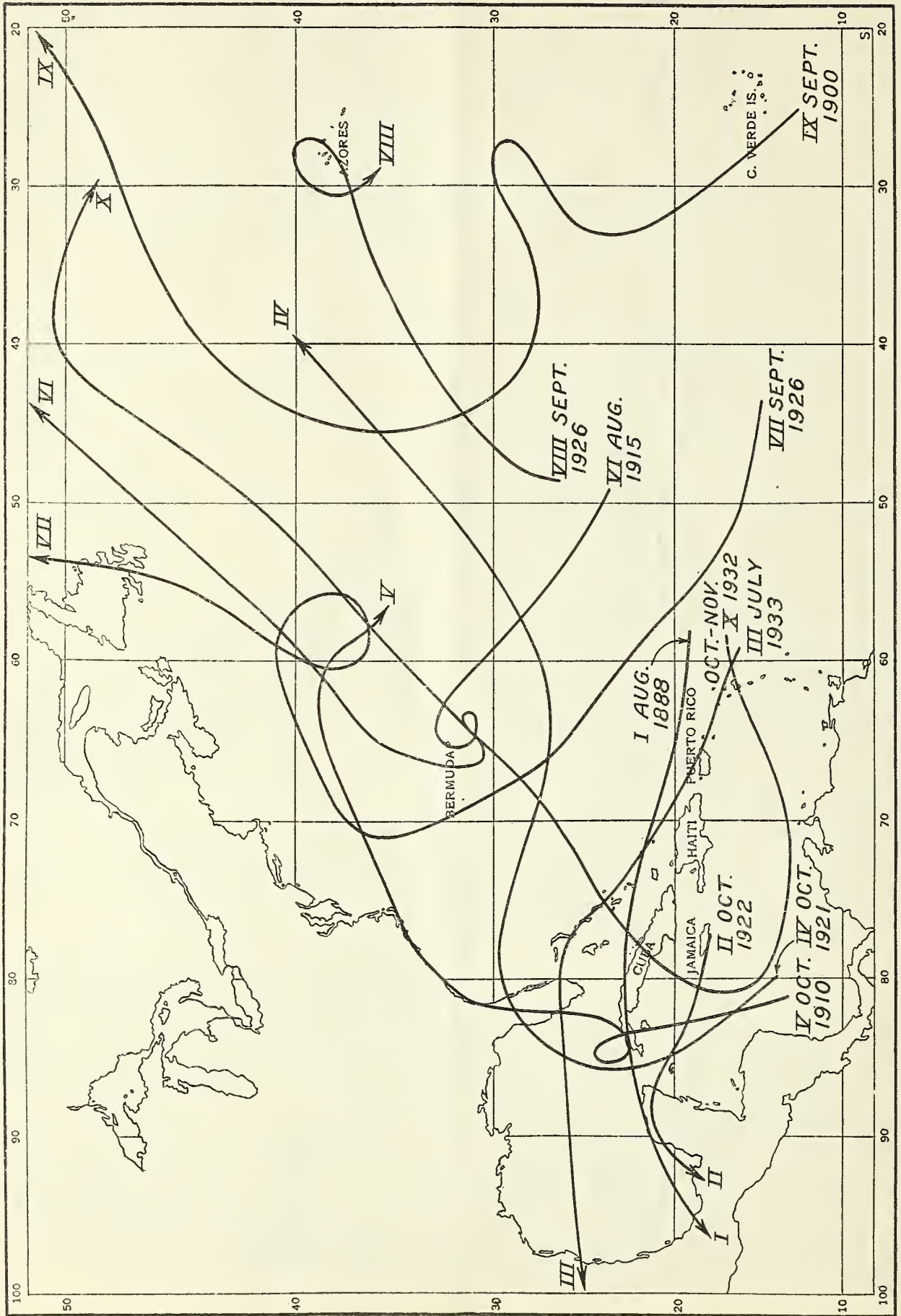


FIGURE 9.—Tracks illustrating irregular movements of hurricanes.

In the case of the hurricanes which reach the South Atlantic and Gulf coasts and move inland a considerable distance, the heaviest rain occurs in the front half of the storm, at least after it reaches land, and usually in the right-front quadrant, while there is less rain, and sometimes very little, in the rear half. But in those which cease to move after reaching land the rainfall is distributed more or less irregularly throughout the storm area. This is usually an indication that the storm is losing intensity and that very high winds are not likely to be a feature of its future progress.

TIDES

Along the coast toward which the hurricane is advancing the tide begins to rise while the storm center is a long distance away. It continues to rise as the storm advances, slowly at first, then more rapidly. If the observer stands on the shore facing the storm center the highest tides will be created on his left and will be highest at and somewhat to the left of the point where the center crosses the coast. At his right the tides will not be so high, and as the center moves inland the water, driven by off-shore winds, may be very low. Along the Gulf and South Atlantic coasts of the United States the highest tides created by hurricanes have ranged from 10 to 16 feet above normal.

The inundations attending hurricanes and other tropical storms have in some instances caused great loss of life and destruction to property. In fact, greater loss of life and property damage have been directly attributable to water than to the force of the winds. Debris from structures wrecked by the waves and carried by the hurricane winds and the advancing water batter other buildings to pieces. Few structures can withstand such an onslaught, especially when the water undermines the foundations.

Other things being equal, a storm of large diameter creates higher tides on the coast than one of small diameter, and a slow-moving storm higher tides than one of rapid progress. In each case the higher water is owing to the greater duration of the drive of the wind on the water in the same direction.

THE LAW OF STORMS

Winds of the hurricane blow around and incline towards the center. Their direction in the northern hemisphere is counter-clockwise (fig. 11). The "law of storms", as enunciated by Buys Ballot, is that the observer standing with his back to the wind will find the storm center on his left. Since the winds have some incurvature, the center will be on his left and slightly to the front.

On the side of the storm where the direction of the winds is the same, roughly, as the progressive movement of the storm, the observer experiences higher winds than on the side where the winds and the progressive movement are oppositely directed. If the observer faces the center of the approaching storm, and the center passes over him, the highest winds will occur in his immediate vicinity and at places to his left.

DIMENSIONS OF THE HURRICANE

In small hurricanes the diameter of the area of destructive winds may not exceed 25 miles, while in some of the greatest the diameter may be as much as 400 to 500 miles. In hurricanes of small diameter the

winds for a relatively brief time rise as high as in great hurricanes and the central pressure is sometimes as low.

The form of the isobars, or lines of equal pressure drawn on the weather map, about the center of the hurricane are more or less circular, and the wind system is closely coincident. In some instances the shape of the hurricane is somewhat elliptical, particularly when it encounters resistance to its progress in the form of high pressure, and the center may be displaced so that the hurricane is unsymmetrical. As a rule, the tropical cyclone approaches much more closely to the circular form than does the extratropical cyclone of higher latitudes.

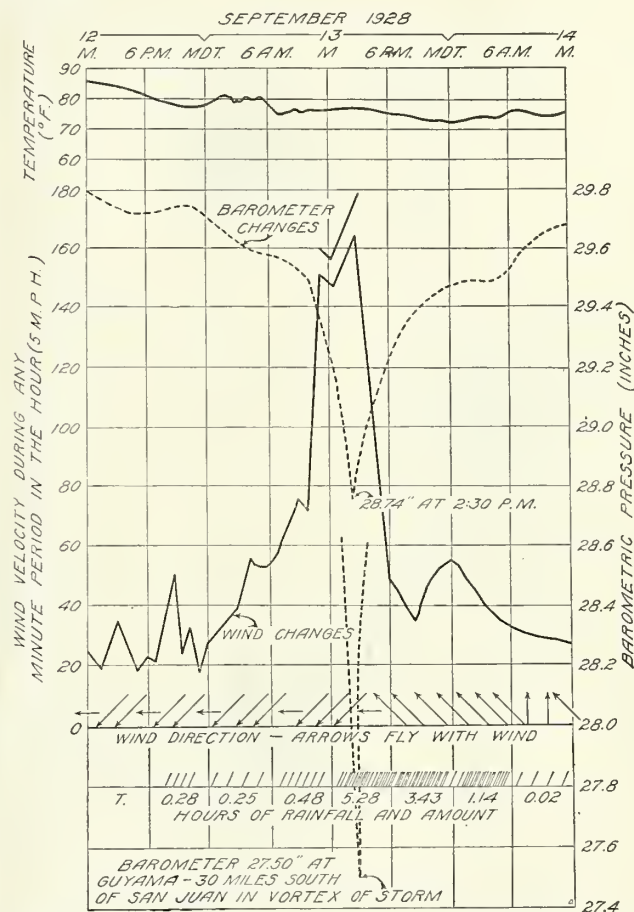


FIGURE 10.—Changes in barometric pressure and other conditions at San Juan P.R., during the passage of the hurricane of September 13, 1928.

In the absence of upper-air observations within the hurricane, there are no definite data as to its height. Some of its effects undoubtedly extend 6 to 8 miles above the earth's surface.

PREMONITORY SIGNS

In the Tropics the weather is normally somewhat the same from day to day. The extratropical cyclones and the anticyclones, which cause frequent changes in weather conditions in higher latitudes, seldom extend their influence into the tropical and subtropical regions to any marked degree. For that reason the approach of the hurricane is sometimes suspected when it is a long distance away because of relatively slight changes from the prevailing weather conditions for the season.

One of the first definite signs is the sea swell. It appears at sea as a long, unbroken wave, with the time

interval between crests considerably longer than it is in waves ordinarily observed. As the storm approaches, the seas become heavier and rougher and the tide rises above its normal height. In places where the sea cannot be observed, one of the first indications is the appearance of cirrus, or high feathery clouds, which often seem to converge at a point on the horizon. By some observers the point of convergence of high clouds on the horizon is considered a reliable indication of the direction in which the storm center lies.

At sunset and sunrise the clouds on the outer border of the hurricane are highly colored; hence a brilliant

States to cause winds of hurricane force. No State along the South Atlantic and Gulf coasts has an average of one tropical storm of full hurricane force in a year.

The number of tropical storms recorded in each month, for the period 1887 to 1933, inclusive, is as follows: May, 3; June, 20; July, 22; August, 61; September, 104; October, 84; November, 23; December, 2; total, 319.

The number of tropical storms of the North Atlantic Ocean (including the Gulf of Mexico and Caribbean Sea) for each year of the period 1887-1933, was as follows:

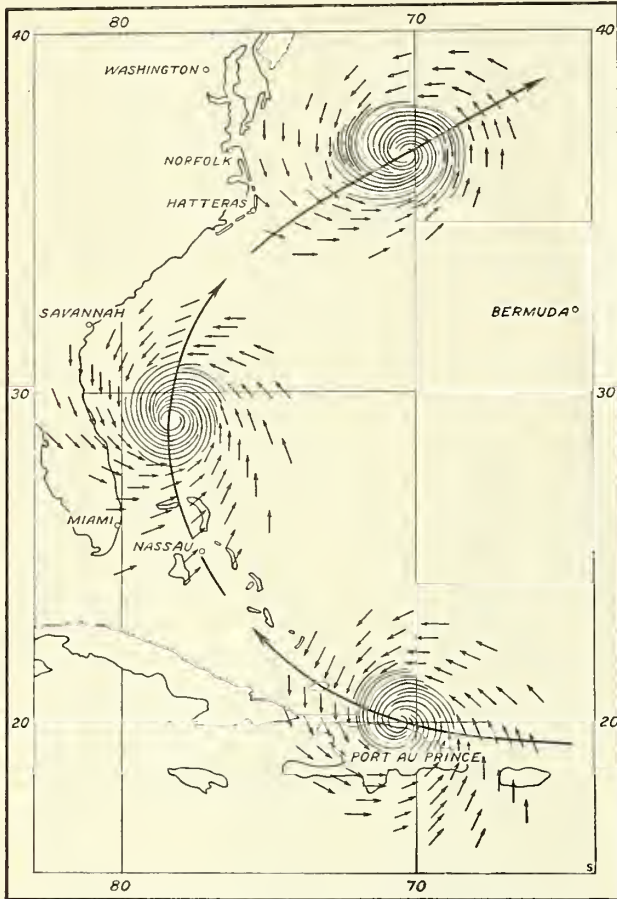


FIGURE 11.—Track and wind system of a hurricane. The winds are depicted here as they are directed, momentarily, about the center of a progressing cyclone. As experienced at the earth's surface, over which the cyclone passes, the winds are the resultants of progressive and cyclonic movements.

red sky is one of the well-known signs of an approaching hurricane.

FREQUENCY

The largest number of tropical storms recorded in a single year in the North Atlantic Ocean, including the Gulf of Mexico and Caribbean Sea, was 21, in 1933. In several years there were only two. The number per year averages between 6 and 7.

Approximately 50 percent of all of these storms reach full hurricane intensity. Only about one fourth approach close enough to the coasts of the United

1887	16	1912	8
1888	10	1913	4
1889	8	1914	2
1890	1	1915	5
1891	11	1916	13
1892	9	1917	2
1893	11	1918	4
1894	6	1919	4
1895	6	1920	4
1896	6	1921	6
1897	5	1922	5
1898	8	1923	5
1899	5	1924	8
1900	6	1925	3
1901	10	1926	10
1902	4	1927	7
1903	8	1928	6
1904	9	1929	2
1905	3	1930	2
1906	9	1931	8
1907	4	1932	11
1908	6	1933	21
1909	12		
1910	4	Total	319
1911	2		

HURRICANE WARNINGS

The service of the United States Weather Bureau in connection with tropical storms is fully described in a leaflet entitled "The Hurricane Warning Service", a copy of which may be secured on application to the Weather Bureau, Washington, D.C., or to any Weather Bureau station along the South Atlantic and Gulf coasts.

TRACK CHARTS

Tracks of centers of all tropical disturbances during the 10-year period, 1924-33, are given in figures 12, 13, 14, and 15. Solid tracks indicate that the disturbance was of known hurricane intensity; broken tracks, doubtful as to hurricane intensity. Dotted tracks, not of hurricane intensity. Open circles on lines indicate 24-hour movement (8 a.m. to 8 a.m., seventy-fifth meridian time). Figures beside first circle of each track indicate day of month. Each storm is credited to the month during which it was first observed, e.g., a storm first observed on August 31 is shown on the August track chart.

A disturbance of known hurricane intensity, according to the classification of C. L. Mitchell used in these charts, is one with central barometric pressure 29 inches or lower and winds near center of more than 60 miles an hour.

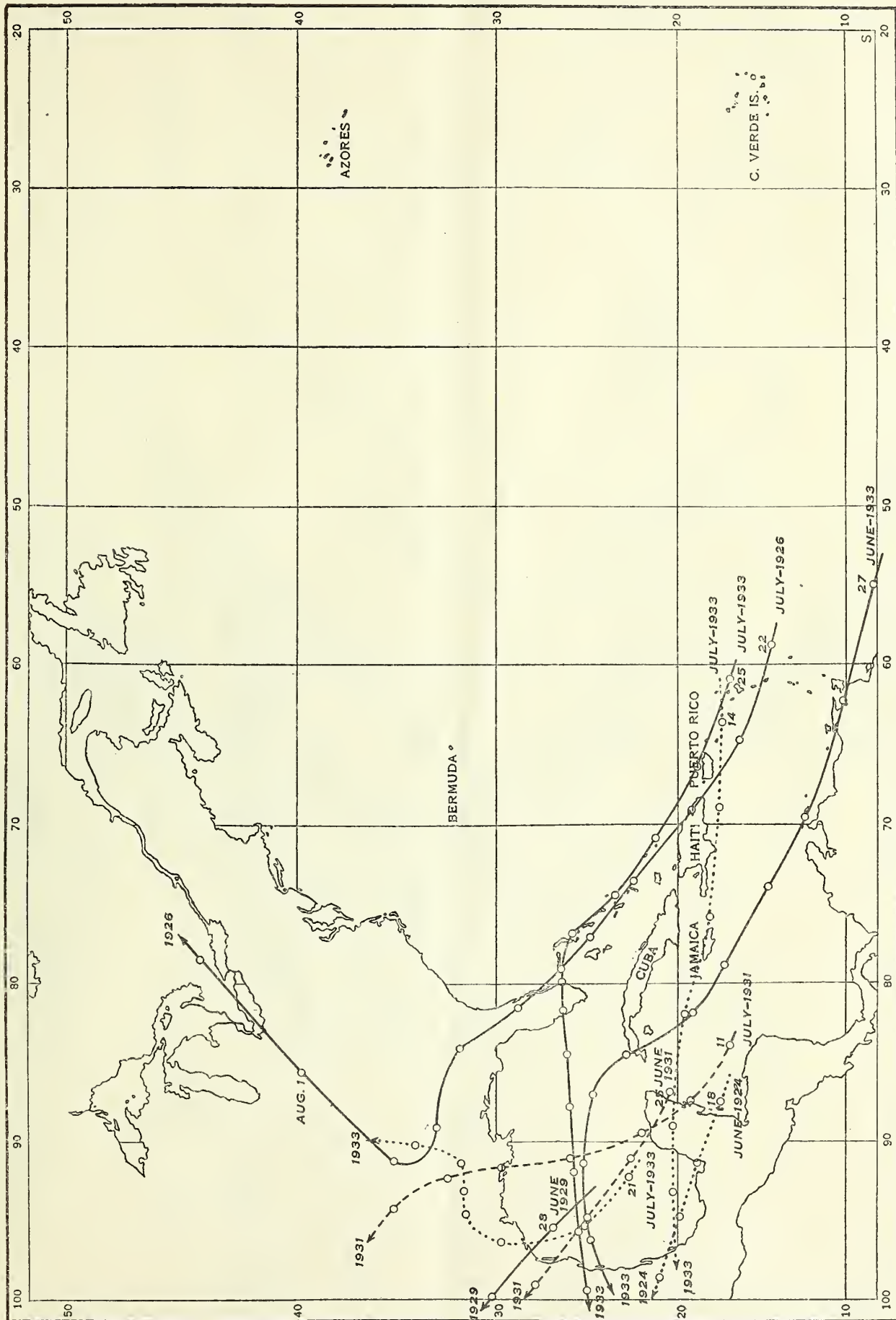


FIGURE 12.—Tracks of June and July tropical storms 1924 to 1933, inclusive.

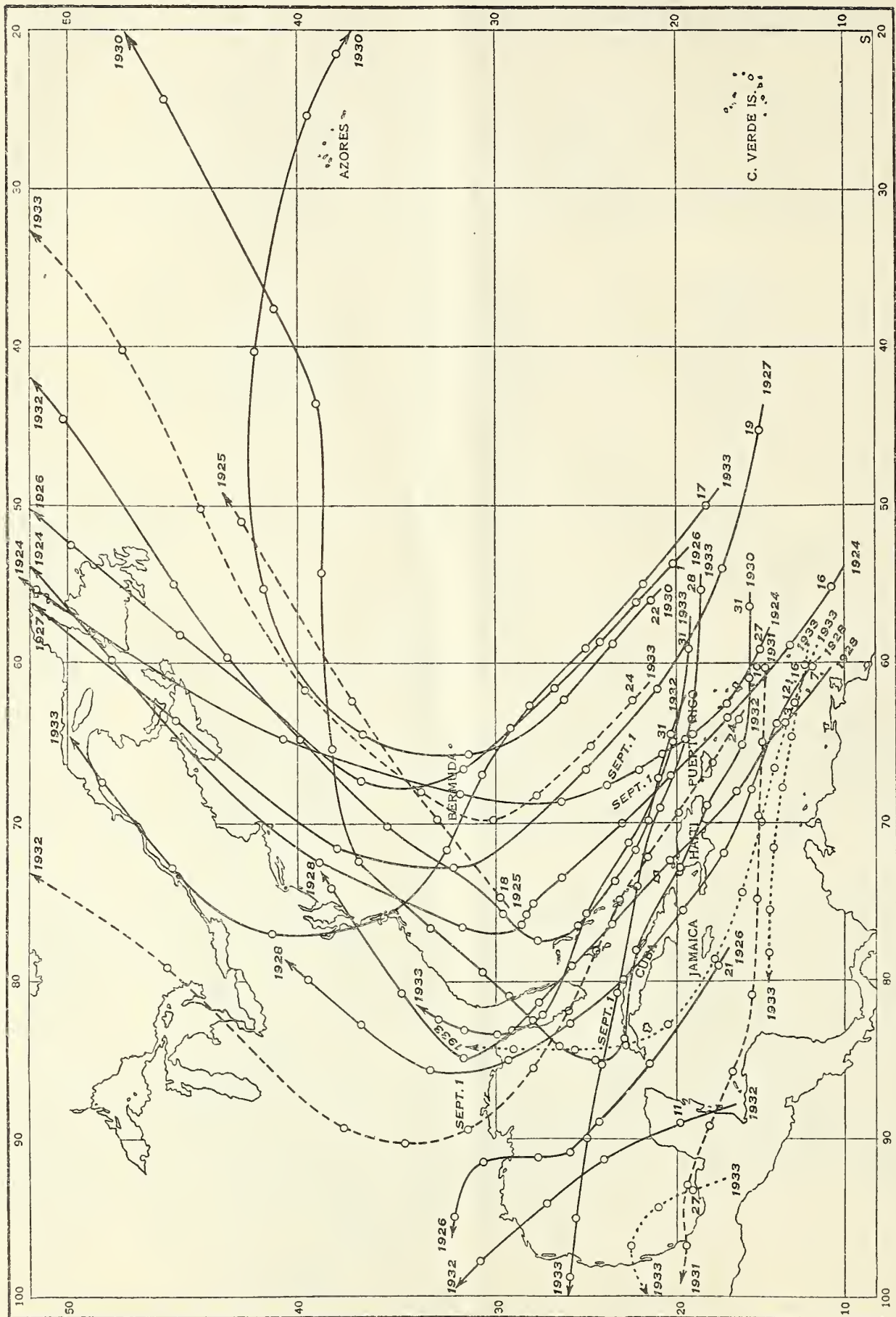


Figure 13.—Tracks of August tropical storms 1924 to 1933, inclusive.

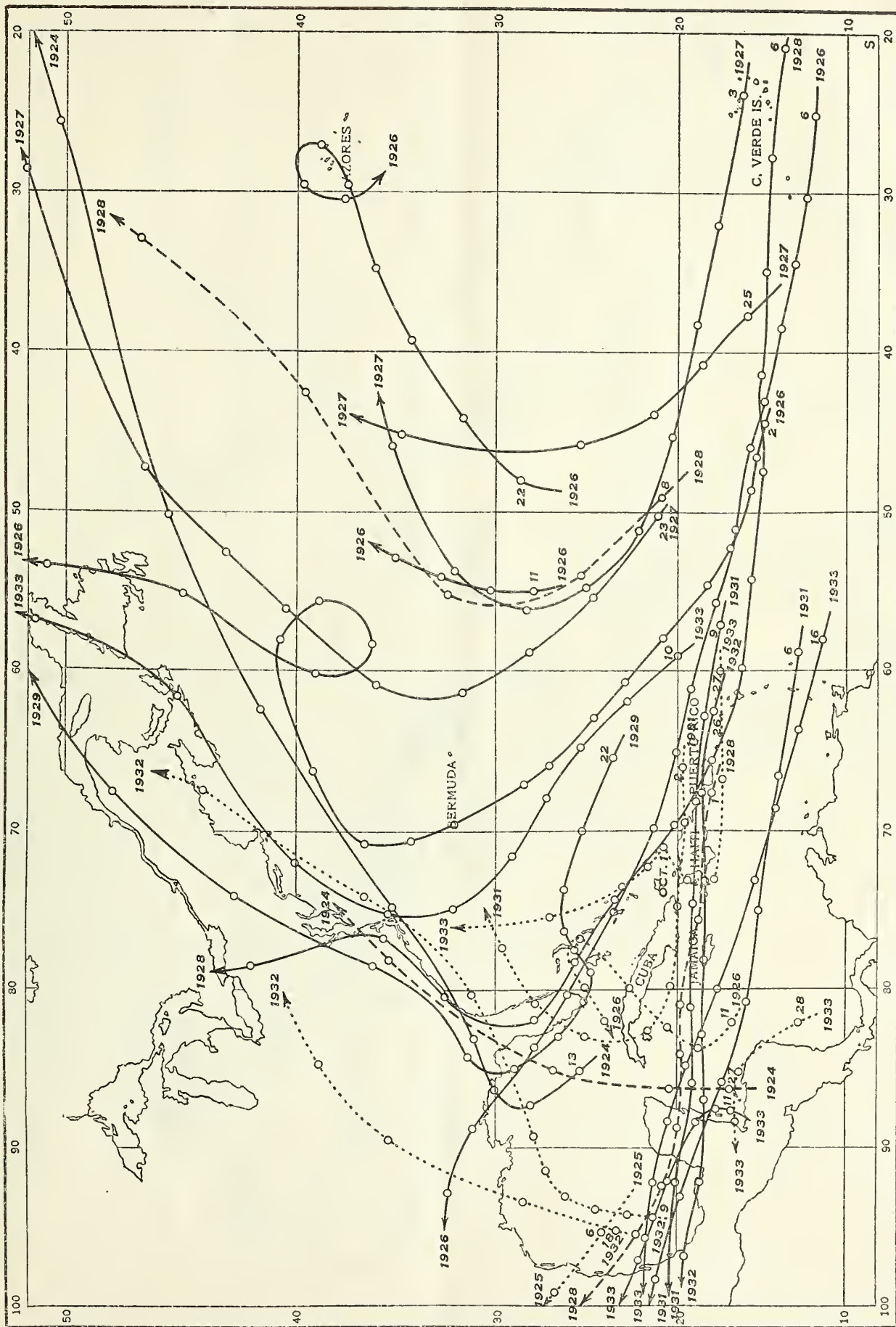


FIGURE 14.—Tracks of September tropical storms 1924 to 1933, inclusive.

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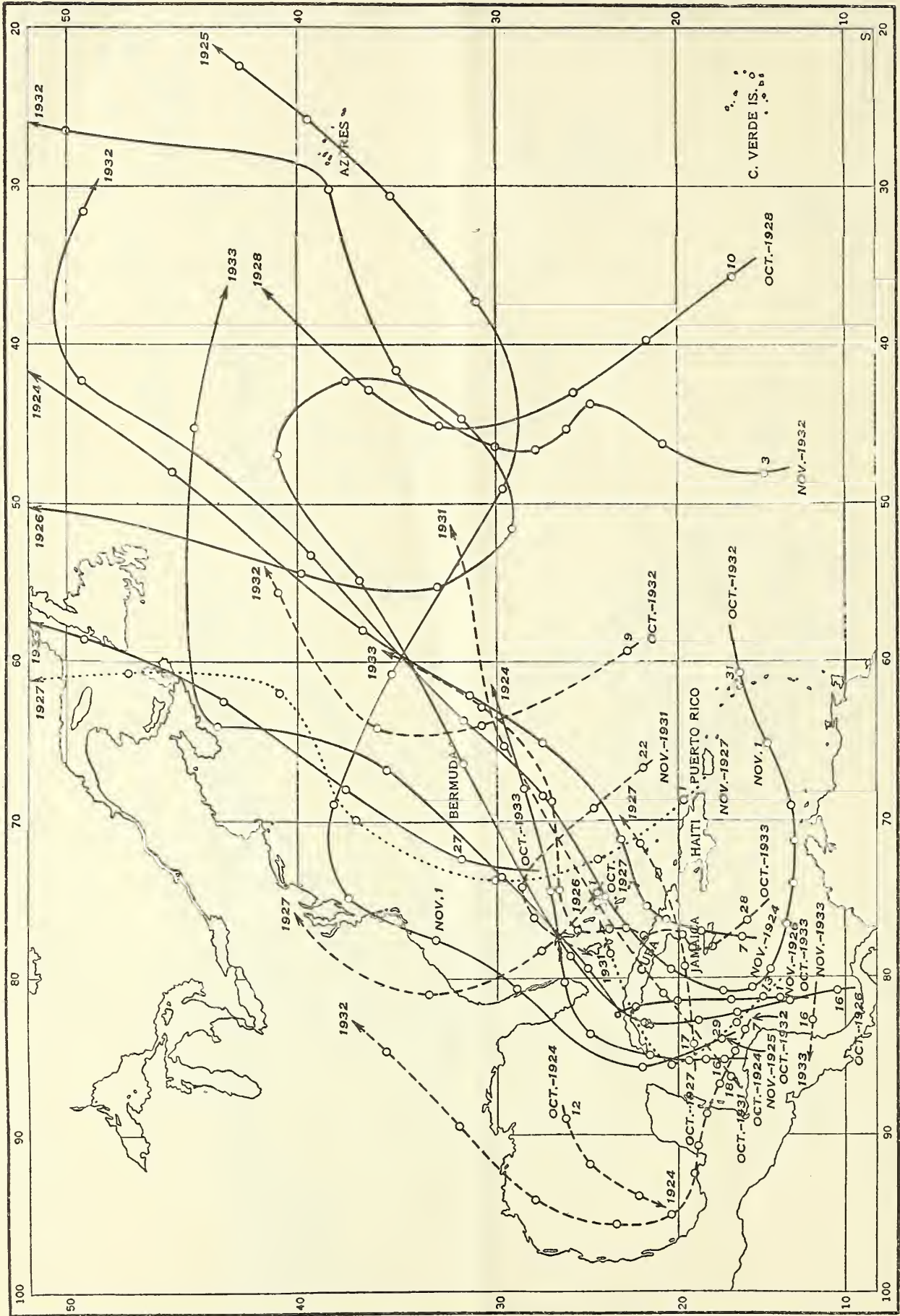


FIGURE 15.—Tracks of October and November tropical storms 1924 to 1933, inclusive.

