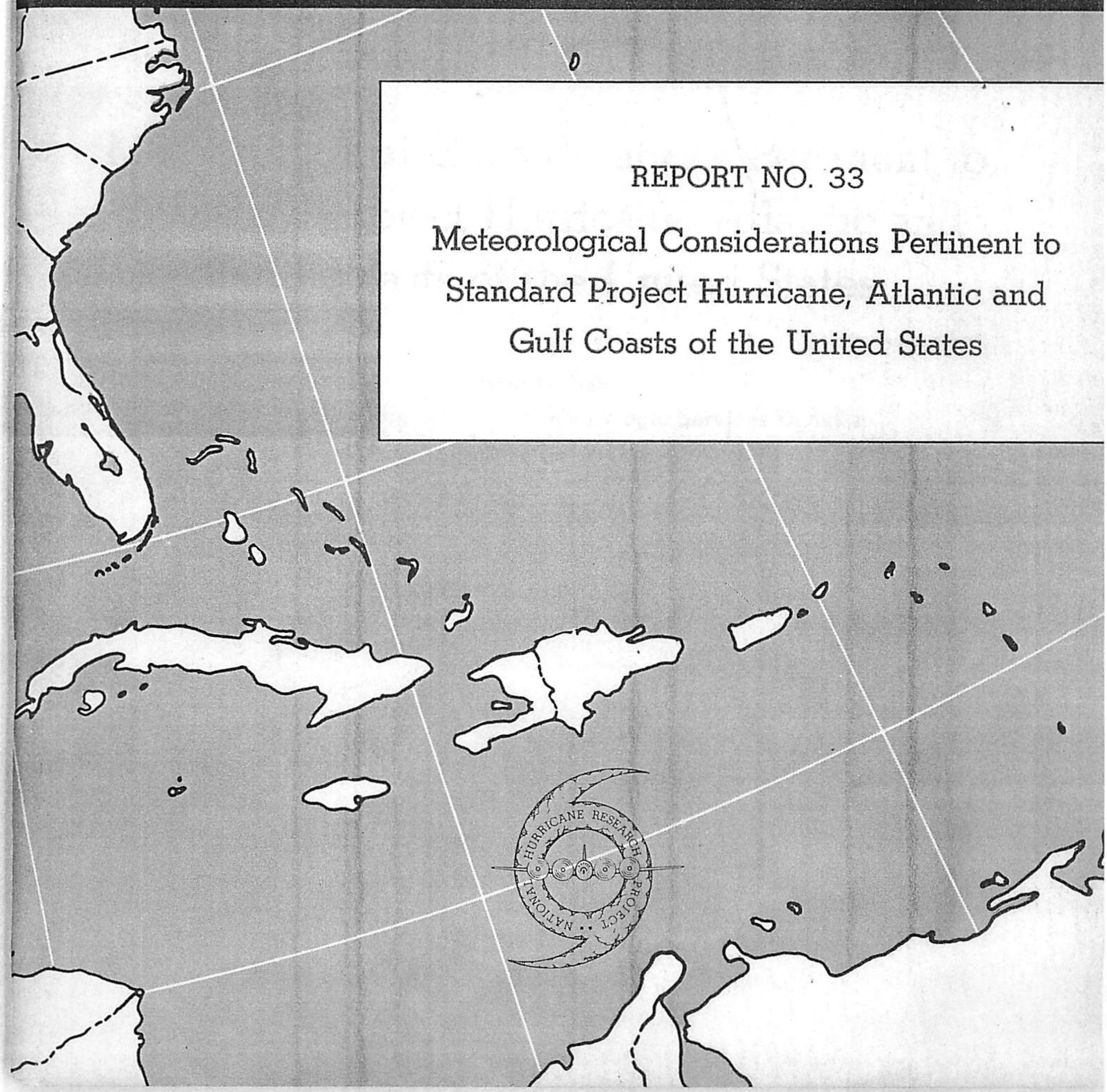
NATIONAL HURRICANE RESEARCH PROJECT

REPORT NO. 33

Meteorological Considerations Pertinent to Standard Project Hurricane, Atlantic and Gulf Coasts of the United States



U. S. DEPARTMENT OF COMMERCE
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WEATHER BUREAU
F. W. Reichelderfer, Chief

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Meteorological Considerations Pertinent to Standard Project Hurricane, Atlantic and Gulf Coasts of the United States

by
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A partial report of work accomplished under P. L. 71, 84th Congress, 1st Session

Washington, D. C.
November 1959

NATIONAL HURRICANE RESEARCH PROJECT REPORTS

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METEOROLOGICAL CONSIDERATIONS PERTINENT TO STANDARD PROJECT HURRICANE, ATLANTIC AND GULF COASTS OF THE UNITED STATES

Howard E. Graham and Dwight E. Nunn

1. INTRODUCTION

Authorization

The 84th Congress, first session, by Public Law 71, authorized and directed the Secretary of the Army in cooperation with the Secretary of Commerce and other Federal agencies concerned with hurricanes, to cause an examination and survey to be made of the eastern and southern seaboard of the United States. This survey was to include, among other things, the securing of data on the behavior and frequency of hurricanes, and possible means of preventing loss of human lives and damages to property with due consideration of the economics of proposed breakwaters, seawalls, dikes, dams, and other structures. Weather Bureau participation, as agreed upon, was defined under seven subprojects in a memorandum prepared by the Office of the Chief of Engineers, Civil Works Division, dated November 25, 1955. The material described in the following report is part of subprojects 1, 2, and 7. These subprojects call for reports on regional frequencies of hurricanes in coastal areas of the Atlantic and Gulf of Mexico, study of selected hurricane characteristics and correlation of these with probabilities of occurrence in various regions, and special wind analyses pertinent to determination of wave and tidal effects at specific locations involved in engineering studies, such as Narragansett Bay, R. I.

Purpose

This report was prepared to provide generalized hurricane specifications that are consistent geographically and meteorologically for use in planning, evaluating, and establishing hurricane design criteria for hurricane protection works. The specifications, criteria, procedures, and methods were derived jointly by representatives of the Hydrometeorological Section, U. S. Weather Bureau and the Office of Chief of Engineers, Corps of Engineers. In addition to serving as an example of the application of meteorology to an engineering project, this report contains a climatological synthesis of aspects of hurricanes that is not duplicated elsewhere.

The Standard Project Hurricane (SPH) indices were derived for use in selecting the standard project hurricane criteria for specific projects. The SPH index for various places on the United States Atlantic and Gulf Coasts is defined and illustrated. The SPH index is the wind speed and direction pattern with specified dimension spans, and ranges of forward speed and direction of movement for a specific location. The meteorological characteristics and dimensions of the SPH indices are based on analyses of past hurricanes of record. The report presents analyses of the data which form the basis for defining the limits of the SPH indices. Various hurricane characteristics are correlated with intensity criterion, latitude, and other features. A generalized procedure for determining the SPH criteria is shown for the Atlantic and Gulf Coasts.

Definition

The name "Standard Project Hurricane" is analogous to the "Standard Project Storm," defined by the Corps of Engineers for a particular drainage basin and season of year as "...the most severe storm that is considered reasonably characteristic of the region in which the basin is located." Like the Standard Project Storm precipitation, the SPH index is based on enveloping the records of meteorological events with elimination of a few extreme events. The first SPH was approved by the Corps of Engineers in a design study for Lake Okeechobee, Fla. [1]. The SPH index parameters discussed in this report and the Lake Okeechobee SPH are consistent within the limits imposed by regional variation of climatological features.

The standard project hurricane wind field and parameters represent a "standard" against which the degree of protection finally selected for a hurricane protection project may be judged and compared with protection provided at projects in other localities. The SPH indices are intended as a geographically consistent set of criteria against which the individual requirements of a project can be judged. The SPH indices and parameters provide a procedure for determining the SPH estimate which reflects a generalized analysis of hurricane potentialities in a region (Zone).

2. CORRELATIONS OF HURRICANE CHARACTERISTICS

Zones

In order to facilitate an analysis of hurricane data, the Atlantic and Gulf coastal areas of the United States were divided into zones of approximately equal area.

Atlantic Coast. - The Atlantic coastal area was divided into four zones as shown in figure 1. Each zone has an area of approximately 60,000 square nautical miles. The zones have a latitudinal extent of 5 degrees and a width of about 200 nautical miles, extending from about 50 nautical miles west of a generalized coastline to 150 nautical miles east of such a line. Latitude lines mark the boundaries between the zones. The boundaries were selected so that the bulk of the data fell near the middle of a zone rather than on the boundary between two zones.

Gulf Coast. - The Gulf coastal area was divided into three zones as shown in figure 11. Each of these includes an area of approximately 80,000 square nautical miles. Each zone is about 400 nautical miles long and extends 50 nautical miles inland from a generalized coastline to 150 nautical miles offshore from that line.

Frequency of Central Pressure Index

Central pressure index. - The central pressure index (CPI) is the estimated minimum pressure for individual hurricanes in each zone. The CPI is the principal intensity criterion for defining the SPH index. A record was made of all tropical storms (1900-1956) that passed through each zone and had at any time been of hurricane intensity. A notation was made for the period from 1900 to 1956 of the CPI whenever it was estimated to be less than 29.00 inches in any of the zones (listed in table A of the appendix). For any hurricane, the CPI was determined from: (a) observations of minimum pressure at a given location, (b) computations based on observational data [2], or (c) by estimate in event that the hurricane passed through a zone where there were insufficient pressure observations to complete a computation but with enough evidence to warrant an estimate. In the latter case, the CPI has been determined by (a) or (b) in an adjoining zone.

Cumulative percent of occurrences. - In consideration of the small amount of data available, a plot was first made for each zone of the CPI versus the cumulative number and the cumulative percent of storms. This was done as described below to aid in determining the frequency of CPI occurrence on a 100-year basis. The plot was made of storms in which the particular CPI was equal to or less than other CPI values. For example, in zone 1 there has been one hurricane with a CPI of 26.35 inches, and there have been seven hurricanes with a CPI of 28.00 inches or lower. Any one hurricane is represented only once within a zone, but several hurricanes are represented in two or more zones. Curves of CPI versus cumulative number of occurrences, as computed and drawn for each zone, are shown in figure 2 for the Atlantic Coast and figure 12 for the Gulf Coast.

Next, latitudinal profiles were constructed using values taken from the graphs of cumulative frequency in the order of magnitude by zones (figs. 2 and 12), and plotted against the approximate mean location of the data in each zone and smoothed. The profiles of cumulative frequency of hurricane CPI were constructed through the zones more or less parallel to the coastline showing the percent of hurricanes having a certain CPI or less for any given point along the coast. The variations for a given percent of occurrence of CPI's along the Atlantic and Gulf Coasts of the United States are shown in figures 3 and 13 respectively.

Occurrences per 100 years. - Profiles of variations of average frequency of CPI occurrences on a 100-year basis are shown for the Atlantic and Gulf Coasts in figures 5 and 15. In developing the profiles, the frequency of CPI occurrence was computed for each zone on the probability basis using the formula

$$P = \frac{100(M - 0.5)}{Y} \qquad (1)$$

where P is the percent chance of occurrence per year, M the number of the event (rank), and Y the number of years of record (57). The data were plotted on a normal probability scale so that the data with a normal distribution would fall in a straight line. In the drawing of curves for each zone, consideration was given to the profiles of cumulative percent of occurrences which are described above. The zone frequency probability of CPI's (per 100 years) was considered representative at the mean geographic position of data for the respective zones. The probability frequency curves of the hurricane CPI by zones for the Atlantic and Gulf Coasts respectively are shown in figures 4 and 14. A graph of profiles of variation of the CPI frequency along the coast was then constructed from zone probability curves. The correlated variations of CPI with latitude along the Atlantic Coast and with distance along the Gulf Coast are shown on figures 5 and 15. In order to have a smooth transition of frequency curves from the east coast of Florida to the west coast, the curves of figure 15 were correlated to the corresponding curves from zone 1 (fig. 5) at 24° N. latitude. This is at mile 1340 of figure 15.

Distribution of hurricane occurrences within zones. - The total number of transits through each zone and smaller sub-zone of approximately 10,000 square miles by tropical storms which had reached hurricane intensity, either in the zone or previously, is shown in figures 6 and 16 for the 57 years of record. These data are presented in order to give some indication of the hurricane distribution within zones. A hurricane passing through a zone or sub-zone need not necessarily severely affect the entire coast within the zone. The frequency of damaging effects at a specific coastal site depends on many factors including the CPI frequency, the variations of storm tracks (direction of approach), and the occurrence of maximum winds for various radii and forward speeds that are possible for a given CPI.

Radius of Maximum Winds

Index of hurricane size. - Radius to region of maximum winds (R) is an index of hurricane areal size and is an important factor in the generation of waves and tides. In general, a larger hurricane will have a longer fetch that could be affected by high winds. The R has been determined for most of the tropical storms of hurricane intensity (CPI less than 29.00 inches) that passed through the zones. The values of R for hurricanes of record are shown in table A of the appendix. R was determined either from observations at a wind reporting station or by computations made from the pressure field. The observed R was used, whenever available, for all correlations. In the absence of an observed R, the computed value was substituted. To determine the validity of substituting one type of R for another, all observed R's were plotted against computed R's in the same storm (not shown). The grouping of the plotted points about the 45° line drawn through the origin of the graphs was sufficiently symmetrical to warrant the assumption that observed R averages about the same as computed R.

Variation of radius of maximum winds with central pressure index. - The relationship and variation of R to CPI as determined graphically for the Atlantic and Gulf coastal areas are shown in figures 7 and 17 respectively. Due to the variation of R for a given CPI, three values of R were selected corresponding to a representative small radius of maximum winds (RS), representative mean radius (RM), and representative large radius (RL). Data for R and CPI from all of the hurricanes (CPI less than 29.00 inches from 1900 to 1956) which have occurred in zones 1, 2, 3, and 4 are shown in figure 7 and in zones A, B, and C in figure 17. The relationship of R to CPI shows the tendency for hurricanes of lower CPI also to have smaller variation of R, although there is a considerable degree of variation of R with any given CPI. The relationship of R to CPI observed in the study corresponds with findings of various authors and previous Hydrometeorological Section studies [2], [3], and [4].

Variation of radius of maximum winds with latitude, Atlantic Coast. - It was determined, for the Atlantic Coast, that there is a slight variation of R with latitude in addition to the CPI relation. The representative mean radii (RM) of maximum winds over the CPI range for selected latitudes are shown for the Atlantic Coast by the curves labeled 23°, 28°, 33°, 38°, and 43° N. latitude in figure 7. In order to determine curves of mean radii (RM) of maximum winds through the CPI range for a given latitude, the departures of the individual points from the mean curve of figure 7 were plotted against latitude as shown in figure 8. The approximate mean of the points on figure 8 for each selected latitude was then transferred back to figure 7 and labeled for that latitude.

Variation of radius of maximum winds with latitude and longitude, Gulf Coast. - For the Gulf Coast, no further refinements of the relationship between R and CPI were made due to other variables. To determine whether the introduction of other variables would make possible further refinement in the Gulf Coast analysis, the variation of R from the mean curve of figure 17 was plotted against both latitude (fig. 18) and longitude (fig. 19). The wide scatter of points in figure 18 indicates that, for the Gulf Coast, there is little or no correlation of R with latitude. In figure 19, where the variation of observed R from the mean curve of figure 17 was plotted against longitude, the curve of best fit suggests that there may be a slight additional variation of R with longitude, with the smaller R's occurring in zone C.

Forward Speed

The forward speed of translation of the hurricane centers for the hurricane of record has been determined as the average speed for the period from 2 hours before to 2 hours after the hurricane enters the coast. Forward speed of translation of the hurricane center appears to be a function of latitude only and independent of CPI and R. For the Atlantic Coast, speed of the hurricane center was plotted against the latitude where the speed was determined and a mean profile and enveloping curves were drawn through the plotted points. These envelopes were drawn with the aid of supplementary data obtained from the hurricane of September 21, 1938, Hazel of October 15, 1954, and Carol of August 28, 1954. The latitudinal variation of hurricane center movement along the Atlantic Coast is shown in figure 9. Due to the limited latitudinal variation and limited data available, all of the Gulf Coast hurricane forward speeds were consolidated in figure 20 showing the rate of hurricane translation against cumulated percent of occurrences. Due to the wide variation of forward speeds, data were selected corresponding to a representative slow speed of translation of hurricane center (ST), representative moderate speed of translation (MT), and representative high speed of translation (HT).

Direction of Hurricane Movement

The azimuth distribution of paths followed by hurricanes of record in zones 1, 2, 3, and 4 is shown in figure 10, and in zones A, B, and C in figure 21. No evidence of a systematic relationship between hurricane intensity and direction of movement could be found. All tropical storm path directions may therefore be used to judge azimuth characteristics of paths of severe storms in the zones. The storm data from which figures 10 and 21 were constructed are listed in table B of the appendix. The average direction of movement changes slowly from zone 1 northward through zone 4. The directions in zone 1 are mostly from the southwest to southeast. The average zone 2 direction is from the south, zone 3 from the south-southwest, and zone 4 from the southwest to south-southwest. The average direction of movement in the Gulf also changes slightly from zone to zone. The West Coast of Florida receives most hurricanes from the southeast direction although another large group enters the area from the south-southwest. Most hurricanes pass through zone B from the south and the southeast, and through zone C from the east and southeast.

3. STANDARD PROJECT HURRICANE INDICES

The various correlations described in detail in section 2 were used as a basis from which to develop specifications and limits of hurricane dimension spans which are called "Standard Project Hurricane (SPH) Index Characteristics." The term SPH index was defined in section 1. Hurricane wind speed patterns are synthesized within the limits dictated by these characteristics. There are also described in this section the various considerations necessary for applying the SPH indices to determine the SPH for a specific project area.

Hurricane Parameters and Characteristics

The SPH indices listed in table 1 are based on analysis of meteorological factors that are pertinent to the Atlantic and Gulf Coasts and that are consistent meteorologically from point to point along the coasts. The listed indices were obtained from figures 1, 5, 5a, 7, 9, and 22 for the Atlantic Coast and figures 11, 15, 17, 20, and 22 for the Gulf Coast. These indices are discussed in the following paragraphs.

Central pressure index. - The central pressure indices (CPI) selected as representative of an SPH index central pressure and pertaining to each location along the coast, as listed in table 1, were taken from figure 5a for the Atlantic Coast zones and from figure 15 for the Gulf Coast zones, indicating an average return period of approximately 100 years within the respective zones. In zone 2, during the 57 years of record, there have been only 11 hurricanes with a CPI of 29.00 inches or lower. An analysis of these data (fig. 5) indicated a frequency of occurrence of certain CPI's in the center of zone 2 (near the northern boundary of Florida) lower than might be experienced near Cape Hatteras or near the southern tip of Florida. However, with only 11 storms on which to base a conclusion, it is not possible to be sure of the degree of lesser risk in zone 2. A portion of figure 5 is reproduced in figure 5a showing a frequency curve with a recurrence interval of once in 100 years and the modifications from which the representative CPI values for zone 2 were derived. The modified curve is adjusted by smoothing the 100-year curve of figure 5 at the northern limit of zone 1, and on the southern boundary of zone 3 and also by enveloping the CPI of hurricane Hazel of October 15, 1954.

Radius of maximum winds. - For each selected CPI corresponding to the SPH index, the representative small radius of maximum winds (RS), mean radius (RM), and large radius (RL) to region of maximum winds, as listed in table 1, were taken from figure 7 for Atlantic Coast zones and from figure 17 for the Gulf Coast zones. The RS and RL were taken from the enveloping curves. The RM values were taken from the mean radius curve of figure 17 and from the mean radius curves pertaining to the individual latitudes of figure 7.

Forward speed. - Values of representative moderate speed (MT), high speed (HT), and slow speed (ST) of translation of the hurricane center in the Atlantic Coast zones, shown in table 1, were read from the respective curves shown in figure 9. Forward speeds in the Gulf Coast zones B and C were taken from figure 20 where the slow speed and high speed rates are the two extremes of observed speeds and where the moderate speed is the median of the data. The forward speeds of record in zone A of the Gulf Coast allow an analysis corresponding to the east coast of Florida as shown in figure 9. Forward speeds assigned to zone A, on the Gulf Coast, in table 1 are the same as for the corresponding latitudes in zone 1, on the Atlantic Coast, and were taken from figure 9.

Maximum gradient wind. - The maximum gradient wind (V_{gx}) as related to CPI, R, and latitude is shown in figure 22. Graphs were determined from the equation

$$V_{gx} = 73(p_n - p_o)^{1/2} - R(0.575f) \qquad (2)$$

where V_{gx} is the maximum gradient wind speed in miles per hour, p_o is the central pressure in inches, p_n the asymptotic pressure in inches, R the radius of maximum winds in nautical miles, and f the Coriolis parameter in units of hour^{-1}. The maximum cyclostrophic wind (upper graph in figure 22) is a function of $p_n - p_o$. The outer dashed curves in the graph are based on extreme values of p_n, derived in turn from envelopes of a plot (not shown) of p_n versus p_o values from table 3-1 of reference [4]. The center solid curve of figure 22 is based on the standard sea level pressure of 29.92 inches, which is also the average of all p_n's in table 3-1 of reference [4]. The standard sea level pressure curve (upper fig. 22) is used in connection with the SPH index CPI to determine the maximum gradient wind speeds, assuming little or no forward speed of the hurricane. Limits of the gradient wind speed for a specific CPI at the zone of maximum winds for a hypothetical hurricane assumed with zero forward speed may be determined for the Atlantic and Gulf Coasts from figure 22.

Maximum 30-ft. over-water speeds. - The maximum wind at 30 feet above the open water has been found to vary from about 75 to 100 percent of the above maximum theoretical gradient wind speed. The ratio from the 1949 hurricane at Lake Okeechobee, 86.5 percent, which is near the middle of the range has been selected as the standard [2]. The estimated maximum 30-ft. over-water wind speed (V_x), except in zone B, was computed from the formula

$$V_x = 0.865V_{gx} + 0.5T \qquad (3)$$

where T is the average speed of translation of the hurricane center. A number of analyses of wind fields in hurricanes have shown 0.5T to be a reasonable approximate asymmetry factor. For zone B, the conversion factor from gradient to 30-ft. over-water wind speed was modified by observed hurricanes in the vicinity of Lake Pontchartrain in Louisiana, and other hurricanes that passed through zone B. In the September 1915 hurricane, the September 1947 hurricane, hurricane Flossy of 1956, and hurricane Audrey of 1957, in zone B, the ratio of V_x to V_{gx} was greater than the standard ratio of 0.865. To obtain maximum wind speeds for the SPH index in zone B comparable to speeds estimated from studies of hurricanes that occurred in that zone, the ratio of 30-ft. to gradient wind speed was determined at 0.885. This ratio was based primarily on the September 29, 1915 hurricane at New Orleans. Thus, zone B maximum 30-ft. wind speeds were computed from the formula

$$V_x = 0.885V_{gx} + 0.5T \qquad (4)$$

Isovel Charts

The Standard Project Hurricane index wind fields (isovel* patterns) were developed for the approximate center of each zone from the SPH index parameters listed in tables 1 and 2. The procedures and derivation of the isovel patterns are explained in subsequent paragraphs.

Construction. - Synthetically derived isovel charts for RM and RL hurricanes showing wind speed patterns for Atlantic and Gulf Coast zones are shown in figures 23 through 46. These charts were prepared for the CPI at the approximate middle of the zones, for forward speeds representative of zonal ranges of the moderate and high speeds of center translation, and for the RM and RL hurricanes. The SPH index isovel patterns were modeled after maximum hurricanes of record, such as the hurricanes of September 29, 1915; September 21, 1938; September 14, 1944; August 26, 1949; and June 27, 1957. The isovel charts were constructed in the following steps: (a) computing, for the selected CPI and R, a profile of gradient wind speed for a stationary or slow-moving hurricane using the formula [2]

$$V_g = \left(\frac{1}{\rho}\,(p_n - p_o)\,\frac{R}{r}\,e^{-\frac{R}{r}}\right)^{1/2} - K \qquad (5)$$

where V_g is the gradient wind, ρ is the air density, p_n is the average asymptotic pressure (29.92), p_o is the CPI, R is the radius of maximum winds, r is any assigned radius, and K is a constant depending on latitude and r; (b) reducing the gradient wind-speed profile to a 30-ft. over-water wind-speed profile by empirical factors [2] with the zone B factor increased at the radius of maximum winds as described in the sub-section on "maximum 30-ft. over-water wind speed" and proportionately elsewhere; and (c) applying an adjustment to the 30-ft. over-water wind-speed profile so as to show a pattern

*Same as isotach.

with a moderate degree of asymmetry which is in direct proportion to the rate of forward speed of the center. The asymmetry factor applied to the 30-ft. over-water wind-speed profile was added to the wind speeds in the right sector of the hurricane and subtracted from the speeds in the left sector according to the formula

$$V = V_a + 0.5T \cos \alpha \tag{6}$$

where V is the 30-ft. over-water wind speed at any selected point, V_a the average 30-ft. over-water wind speed at a given radial distance from the center, T the forward speed of hurricane translation in miles per hour, and α the angle between the vectors showing the direction of forward motion of the storm and wind direction. The resulting isovel patterns for the center of each zone (figs. 23 through 46) were obtained by using the values of CPI index and the forward speeds listed in table 2.

Isovel pattern asymmetry and limits of rotation. - Several investigators have found that an isovel pattern showing the strongest winds in the right rear quadrant is the most likely to occur during hurricanes. Cline [5] states that, "the wind velocities are much greater in the right half than in the left half of the cyclone area, and the greatest sustained wind velocities occur as a rule in the right rear quadrant." Hughes [6] has summarized a large number of reconnaissance flights, producing what is believed to be the best and most definitive composite low-level wind speed pattern yet available. Hughes states that the strongest winds are in the right rear quadrant in the wind speed pattern. Many variations may occur in the standard project hurricane index isovel patterns shown in figures 23-46. To represent the many patterns that would be reasonable to expect in each zone with the same parameters (CPI, R, speed of translation, and V_x) the isovel patterns in figures 23-46 may be rotated with limits of 100° counterclockwise and 50° in a clockwise direction. The limits of rotation are indicated on the isovel charts by dashed arrows extending outward from the wind center.

Variation of R. - The distance scale on the SPH index isovel charts for each zone is given in terms of R (Radius to maximum winds). Any R listed for a zone in the RM, or RL columns of table 1 may be substituted as the distance scale for the respective isovel pattern for that zone.

Adjusting isovel pattern for variation of CPI. - The isovel patterns shown in figures 23-46, which were constructed for the SPH index CPI at the approximate middle of the zones, may be adjusted for other locations corresponding to the CPI's listed in table 1 for various points in the zone by multiplying all speeds by the ratios listed in table 3. The maximum CPI variation in table 1 for zone B is only 0.05 inch. The wind speed difference due to varying the CPI over this range is about 1 percent. Therefore, the wind speed patterns shown for zone B in figures 43, 44, 45, and 46 can be used over water anywhere in the zone.

Charts for small radius hurricanes. - The recommended wind-speed profile for the small radius (RS) hurricane is shown in figure 47. The variation of wind speed from one side of a small hurricane to the other, at any fixed radius, is not well known. A symmetrical wind speed pattern is, therefore, recommended for RS hurricanes. That is, the isovels are circles concentric with the center of the storm. Figure 47 is in terms of relative distance from the center and relative wind speed. The relative distance, in terms of R, is obtained from the RS column of table 1, and wind speed is obtained from the 30-ft. over-water wind speed, V_x column of table 1, which is pertinent to the selected rate of forward speed. RS hurricanes should be handled in the same manner as RM and RL hurricanes with respect to wind direction, allowance for filling over land, limits of forward speed, adjustment of wind speeds near the shore, and selection of direction of forward motion.

Variation of isovel pattern with forward speed. - Forward speed for an SPH for any specific location within a zone should be selected within the range of forward speeds shown in table 1. Forward speed within these ranges can be assumed to be independent of CPI and R. Fast-moving hurricanes are believed to have a greater asymmetry of their wind-speed fields than slow-moving storms. The highest speeds are most generally found somewhere in the right half of the storm. These two conditions have been taken into account in developing the patterns in figures 23-46, by adding the forward speed factor as described above. This is an empirical approximation and a high degree of refinement of adjusting wind speed patterns to forward speed of translation is not required. The information shown in figures 23-46 was computed for the forward speeds listed in table 2 and can be applied directly to all forward speeds in the respective MT and HT columns of table 1. Isovel patterns for forward speeds other than shown in figures 23-46 may be obtained by an interpolation within the generalization of formula (6).

Wind Direction

The wind direction at 30 feet above the surface for use in conjunction with the isovel patterns given in figures 23-46 may be approximated from table 4. These directions are shown by arrows on the charts. Because of the curving field, direction is correct only at the arrow point.

Adjustment for Filling over Land

The normal weakening of a hurricane, when the center is over land, may be approximated by reducing the open-sea wind-speed values by the factors given in table 5. The use of these factors yields over-water wind speeds in portions of the storm that are still over a water-frictional surface. Further reductions are required to obtain speed for portions of the storm over land as described in the next sub-section.

The factors for reducing hurricane wind speeds depend on the time that the storm center remains over land and upon the size of the land mass. Hurricanes that have moved over the Florida peninsula have generally had a slower rate of filling (weakening) than hurricanes that have moved onshore over the other parts of the Eastern Seaboard. This difference is illustrated in table 5 which lists adjustment factors for both cases. Table 5A lists empirical adjustment factors which were derived from a study of the change in central pressure in eleven storms that moved onshore and remained over land in southeastern United States other than Florida, and table 5B lists similar factors derived from four hurricanes that passed over Florida. Table 5A is used to adjust the wind speed of SPH for filling when the center passes over land except when relatively large peninsulas and bays are involved. In case the hurricane moves over Florida (south of latitude 30°N.), the lower Mississippi Delta, Long Island, or over a large bay such as the lower Chesapeake Bay, table 5B will apply until the center moves beyond that area, after which table 5A will apply as long as the center remains over land.

Adjustment of Wind Speeds Near Shore

If speeds over the water near the shoreline are critical, the reduction of speeds at the 30-ft. level by friction may be approximated in the following manner. Reduce on-shore winds at the shore to 0.89 of the over-water value. This reduction should be made over a transition zone of two or three miles. For off-shore winds at the shore, the reduction factor varies from about 0.40 to 0.70, depending on the frictional characteristics of the shoreline. For a comparatively smooth shoreline such as that at Lake Okeechobee, Fla., the reduction factor may be as high as 0.70, but for a rougher terrain the reduction factor may be as low as 0.40. Adopt, for the SPH off-shore winds at the shore, a 0.70 reduction of the over-water value unless it is otherwise determined that the configuration of a particular location requires a greater adjustment. The "speedup" to over-water values should be accomplished in about 10 miles. The adjustment factors of wind speeds near shore for the SPH conditions are shown in table 6.

Comparison of SPH Indices with Observed Hurricanes

Purpose of comparison. - Comparisons are shown here to afford the user of the SPH indices several bases for relating these SPH indices to like parameters from known hurricane events. The SPH indices are based on a model and statistical analysis of a variety of data from the hurricanes of record. The scatter of data was partially handled by enveloping the data as illustrated in figures 7 and 9. The principal intensity criterion for determining the SPH index is the CPI. However, for observed storms with a given CPI, there is considerable variation in the distribution of wind speed, radius of maximum winds, forward speed of translation, and deflection angles about the center. Resultant tides and waves are functions of these factors. In order to relate an SPH to some known events, SPH indices may be compared with similar parameters from storms of record. The comparison will illustrate, in part, the relative magnitudes of the SPH indices and parameters of several observed hurricanes as illustrated in figures 48 and 49.

Intensity indices. - An intensity comparison may be made between the SPH indices and any of several corresponding parameters from known hurricane events. These may be (1) central pressure index, (2) pressure gradient, (3) radius of maximum winds, (4) wind speed, (5) forward translation speed, and (6) wind stress. The CPI, R, wind speed, and forward speed for known hurricanes are listed in table A of the appendix and may be compared with the corresponding SPH indices listed in table 1. A comparison between observed maximum wind speed and selected SPH index maximum wind speed is shown in figure 48.

Wind stress. - Comparisions between isovel patterns determined according to SPH indices and isovel patterns from observed storms may be made by comparing areas under the curves and the relative shape of the curves shown in figure 49. It is generally assumed that wind stress is proportional to the square of the wind speed and is in the same direction as the wind [7]. The component of the wind stress in the x direction at a point may be given by the formula

$$\tau = kW^2 \cos \theta \qquad (7)$$

where τ is the wind stress (tangential force per unit area), k is a constant, θ is the angle between the wind vector and the x axis, and W is the surface wind speed. The graphs, in figure 49, show the component of wind speed squared along a line through R and parallel to the direction of forward motion for both SPH and selected observed hurricanes in the several zones. The curves integrate, to some extent, such intensity indices as R, wind speed, and forward translation speed. It is assumed that the relative area under a curve is approximately proportional to the storm-surge-producing potential of the storm at that particular time and place.

4. SUMMARY OF CONSIDERATIONS

The hypothetical Standard Project Hurricane for any location is to be selected largely on the basis of the Standard Project Hurricane (SPH) indices developed in this report which include the parameters shown in table 1. To determine the SPH for a specific project area or location, the most severe conditions should be adopted that are within the limits of the parameters of the SPH indices (table 1) for that location. In order to determine meteorological conditions which will produce the most severe surge, consideration should be given to such local characteristics as coastal configuration and ocean bottom contours as well as the SPH indices.

The following conditions should be considered in determining the Standard Project Hurricane criteria from the SPH indices:

(1) Direction of movement. - The most critical path or direction of forward motion for the particular index isovel patterns can be determined on the basis of coastal configuration or inlet, within the span of directions shown to be common on the azimuth charts of past hurricane paths in the zone concerned, figures 10 and 21. It may be necessary to consider several paths to determine the most critical path considering the variations in the isovel patterns, radius of maximum winds, areal size, and forward speed.

(2) Geographic reference points. - In order to determine a series of isovel patterns, the wind field centers should first be located along the selected critical path at appropriate intervals (1-hour intervals will possibly prove satisfactory). The latitude or location of the isovel pattern center should be used to select the appropriate CPI and other parameters from table 1. The hurricane center location is also important in obtaining, from table 3, the ratio required for adjusting the over-water isovel patterns, which are given for the middle of each zone in figures 23-46, to the pattern appropriate for the desired location.

(3) Isovel pattern orientation. - The orientation of the isovel pattern, with respect to the direction of forward motion, should be determined so that the fetch is directed most effectively for the area under consideration. The critical orientation, which will depend somewhat on local topography, will be within the limits of rotation as shown on SPH index isovel patterns (figs. 23-46).

(4) Forward speed. - The most critical forward speed for the project site is to be selected within the span of forward speeds listed in table 1 for that latitude or location.

(5) Radius of maximum winds. - The radius of maximum winds can be selected from the RS, RM, or RL columns of table 1 depending upon the most critical radius of maximum winds for that particular location. The radius of maximum winds will largely determine the length of fetch of high winds, depending on the hurricane track and coastal configuration.

(6) Adjustment for land effects. - As the hurricane approaches land, the isovel pattern near the shore should be adjusted for the greater surface friction, and, if the center moves over land, the entire storm should be adjusted for filling. The adjustment factors for reducing hurricane wind speeds (isovel patterns) due to filling over land and for onshore and offshore winds are presented in tables 5 and 6 respectively.

ACKNOWLEDGMENTS

The authors acknowledge the suggestions and support given by Mr. A. L. Cochran and Dr. Charles S. Gilman. The authors likewise appreciate the many valuable contributions that have been made by Vance A. Myers who gave freely of his time in reviewing various sections of the report, offered many useful suggestions, and gave general guidance. Appreciation is expressed to Georgina N. Hudson for help in preparing many charts, to Lillian K. Rubin for editorial advice, to Mr. Charles B. Pletcher for help in tabulating data, to Cora G. Ludwig and Edna L. Grooms for clerical assistance, and to Carroll W. Gardner and Vivian M. Campbell for drafting the figures.

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TABLE 1. - STANDARD PROJECT HURRICANE INDEX CHARACTERISTICS

EAST COAST UNITED STATES

Location: Zone	Location: Latitude (°N.)	CPI (inches)	Radius of Max. Winds (nautical miles): RS	RM	RL	Forward Speed (knots): ST	MT	HT	Representative Max. Wind Speed (m.p.h.): V_{gx}	V_x	
Figure 1	1 and 5	5a		7			9		22		
1										T = 10 kt.	T = 17 kt.
	23	26.50	4	7	10	3	10	16	134	122	126
	24	26.58	4	7	11	3	10	17	132	120	124
	25	26.68	4	7	12	3	10	17	129	118	122
	25.5	26.74	4	8	13	3	10	17	128	117	121
	26	26.83	4	8	14	4	11	17	126	115	119
	27	27.06	5	10	18	4	11	18	119	109	113
2										T = 11 kt.	T = 22 kt.
	28	27.33	6	12	25	4	11	19	113	104	111
	29	27.50	7	15	32	4	11	20	107	100	107
	30	27.62	7	17	38	4	11	21	104	97	103
	30.5	27.65	7	17	38	4	11	22	104	96	103
	31	27.66	7	18	40	4	11	23	104	96	103
	32	27.66	7	18	40	4	12	26	104	96	103
3										T = 17 kt.	T = 35 kt.
	33	27.65	7	18	40	4	13	30	104	100	110
	34	27.60	7	17	37	5	15	34	105	101	111
	35	27.56	7	17	35	5	17	38	107	103	112
	35.5	27.55	7	17	34	5	18	40	107	103	112
	36	27.55	7	17	34	6	20	42	107	103	112
	37	27.57	7	17	35	7	22	45	106	102	112
4										T = 30 kt.	T = 50 kt.
	38	27.60	7	18	37	9	25	47	105	108	120
	39	27.65	7	19	39	11	27	49	104	107	119
	40	27.71	8	21	43	14	32	50	101	104	116
	40.5	27.74	8	22	45	14	33	51	99	103	115
	41	27.78	8	24	48	15	34	51	98	102	114
	42	27.85	8	27	52	16	36	52	95	99	111
	43	27.93	9	31	57	17	37	52	92	97	109

TABLE 1. - Continued

GULF COAST UNITED STATES

Zone	Location: Mile (From fig. 15)	Location: Lat. at Coast (°N.)	Location: Near City or Other Landmark	CPI (inches)	Radius of Max. Wind (n.mi.) RS	RM	RL	Forward Speed (knots) ST	MT	HT	Representative Max. Wind Speed (m.p.h.) V_{gx}	V_x	
Figure 11	11	11 and 15	11 and 15	15	17			9 and 20			22		
												T = 11 kt.	T = 18 kt.
A	1335	24		26.58	4	7	11	3	10	17	132	120	124
	1280	25		26.68	4	7	12	3	10	17	129	118	122
	1215	26	Marco, Fla.	26.83	4	8	14	4	11	17	126	115	119
	1150	27	Lemon Bay, Fla.	27.06	5	10	18	4	11	18	119	109	113
	1085	28	Dunedin, Fla.	27.32	6	12	21	4	11	19	113	104	108
	1025	29	Yankeetown, Fla.	27.44	6	13	24	4	11	20	111	102	106
	960	30	Carbur, Fla.	27.51	7	14	26	4	11	21	109	100	104
B												T = 11 kt.	T = 28 kt.
	900		Apalachicola, Fla.	27.55	7	14	27	4	11	28	108	102	112
	840		Grayton Beach, Fla.	27.58	7	14	28	4	11	28	108	101	111
	780		Pensacola, Fla.	27.59	7	14	29	4	11	28	108	101	111
	720		Mobile, Ala.	27.60	7	14	30	4	11	28	107	101	111
	660		New Orleans, La.	27.60	7	14	30	4	11	28	107	101	111
	600		Lake Barre, La.	27.59	7	14	29	4	11	28	108	101	111
	540		March Island, La.	27.58	7	14	29	4	11	28	108	101	111
	480		Grand Chenier, La.	27.56	7	14	28	4	11	28	108	102	112
C												T = 11 kt.	T = 28 kt.
	420	30	Port Arthur, Tex.	27.54	7	14	27	4	11	28	109	100	110
	360	29	Galveston, Tex.	27.52	7	14	26	4	11	28	109	101	111
	300	29	Bay City, Tex.	27.49	6	13	25	4	11	28	110	101	111
	240	28	San Antonio Bay, Tex.	27.45	6	13	24	4	11	28	111	102	112
	180	27	Sarita, Tex.	27.38	6	12	23	4	11	28	112	103	113
	120	26	Brownsville, Tex.	27.28	6	11	20	4	11	28	115	105	115

CPI = central pressure index, estimated minimum pressure
RS = representative small radius to region of maximum winds
RM = representative mean radius to region of maximum winds
RL = representative large radius to region of maximum winds
ST = representative slow speed of translation of hurricane center
MT = representative moderate speed of translation of hurricane center
HT = representative high speed of translation of hurricane center
T = speed of translation of hurricane center
V_{gx} = maximum theoretical gradient wind computed for each CPI from figure 22 with P_n = 29.92 and RL
V_x = estimated maximum 30-ft wind speed computed from $V_x = 0.865\ V_{gx} + 0.5T$, (T in m.p.h.);
<u>except</u> for zone B from $V_x = 0.885\ V_{gx} + 0.5T$

TABLE 2. - VALUES OF CPI AND FORWARD SPEED USED IN CONSTRUCTING ZONE SPH INDEX ISOVEL PATTERNS

Zone	SPH index CPI (inches)	Forward speed (knots)		Refer to Figure No.
		MT	HT	
1	26.74	10		23 and 25
1	26.74		17	24 and 26
2	27.65	11		27 and 29
2	27.65		22	28 and 30
3	27.55	17		31 and 33
3	27.55		35	32 and 34
4	27.74	30		35 and 37
4	27.74		50	36 and 38
A	27.06	11		39 and 41
A	27.06		18	40 and 42
B	27.55	11		43 and 45
B	27.55		28	44 and 46
C	27.55	11		43 and 45
C	27.55		28	44 and 46

TABLE 3. - RATIOS FOR ADJUSTMENT OF ISOVELS TO VARIOUS CPI'S

Zone	Latitude (deg.N.)	SPH Index CPI (inches)	Ratio	Refer to Figure No.
1	23	26.50	1.04	23, 24, 25 and 26
	24	26.58	1.03	
	25	26.68	1.01	
	25.5	26.74	1.00	
	26	26.83	0.98	
	27	27.06	0.95	
2	28	27.33	1.07	27, 28, 29, 30
	29	27.50	1.04	
	30	27.62	1.00	
	30.5	27.65	1.00	
	31	27.66	1.00	
	32	27.66	1.00	
3	33	27.65	0.98	31, 32, 33, 34
	34	27.60	0.99	
	35	27.56	1.00	
	35.5	27.55	1.00	
	36	27.55	1.00	
	37	27.57	1.00	
4	38	27.60	1.03	35, 36, 37, 38
	39	27.65	1.02	
	40	27.71	1.01	
	40.5	27.74	1.00	
	41	27.78	0.99	
	42	27.85	0.97	
	43	27.93	0.96	
Mile (from figure 15)				
A 1335	24	26.58	1.10	39, 40, 41 and 42
1280	25	26.68	1.08	
1215	26	26.83	1.05	
1150	27	27.06	1.00	
1085	28	27.32	0.96	
1025	29	27.44	0.94	
960	30	27.51	0.92	
B 900 to 480		27.55 to 27.60	1.00	43, 44, 45, 46
C 420	30	27.54	1.00	43, 44, 45, 46
360	29	27.52	1.00	
300	29	27.49	1.01	
240	28	27.45	1.02	
210	27.3	27.42	1.02	
180	27	27.38	1.03	
120	26	27.28	1.05	

TABLE 4. - WIND DIRECTION FOR STANDARD PROJECT HURRICANE

Radius	Deflection Angle*
Center to region of maximum winds (R)	20°
R to 1.2 R	Transition 20° to 25°
1.2 R and beyond to outer limit of isovel pattern	25°

*Angle between true wind direction and a tangent to a circle with center at the storm center.

TABLE 5. - FACTORS FOR REDUCING HURRICANE WIND SPEEDS WHEN CENTER OVER LAND

A--Center over United States mainland with exception of large peninsulas or bays.

Time (hours)	Adjustment ratio for wind speeds
(Hurricane center)	
t (at the coast)	1.00
t + 1	.93
t + 2	.88
t + 3	.85
t + 4	.82
t + 5	.80
t + 6	.78
t + 7	.76
t + 8	.74

B--Center over Florida south of latitude 30 degrees north, other large peninsulas, or large bays

Time (hours)	Adjustment ratio for wind speeds
(Hurricane center)	
t (at the coast)	1.00
t + 1	.97
t + 2	.95
t + 3	.92
t + 4	.89
t + 5	.86
t + 6	.82

Note: Multiply over-water wind speed by pertinent adjustment factor to obtain adjusted over-water wind speeds after the center has been over land for any interval of time.

TABLE 6. - WIND SPEED ADJUSTMENTS NEAR SHORE

Wind direction	Location	Ratio*
Onshore	2 - 3 miles offshore	1.0
Onshore	At coast	0.89
Offshore	At coast	0.7
Offshore	10 miles offshore	1.0

*Ratio of 30-ft. wind speed at location to open-water wind speed for same distance and direction from hurricane center

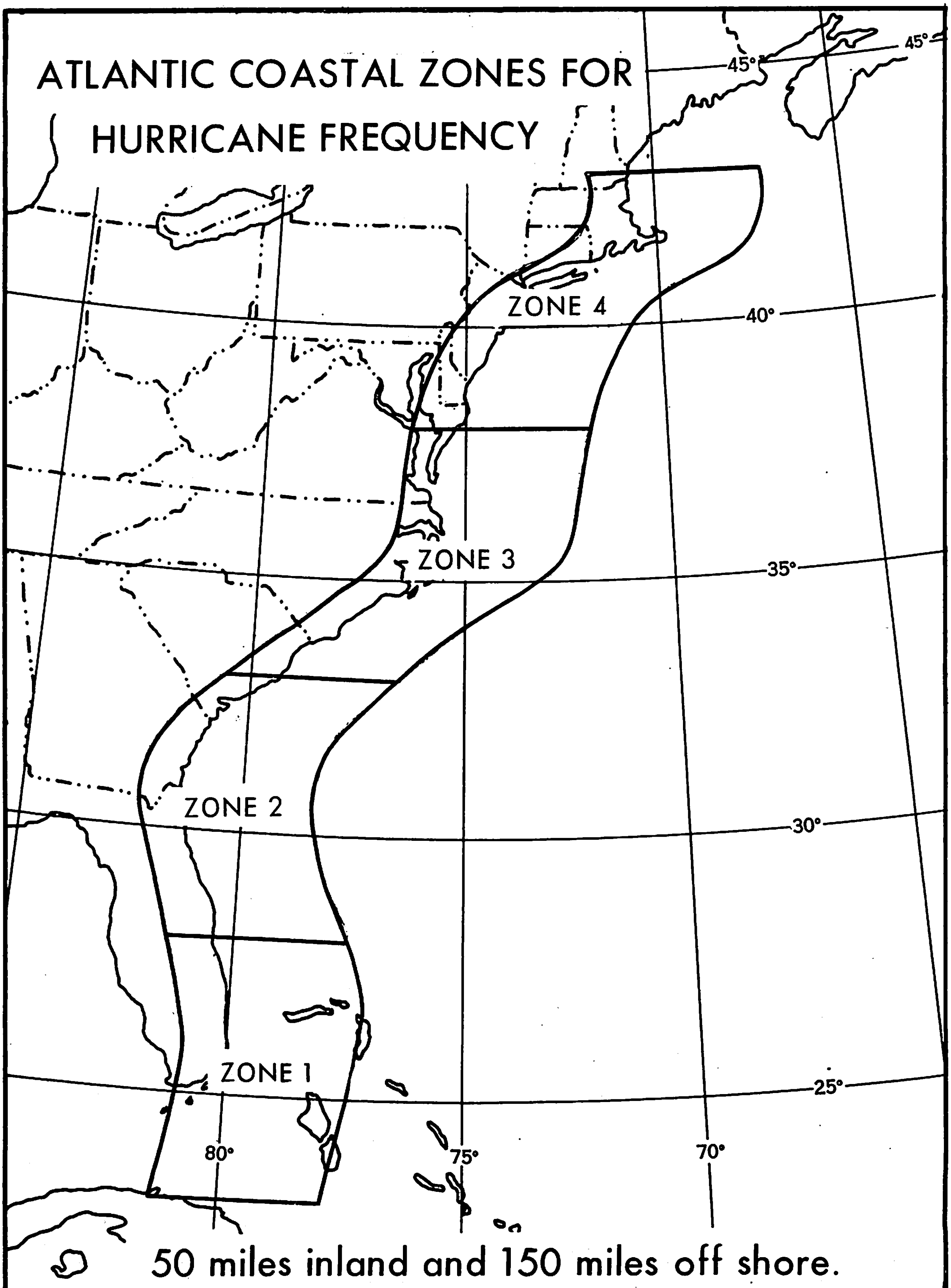

ATLANTIC COASTAL ZONES FOR
HURRICANE FREQUENCY
ZONE 4
ZONE 3
ZONE 2
ZONE 1
45°
45°
40°
35°
30°
25°
80°
75°
70°
50 miles inland and 150 miles off shore.

Figure 1

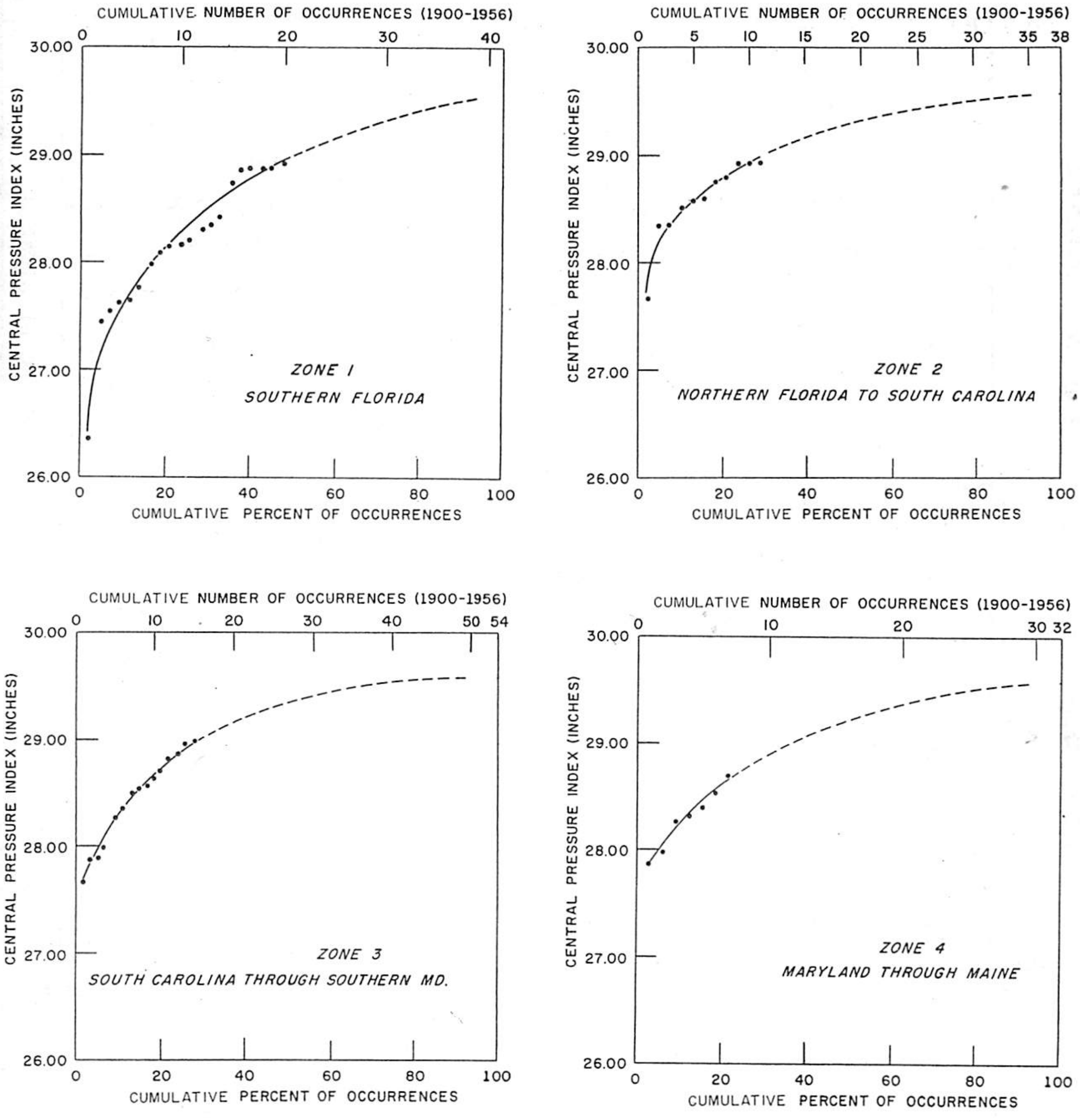


Figure 2. - Cumulative frequencies of hurricane central pressure index, Atlantic Coast United States, 1900-1956.

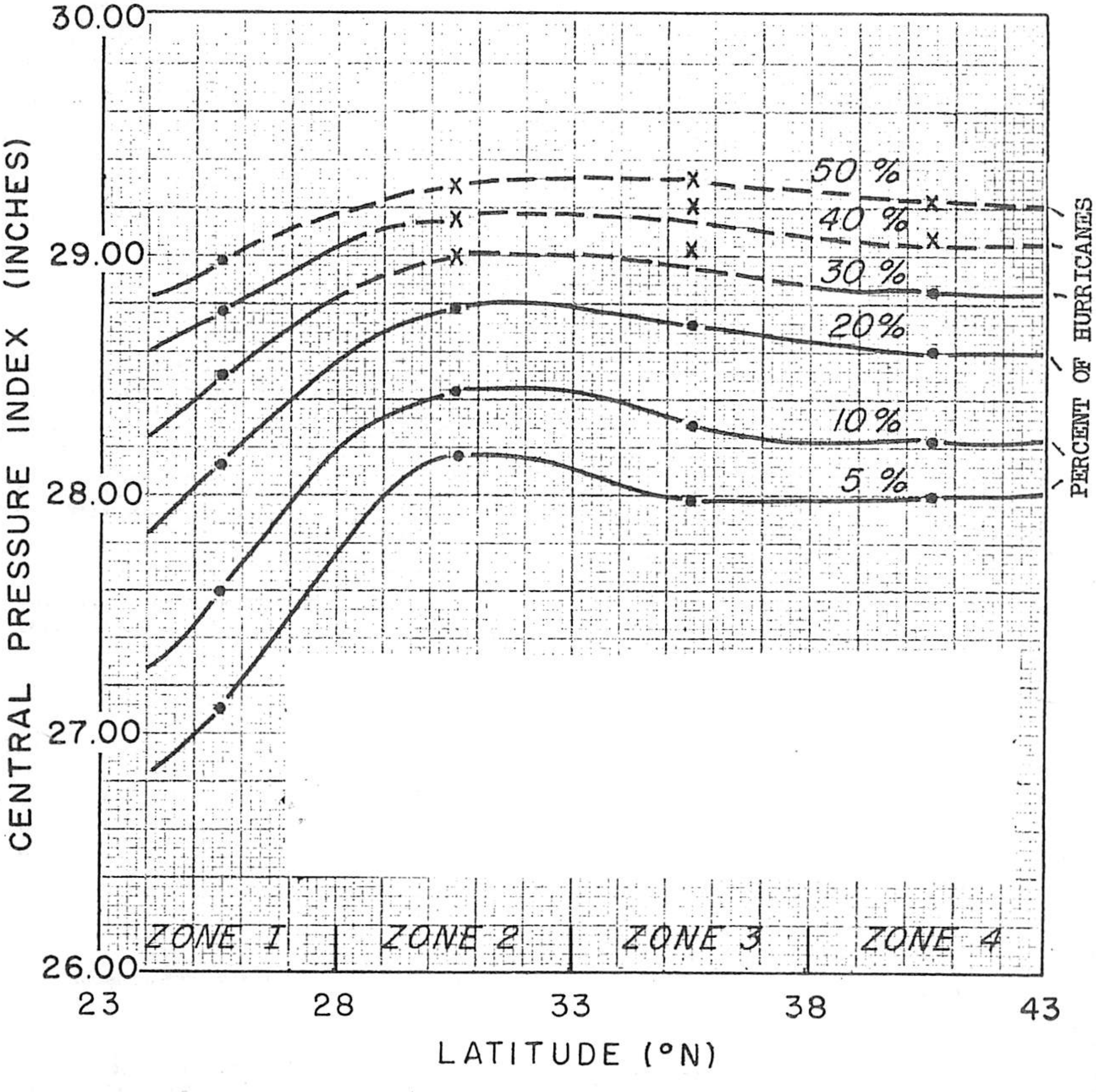


Figure 3. - Latitudinal variation of frequency of hurricane central pressure index, east coast United States (1900-1956) over zones of approximately 60,000 square miles.

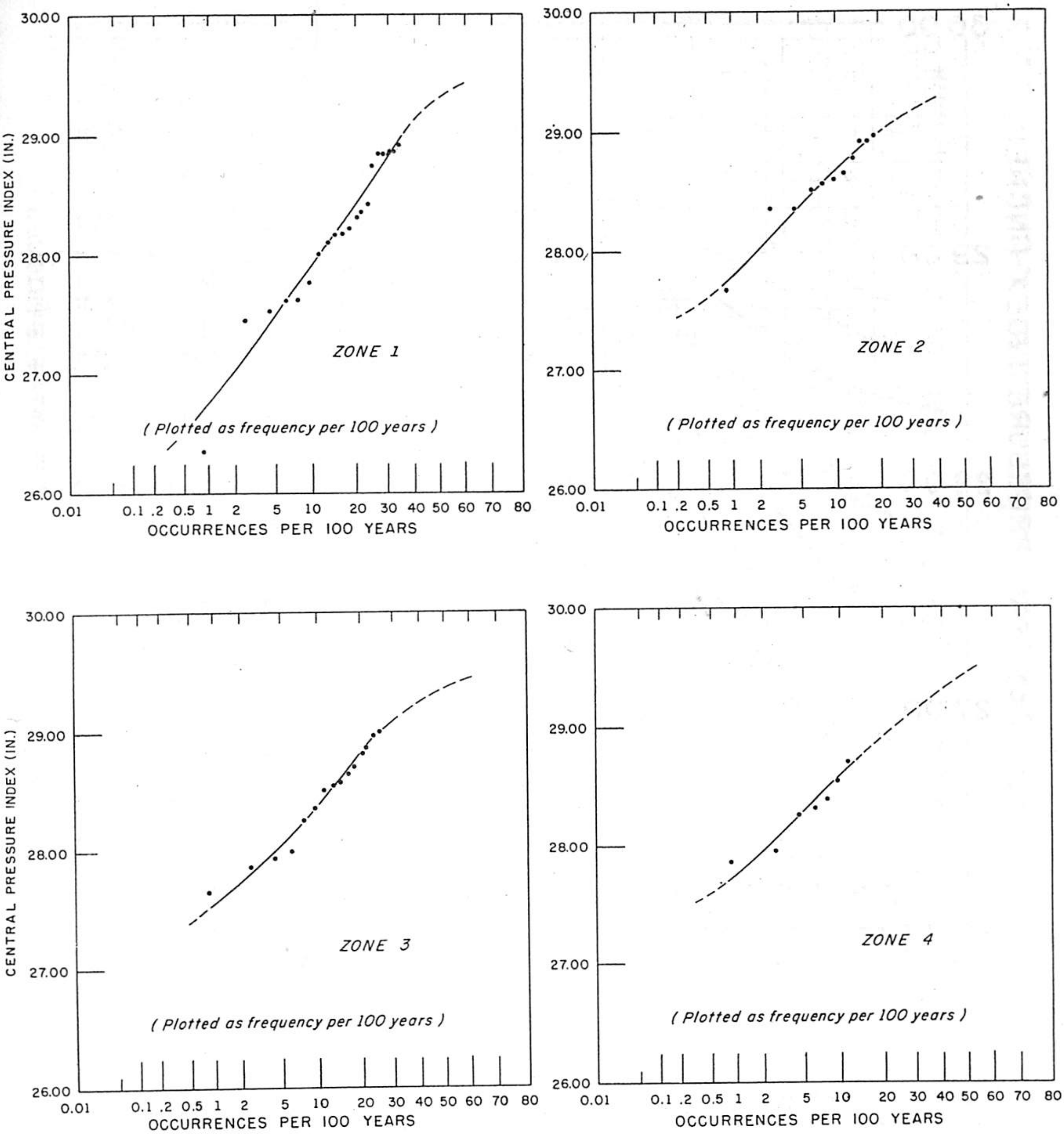


Figure 4. - Cumulative frequencies of hurricane central pressure index, 1900-1956, (plotted as frequency per 100 years).

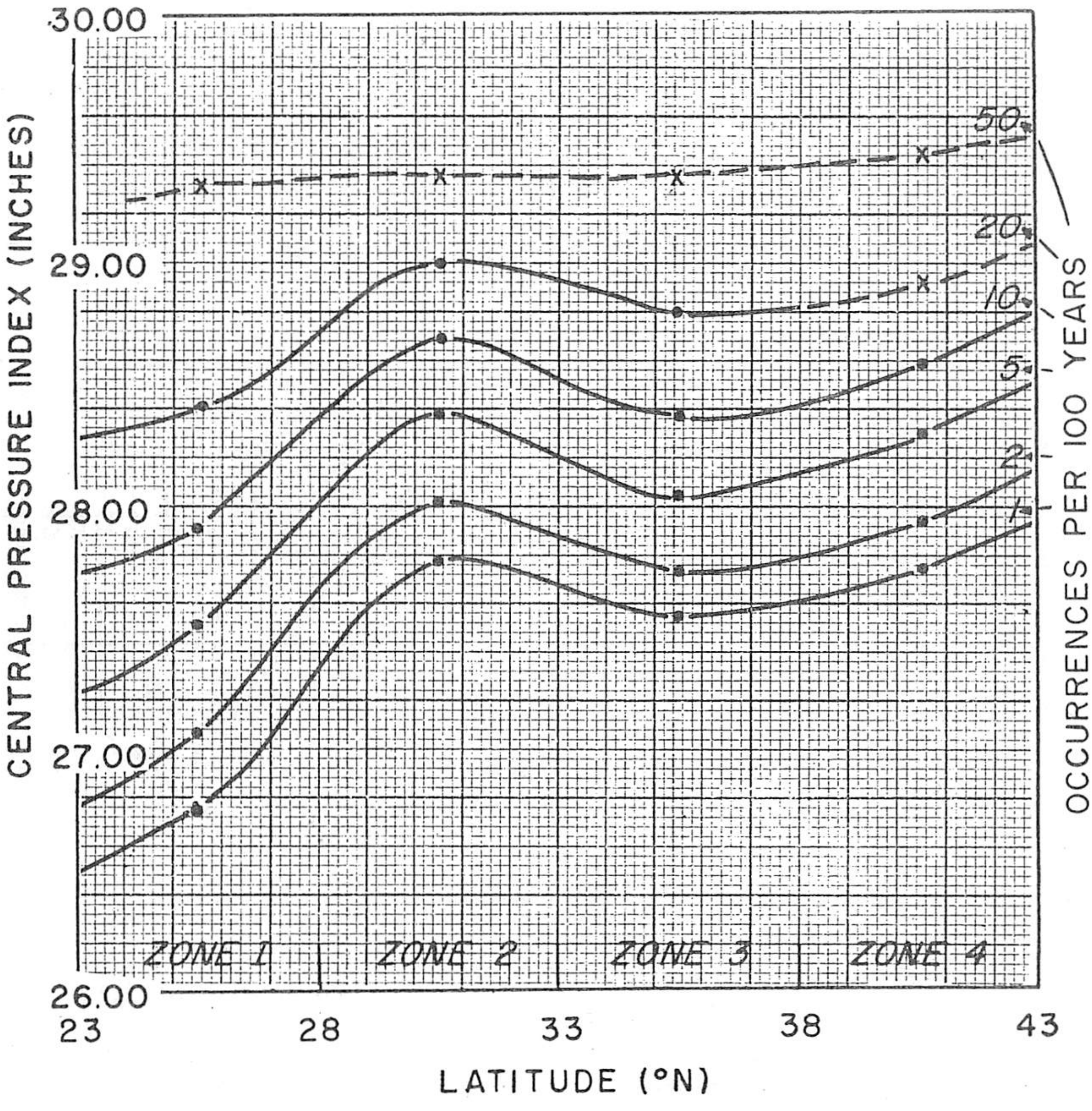


Figure 5. - Latitudinal variation of average frequency per 100 years of hurricane central pressure index, east coast United States (1900-1956) over zones of approximately 60,000 square miles.

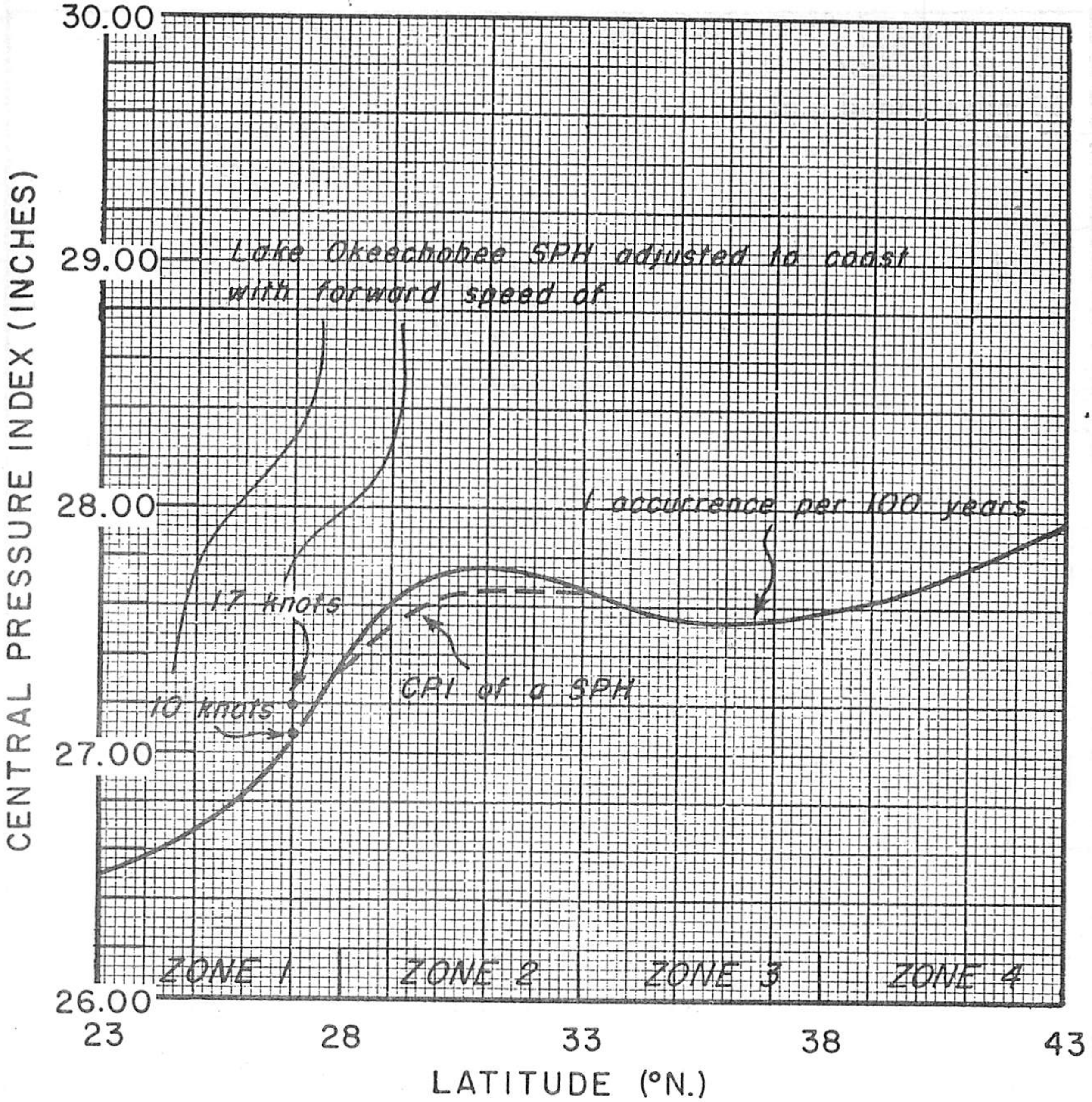


Figure 5a. - Latitudinal variation of central pressure index (CPI) for a standard project hurricane.

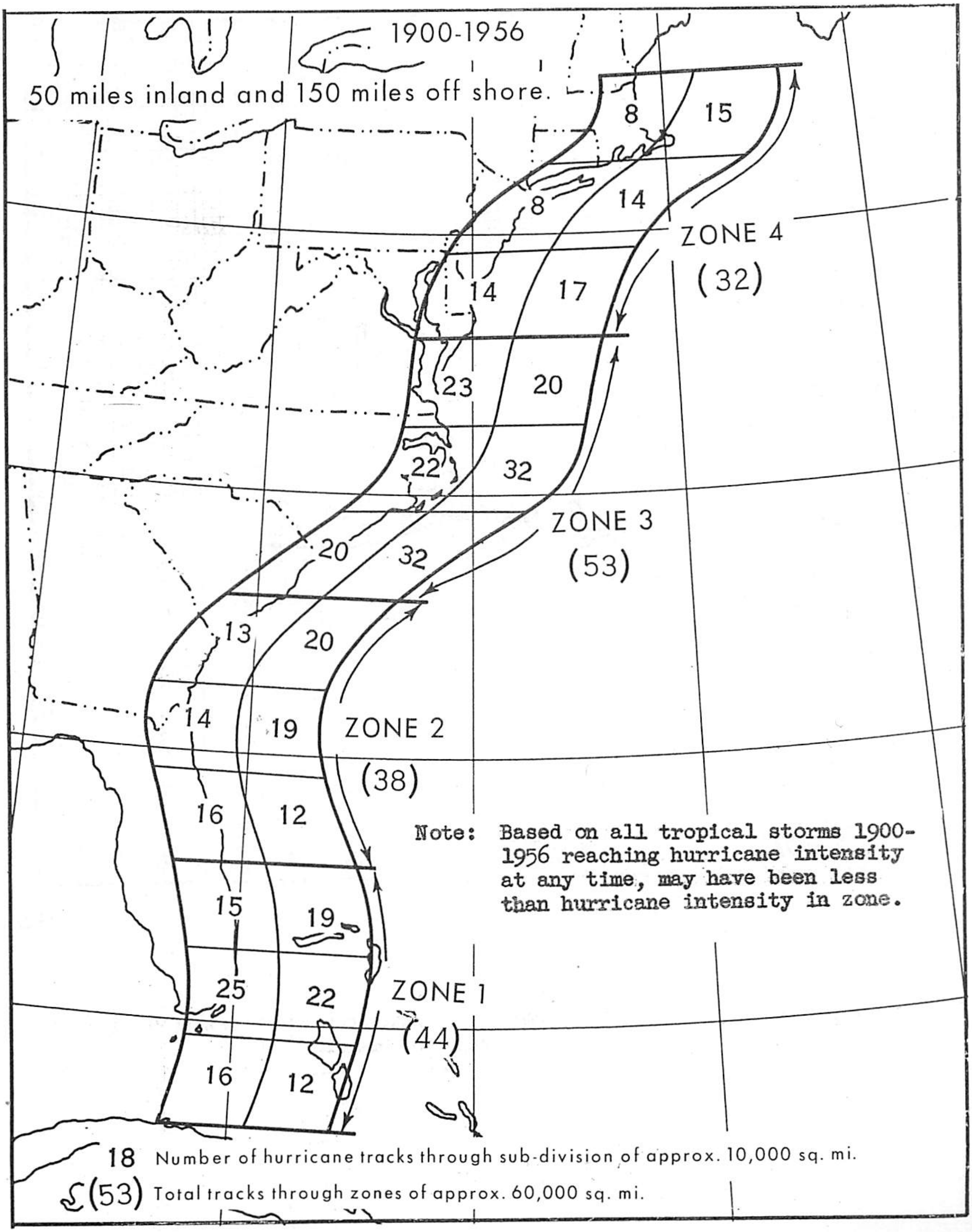


Figure 6. - Atlantic coastal zones with number of hurricane transits per sub-division.

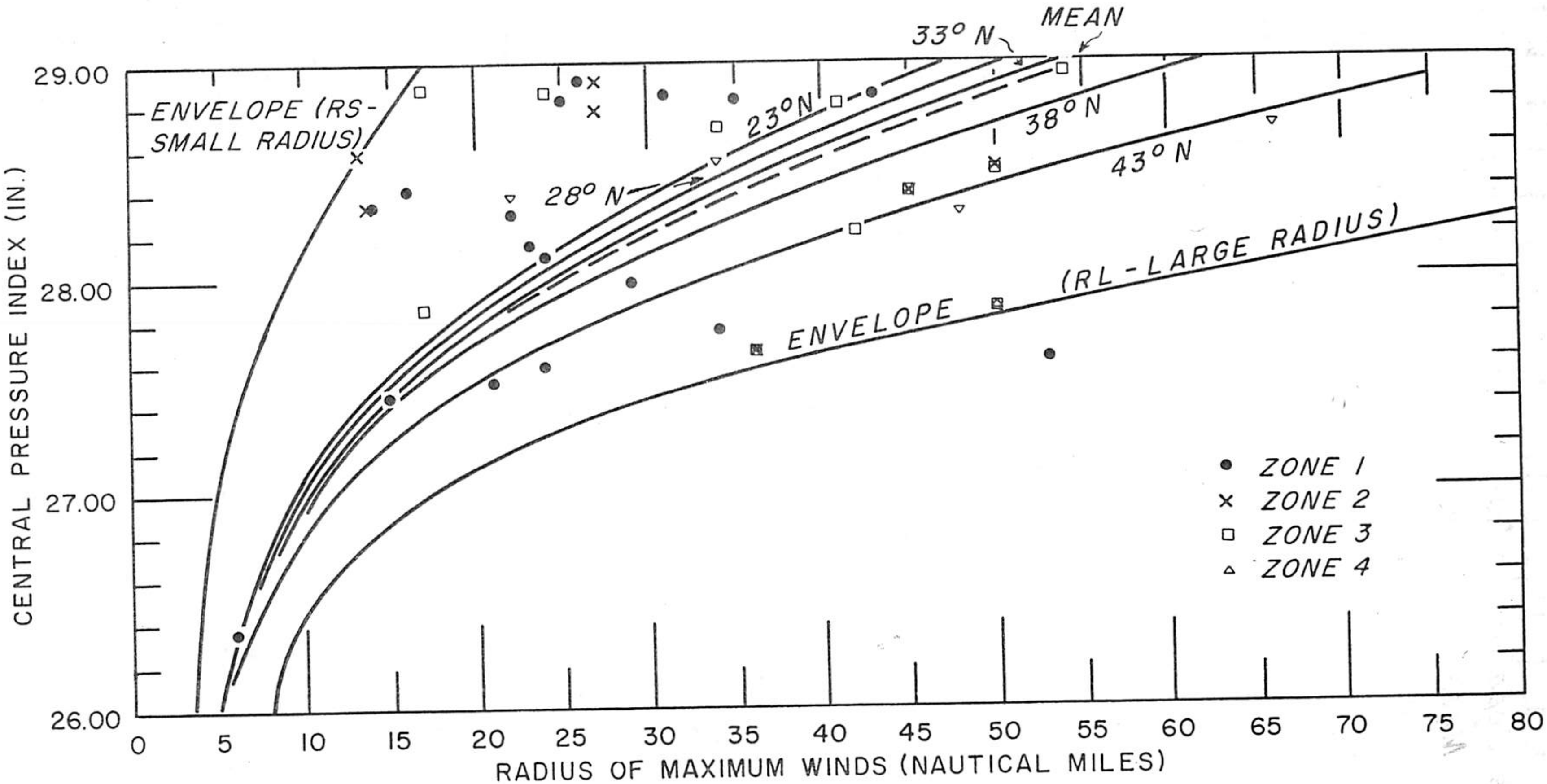


Figure 7. - Variation of radius of maximum winds with central pressure index, Atlantic Coast, 1900-1956.

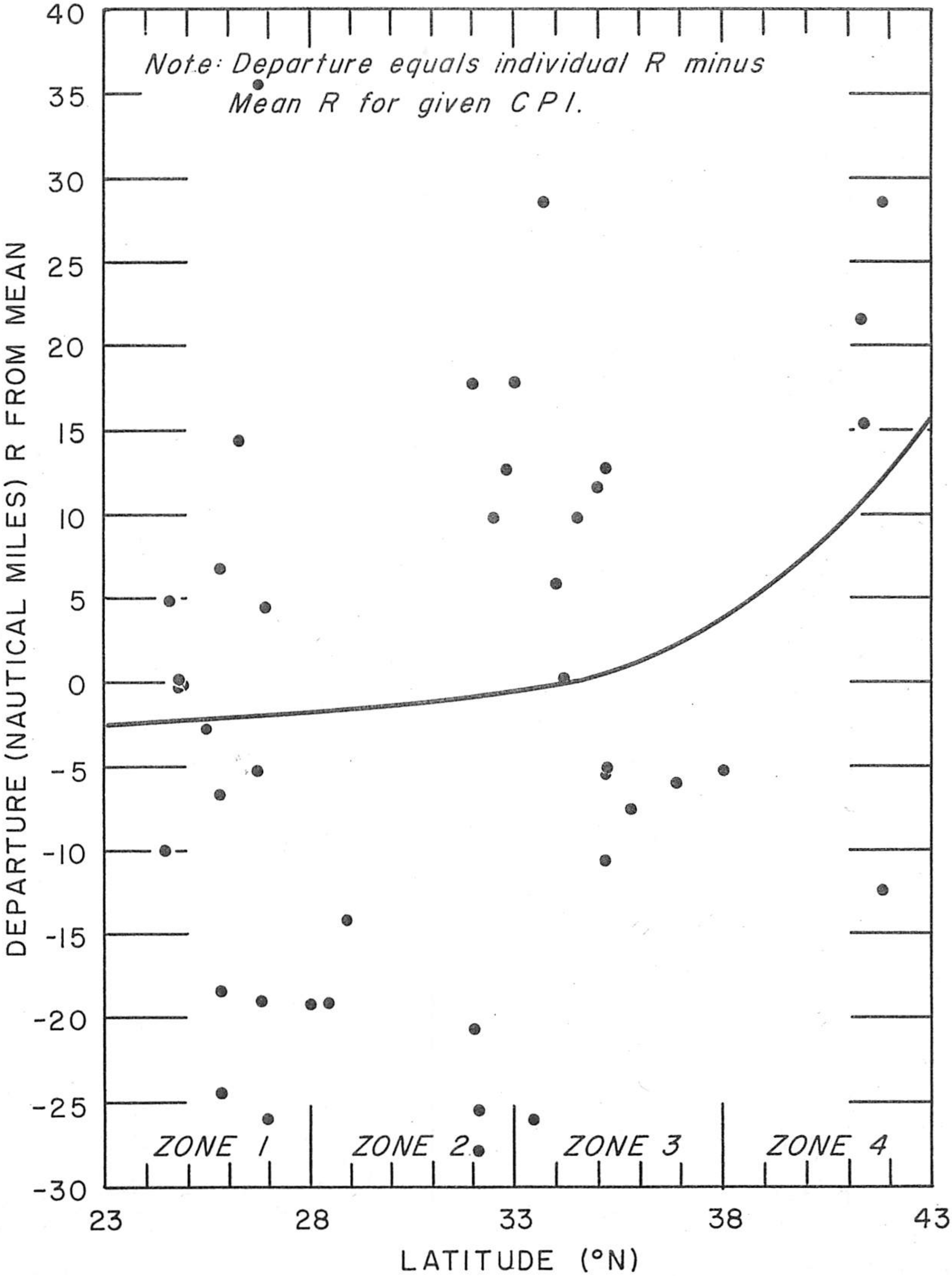
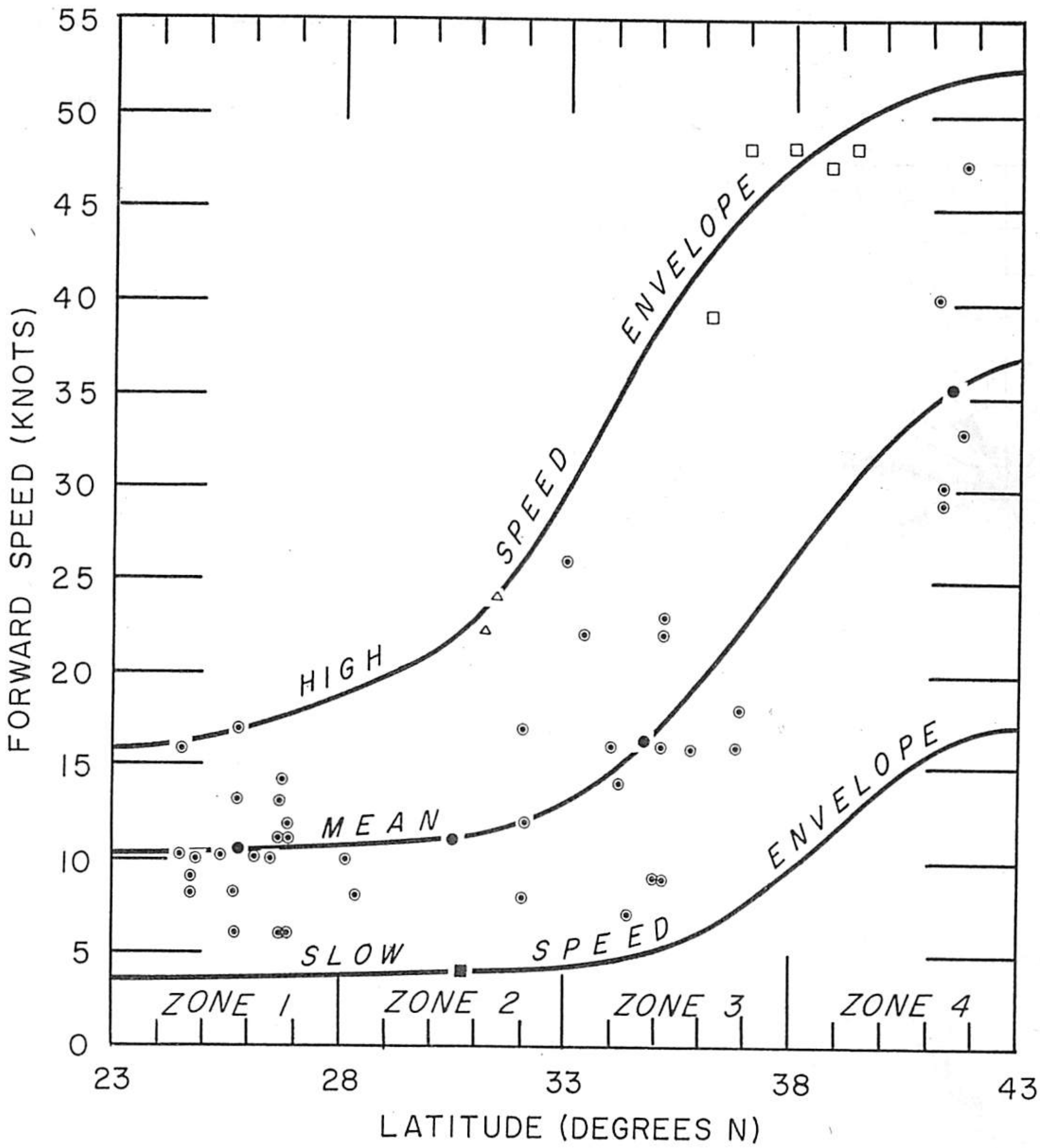


Figure 8. - Variation with latitude of departures of points in figure 7 from mean curve.



Supplementary points:

- ⊙ *Average of 2 hours before and after entering coast*
- ● *Mean for zone of above points.*
- △ *1 hour average speed, October 15, 1954, "Hazel."*
- □ *4 hour average speed, September 21, 1938 at sea.*
- ■ *August 28, 1954 (Carol), 24-hour average, east of zone.*

Figure 9. - Latitudinal variation of rate of movement of hurricane center, Atlantic Coast United States (1900-1956).

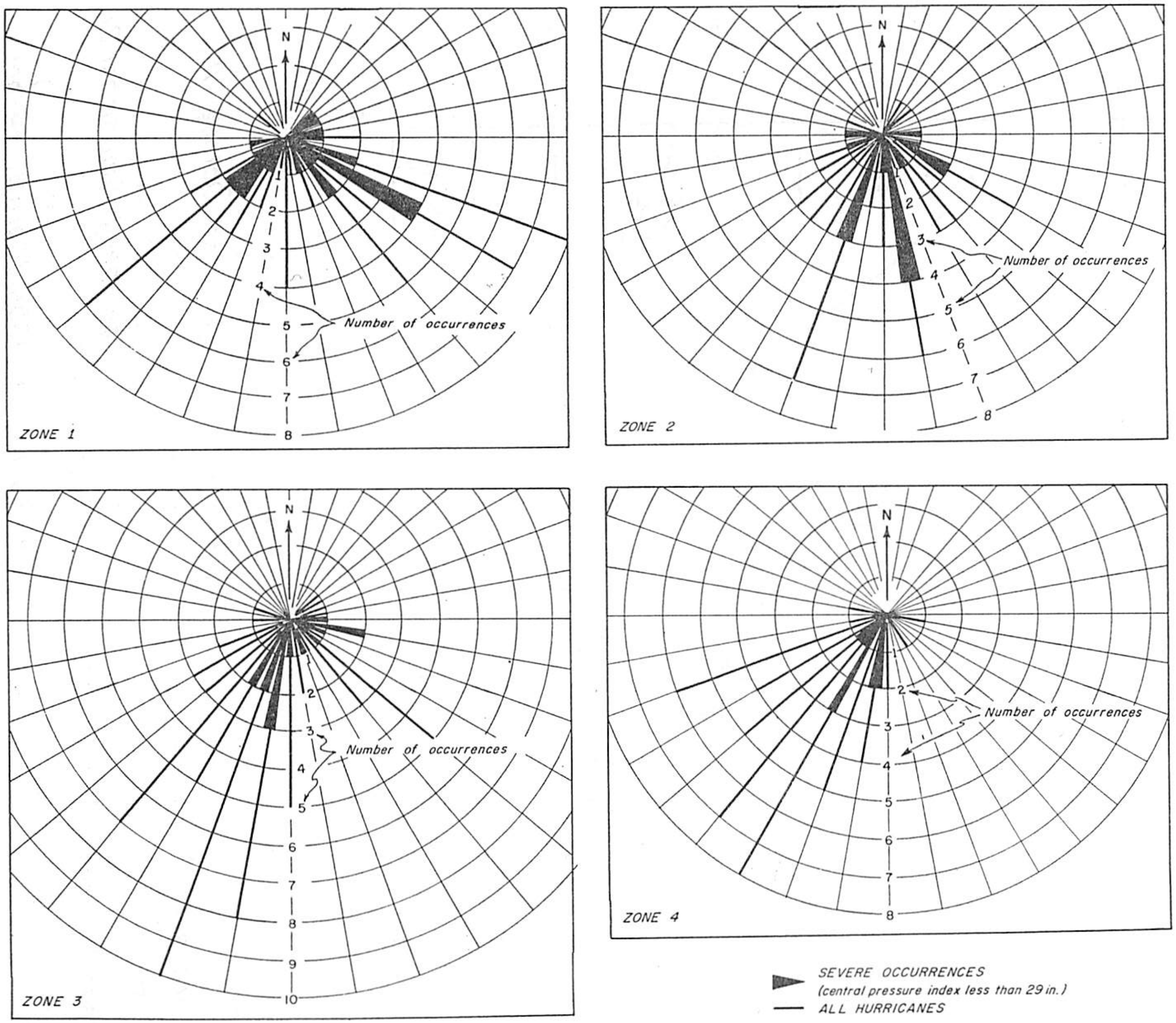


Figure 10. - Azimuth distribution of paths followed by hurricanes, 1887-1956.

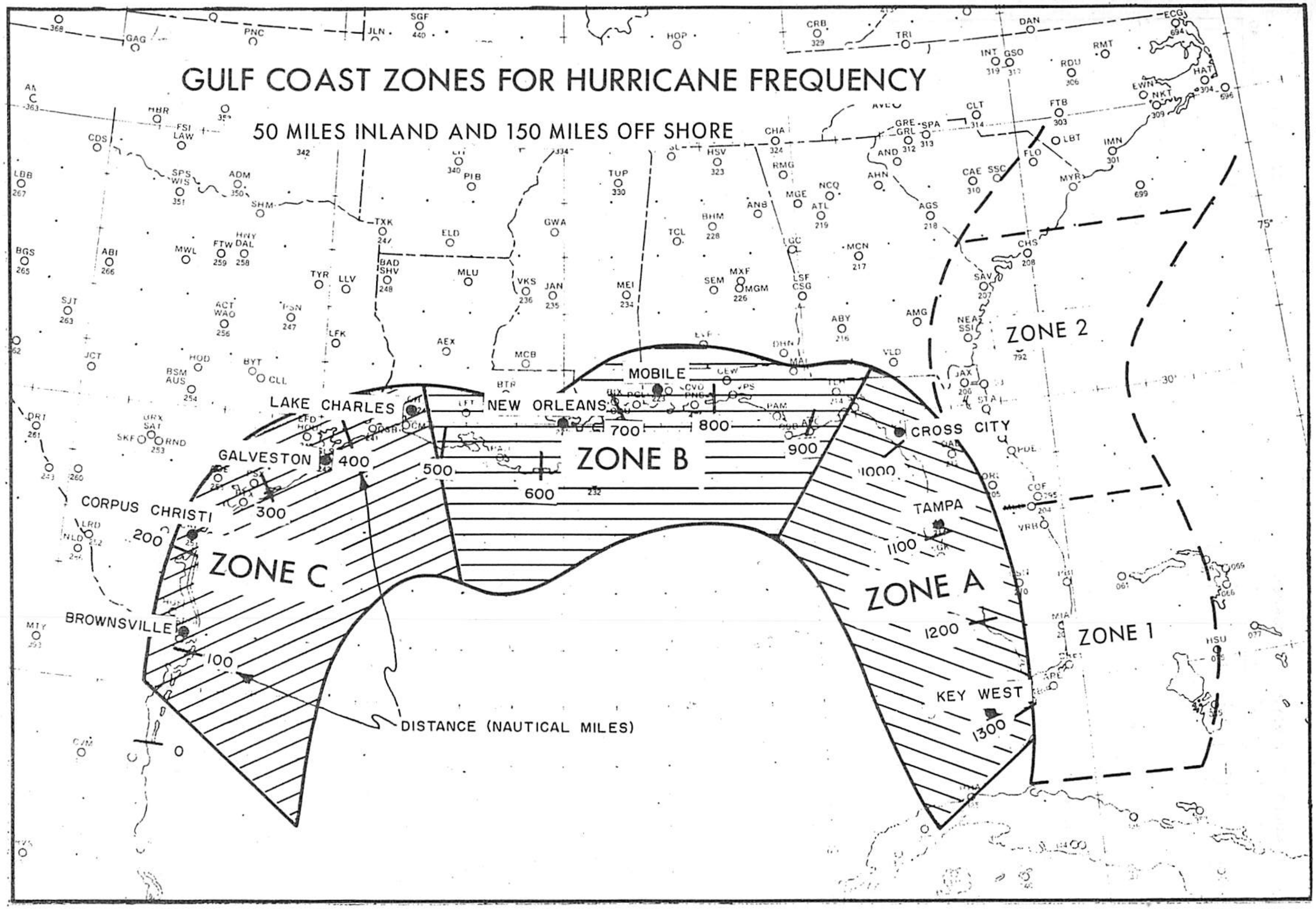

GULF COAST ZONES FOR HURRICANE FREQUENCY
50 MILES INLAND AND 150 MILES OFF SHORE
ZONE A
ZONE B
ZONE C
ZONE 1
ZONE 2
LAKE CHARLES
NEW ORLEANS
MOBILE
CROSS CITY
GALVESTON
CORPUS CHRISTI
BROWNSVILLE
TAMPA
KEY WEST
DISTANCE (NAUTICAL MILES)
0
100
200
300
400
500
600
700
800
900
1000
1100
1200
1300

Figure 11.

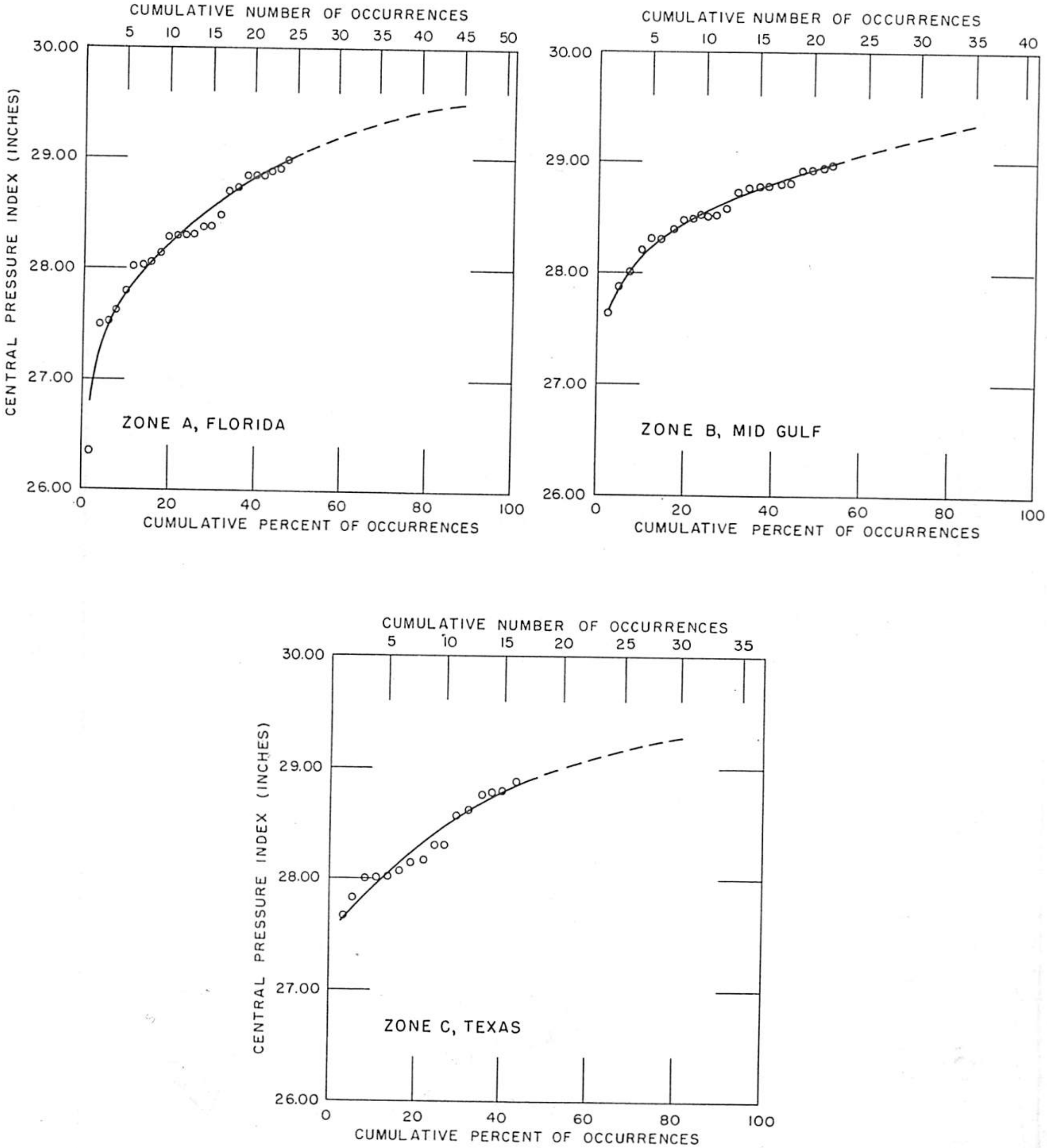


Figure 12. - Cumulative frequency of hurricane central pressure index, Gulf Coast United States (1900-1956).

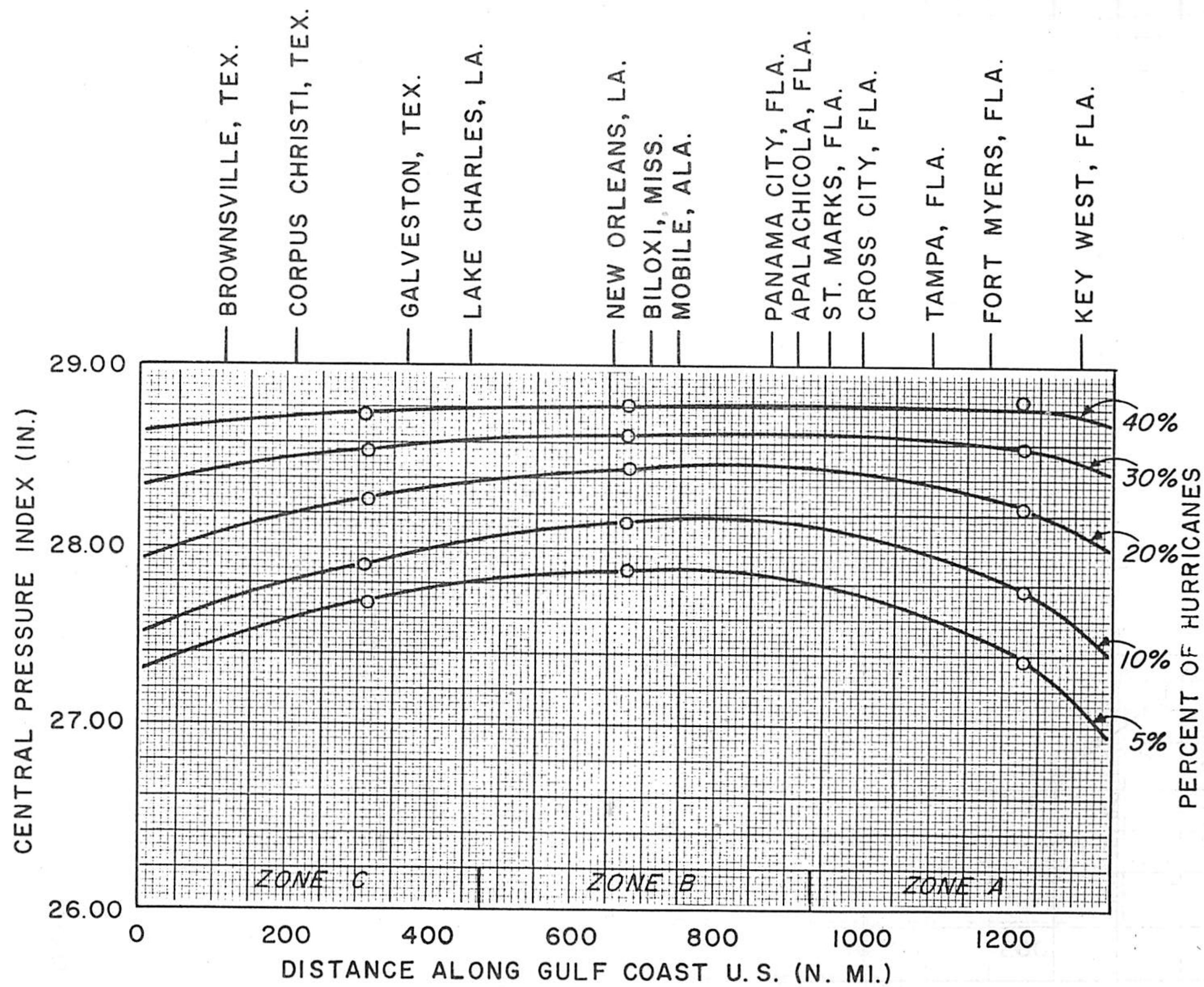


Figure 13. - Geographic variation of cumulative frequency of hurricane central pressure index, Gulf Coast (1900-1956) over zones A, B, and C of approximately 80,000 square miles.

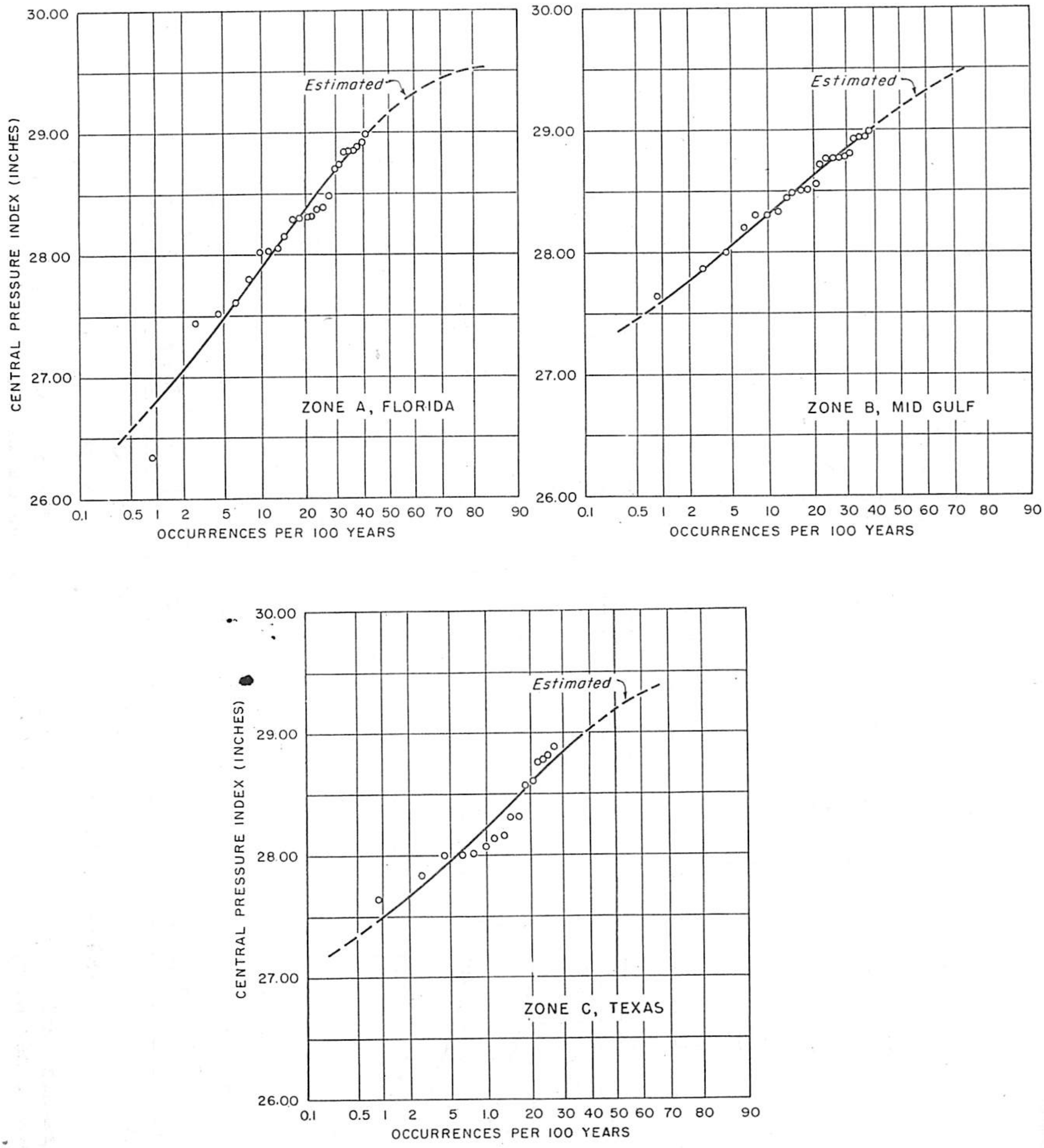


Figure 14. - Cumulative frequency of hurricane central pressure index 1900-1956 (plotted as frequency per 100 years).

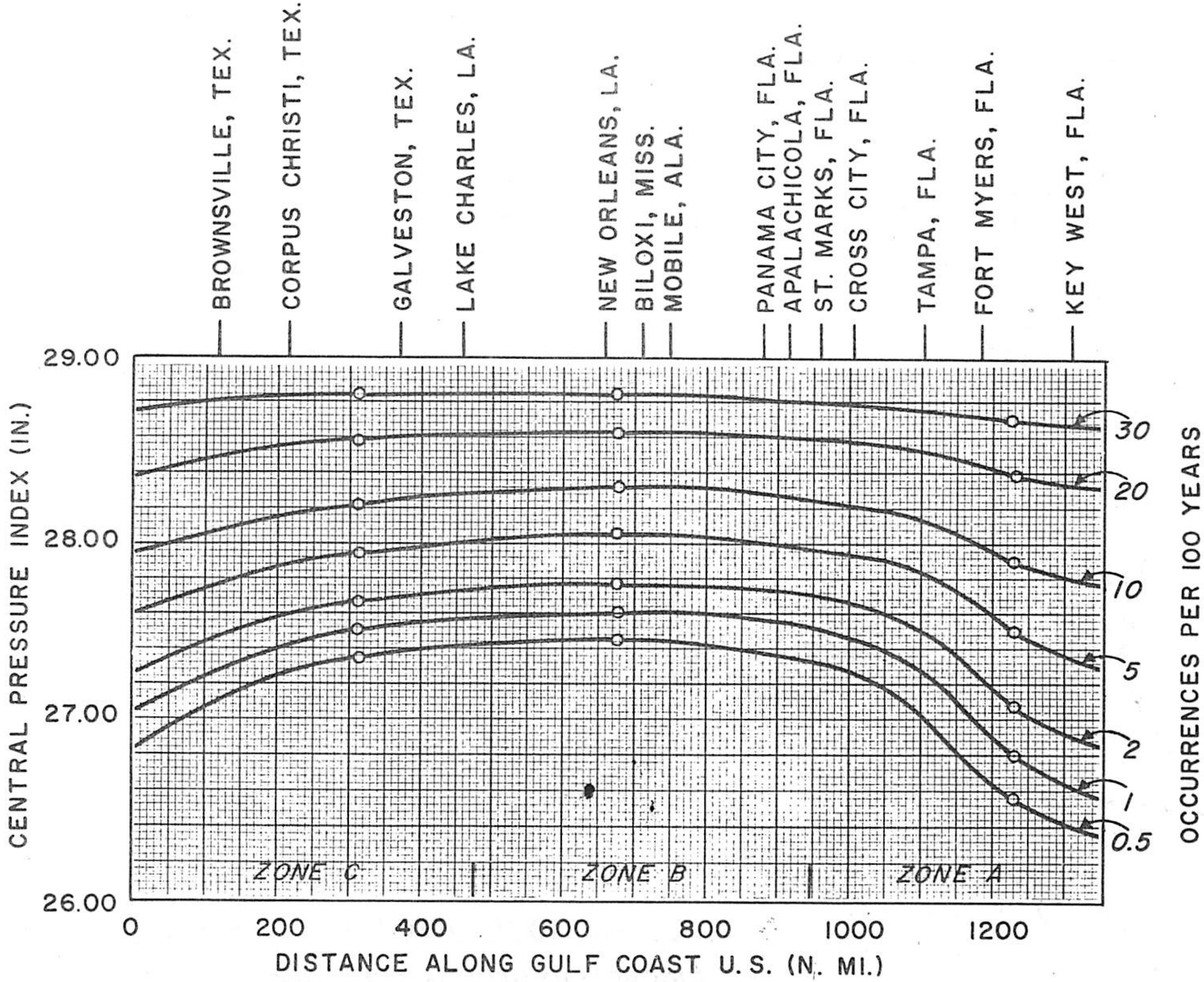
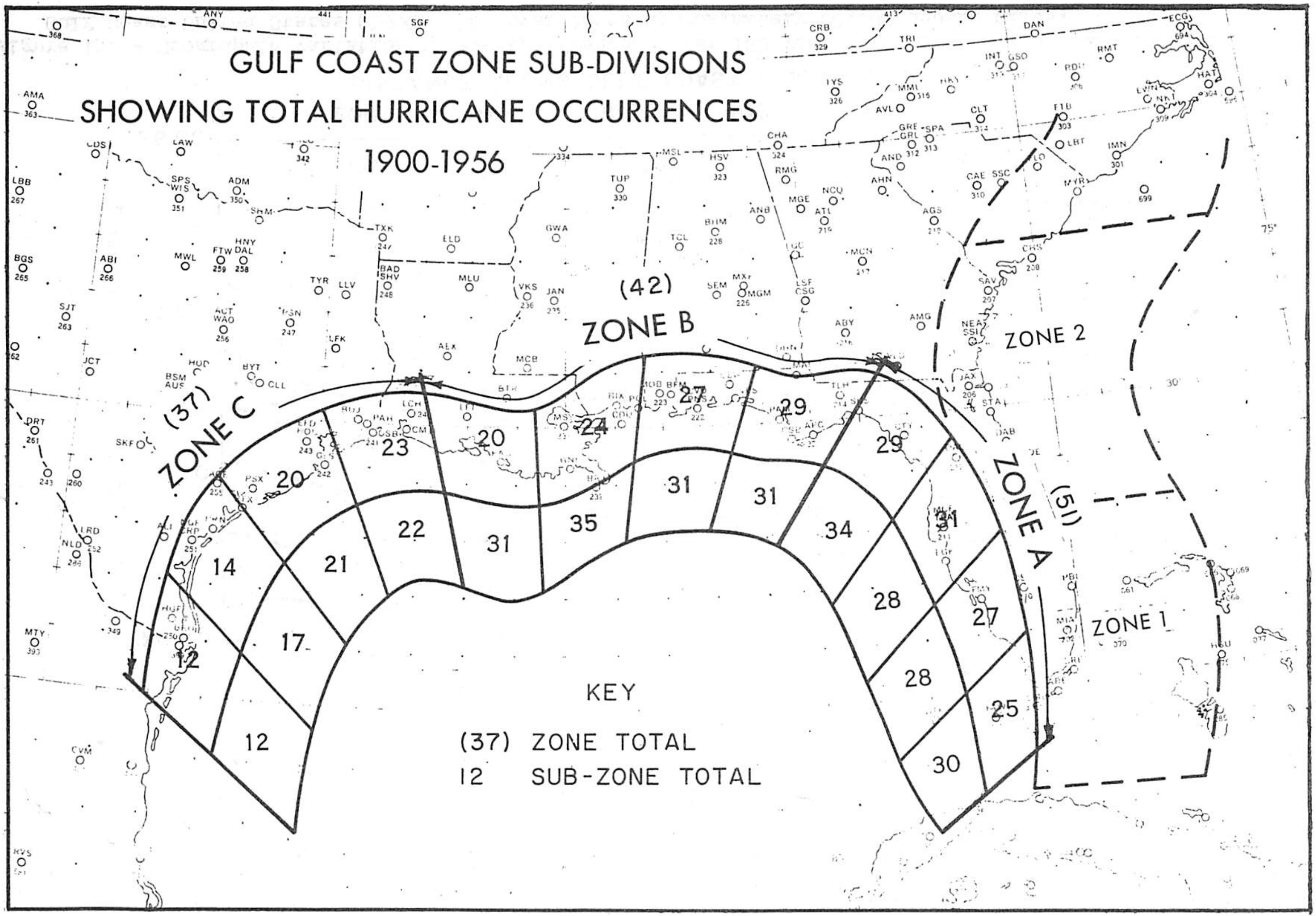


Figure 15. - Geographic variation of average frequency per 100 years of hurricane central pressure index, Gulf Coast United States (1900-1956) over zones approximately 80,000 square miles.


GULF COAST ZONE SUB-DIVISIONS
SHOWING TOTAL HURRICANE OCCURRENCES
1900-1956
ZONE A
(51)
ZONE B
(42)
ZONE C
(37)
ZONE 1
ZONE 2
KEY
(37) ZONE TOTAL
12 SUB-ZONE TOTAL
14
12
17
12
20
21
23
22
20
31
24
35
27
31
29
31
29
34
31
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27
28
25
30

Figure 16

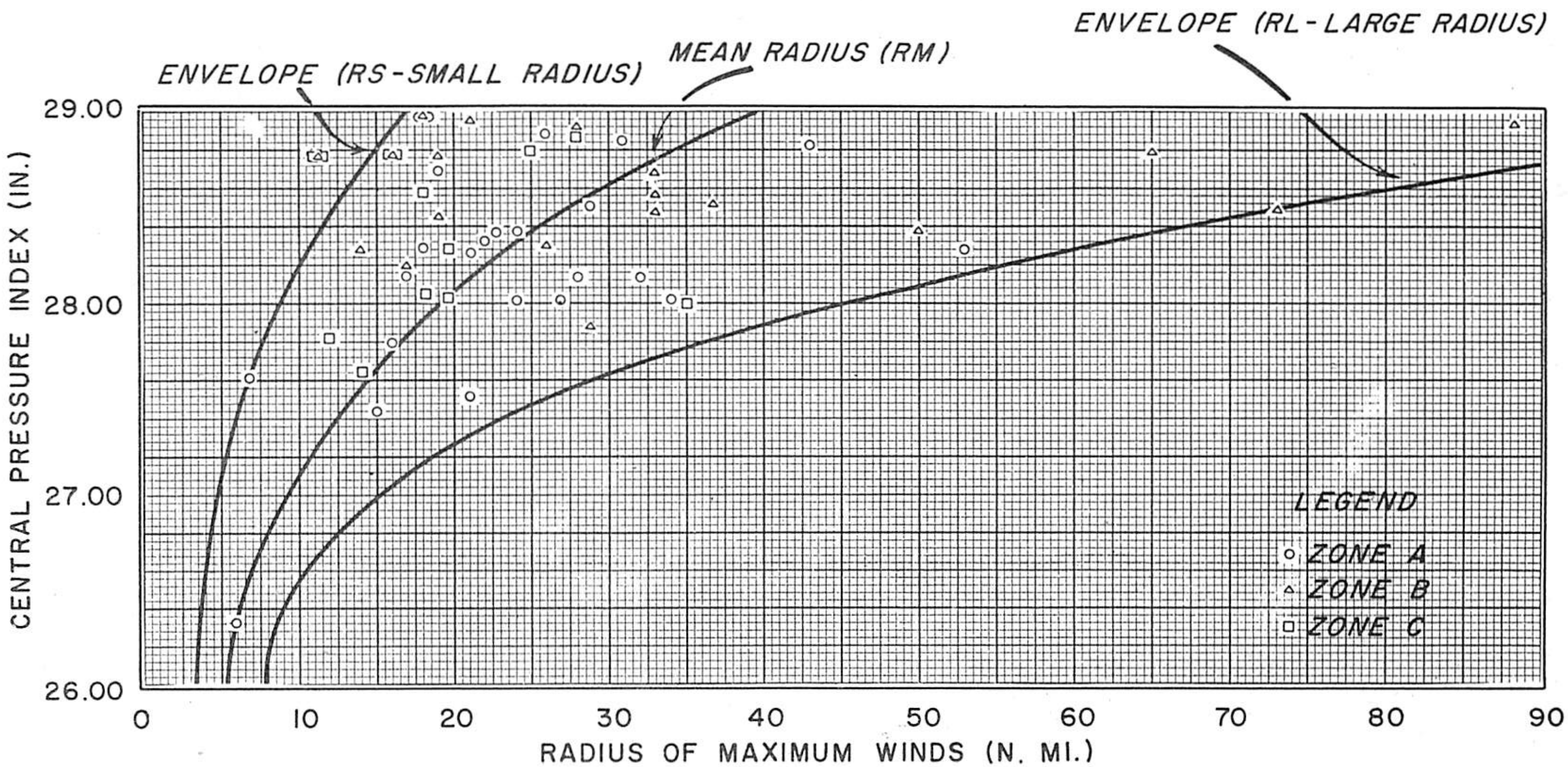


Figure 17. - Variation of radius of maximum winds with central pressure index, Gulf Coast, 1900-1956.

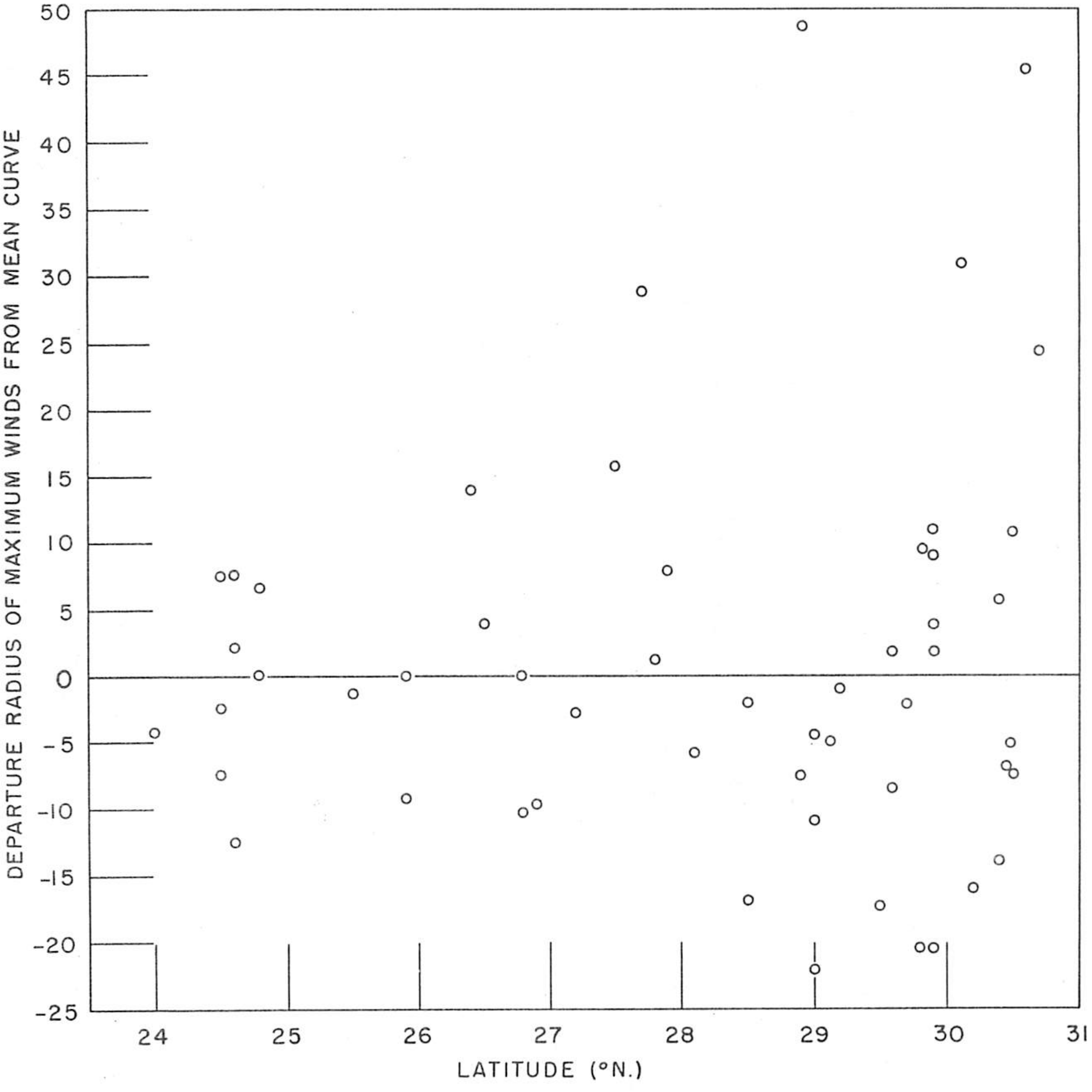


Figure 18. - Variation with latitude of departure of radius of maximum winds from mean curve of figure 17.

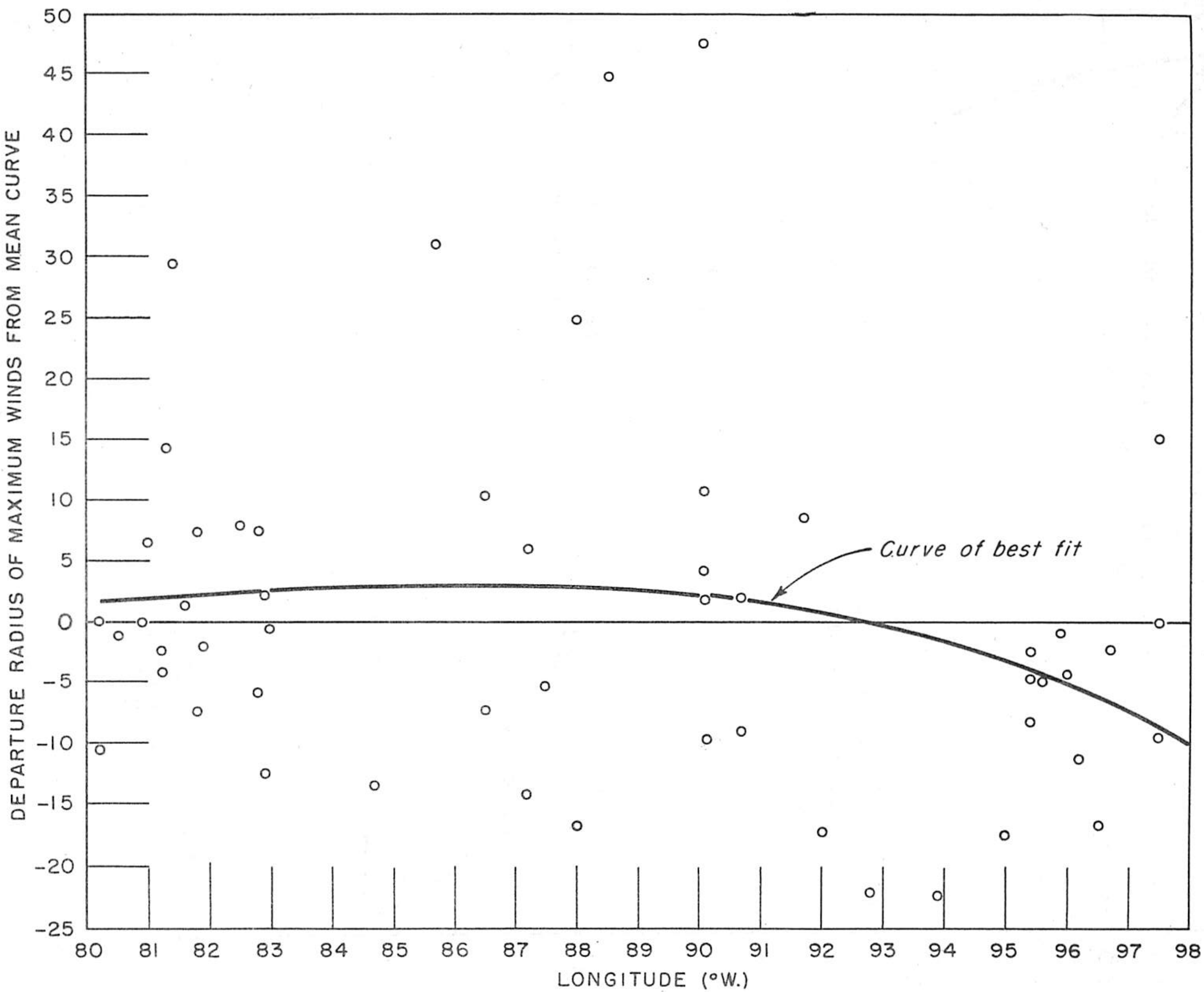


Figure 19. - Variation with longitude of departure of radius of maximum winds from mean curve of figure 17.

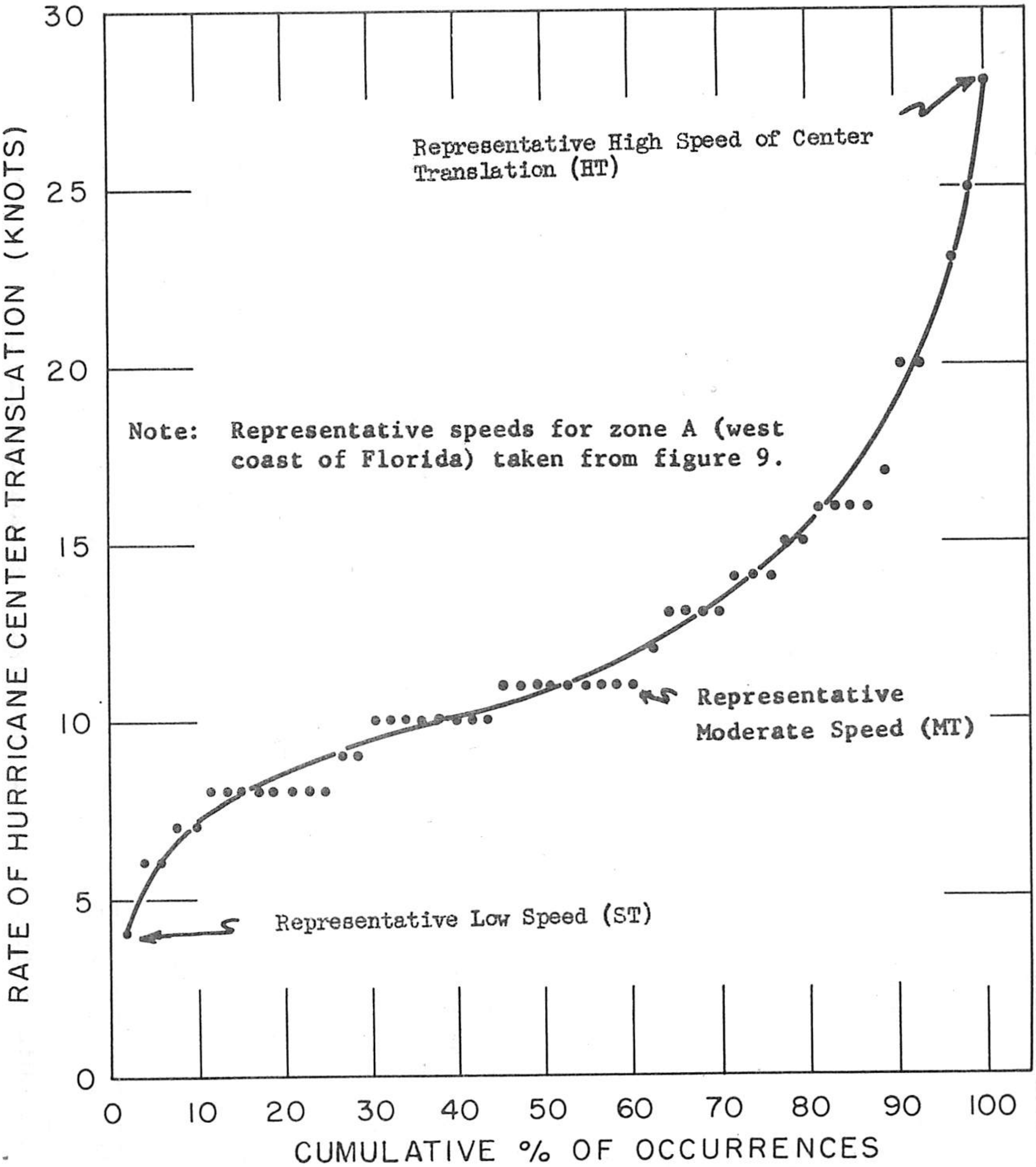


Figure 20. - Percentage distribution of rate of hurricane center translation, Gulf Coast United States, 1900-1956.

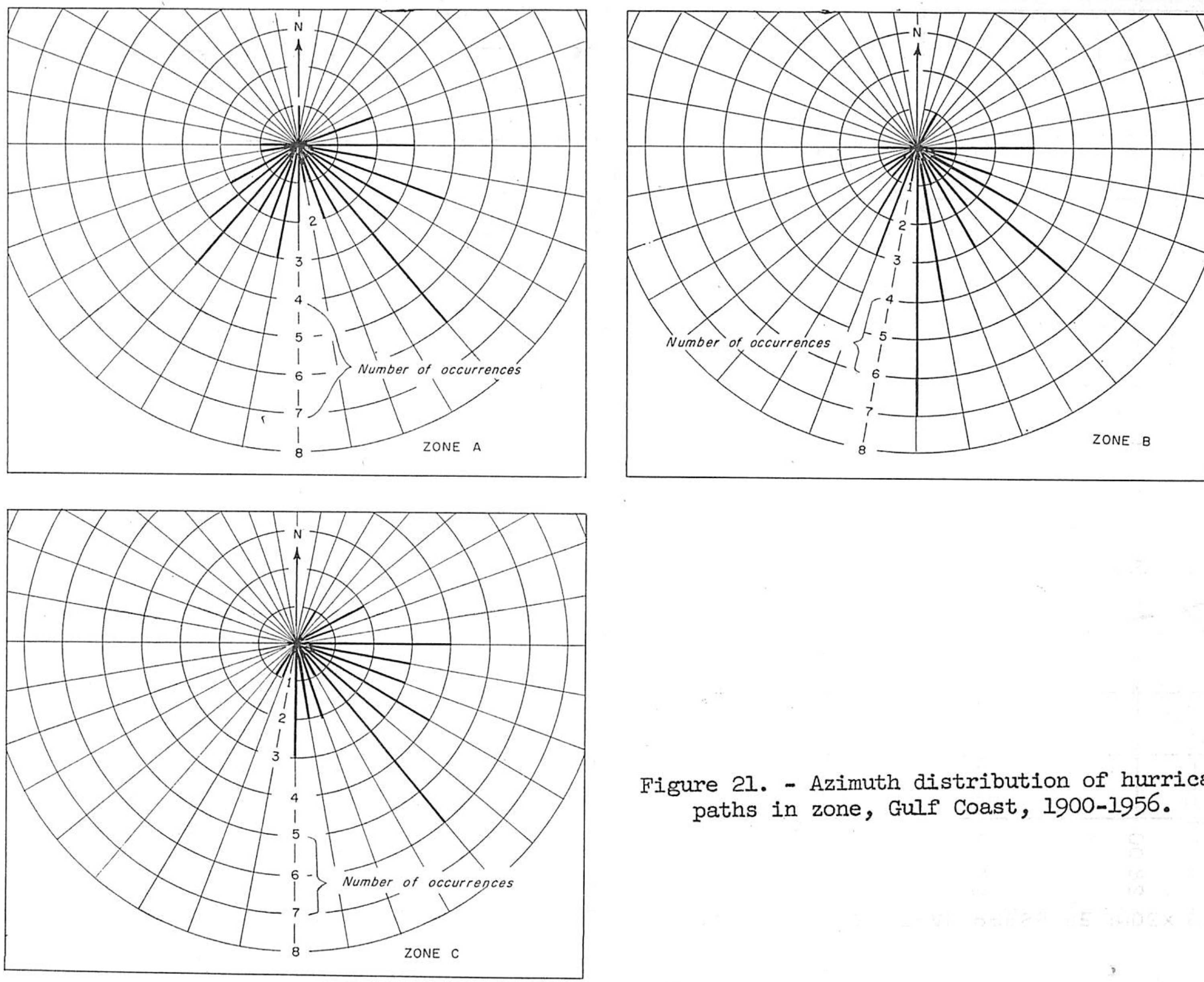
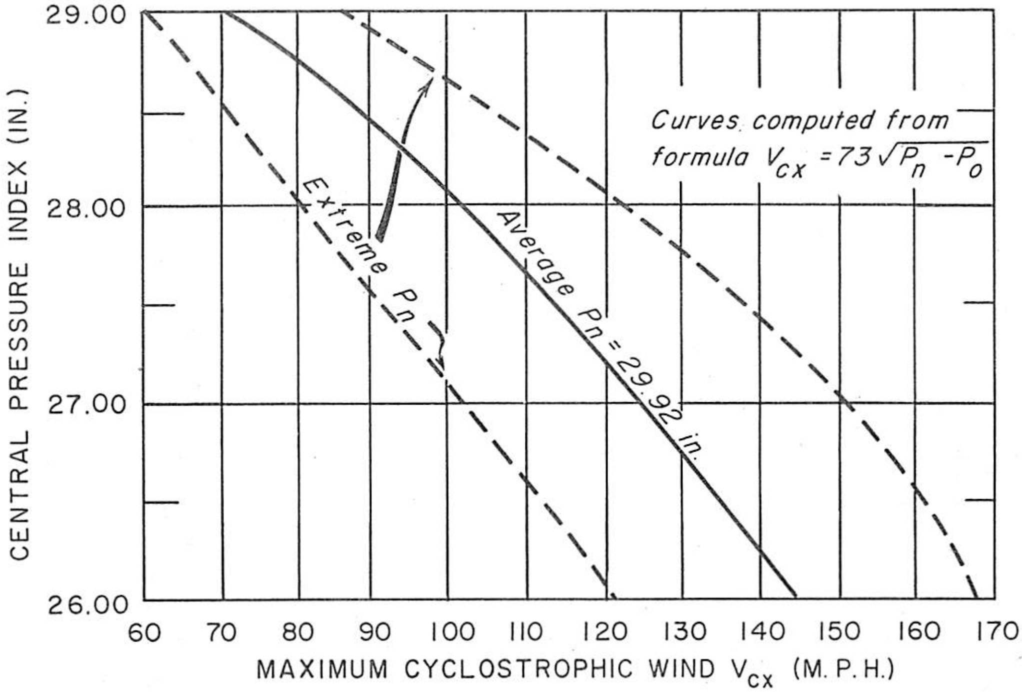
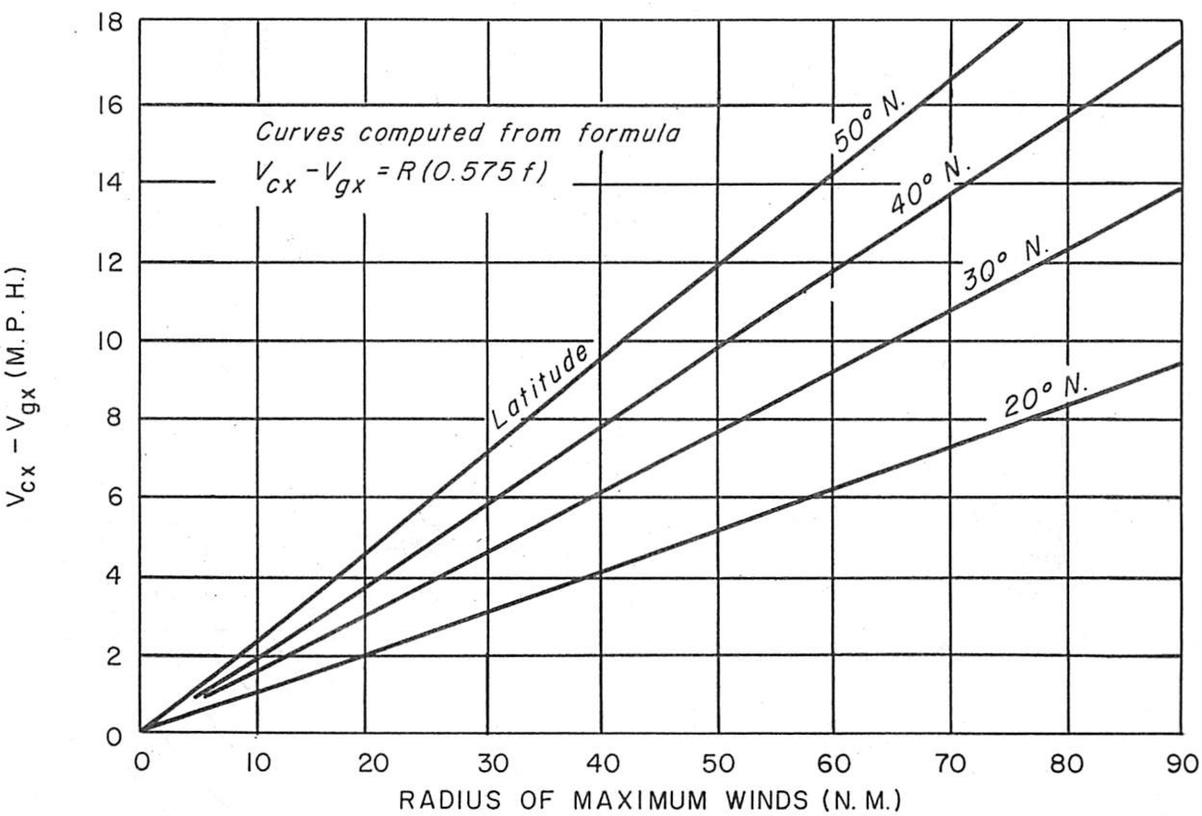


Figure 21. - Azimuth distribution of hurricane paths in zone, Gulf Coast, 1900-1956.

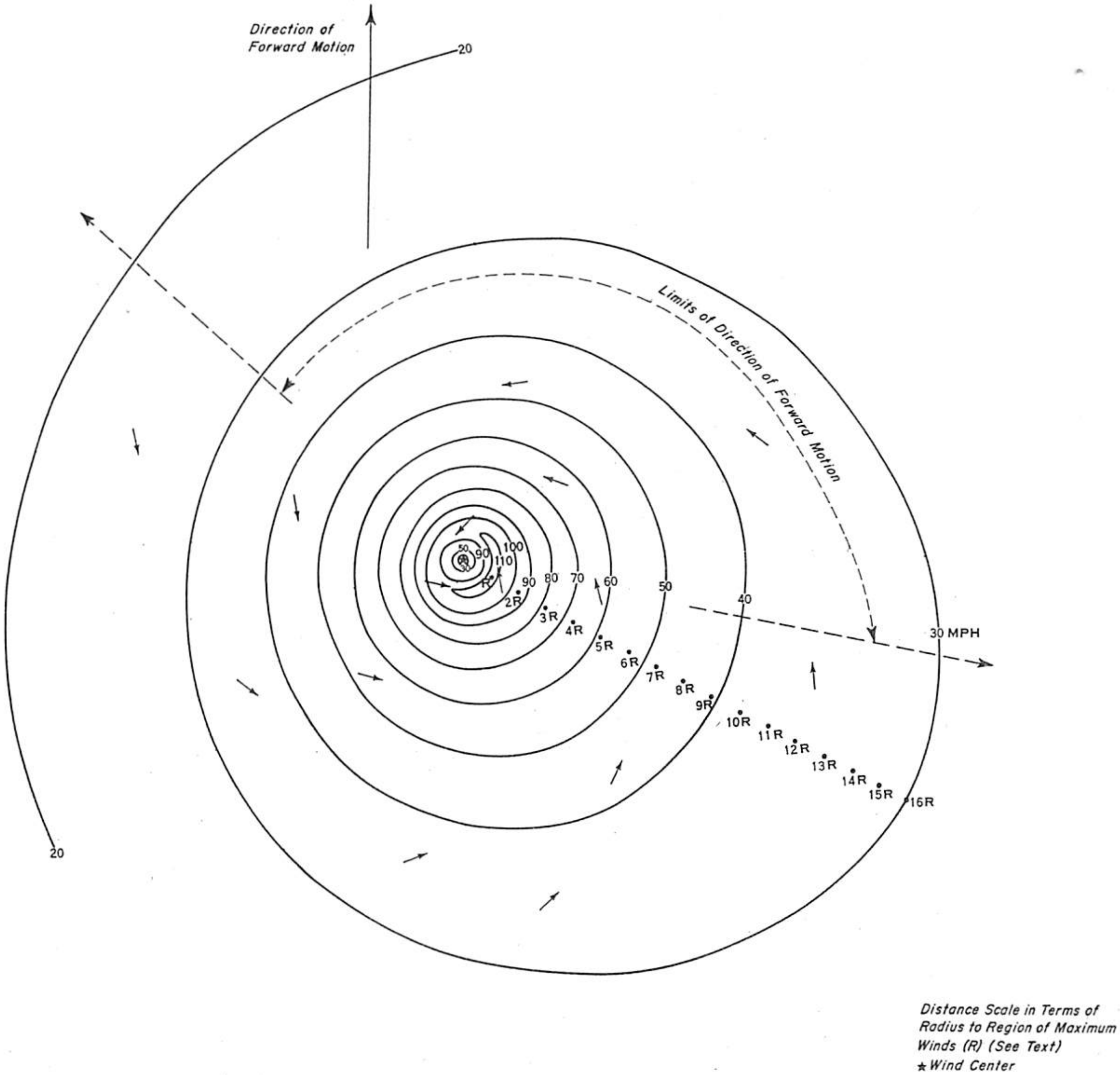




Note: To obtain maximum gradient wind, V_{gx}, find maximum cyclostrophic wind from upper figure and subtract correction obtained from lower figure.

Figure 22. - Relation of maximum gradient wind to central pressure index.

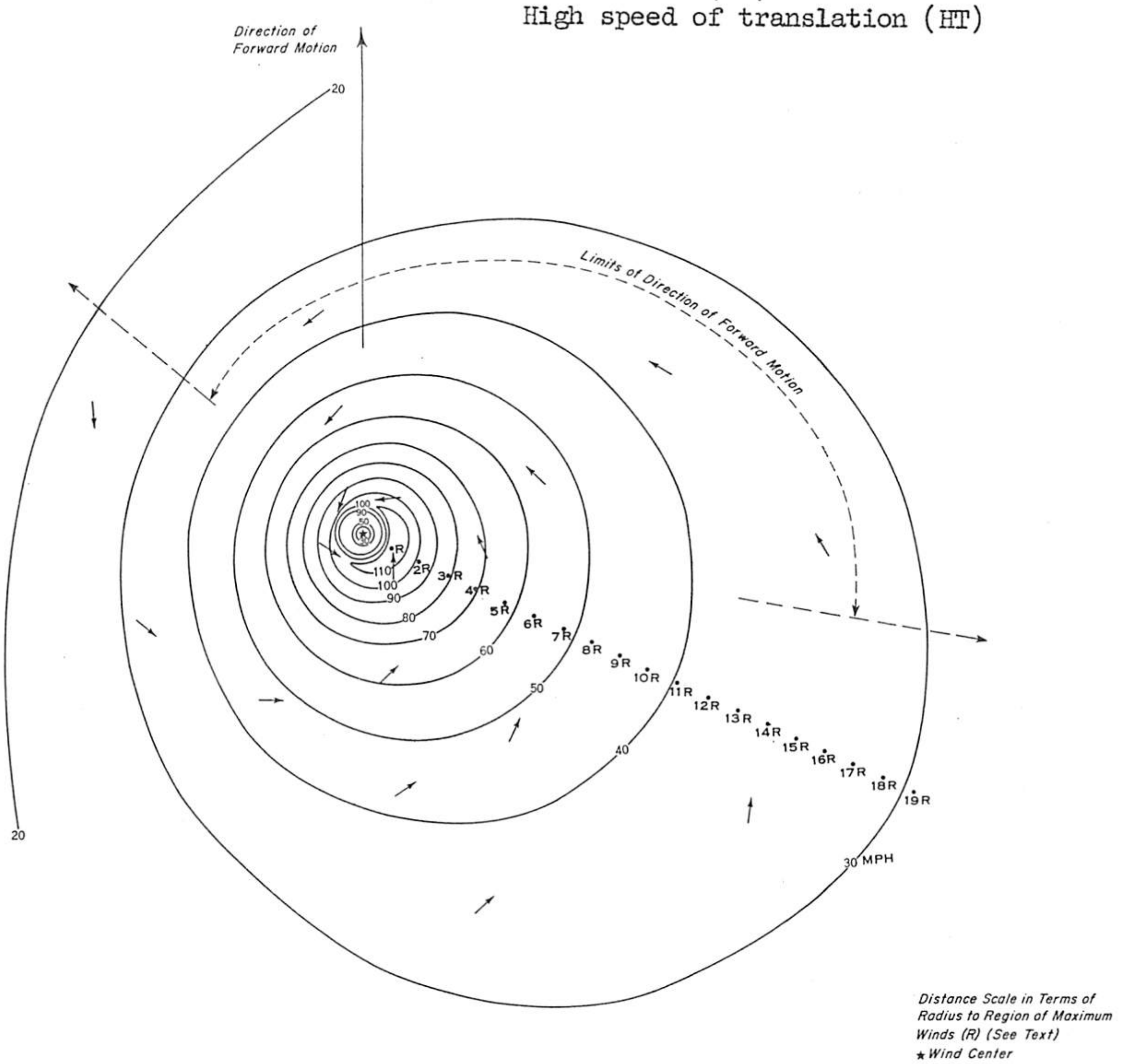
Zone 1 (Southern Florida, East Coast)
Mean Radius (RM)
Moderate speed of translation (MT)



Note: For CPI of 26.74 inches, to adjust CPI, see table 3.

Figure 23. - Standard Project Hurricane 30-ft. over-water isovel pattern.

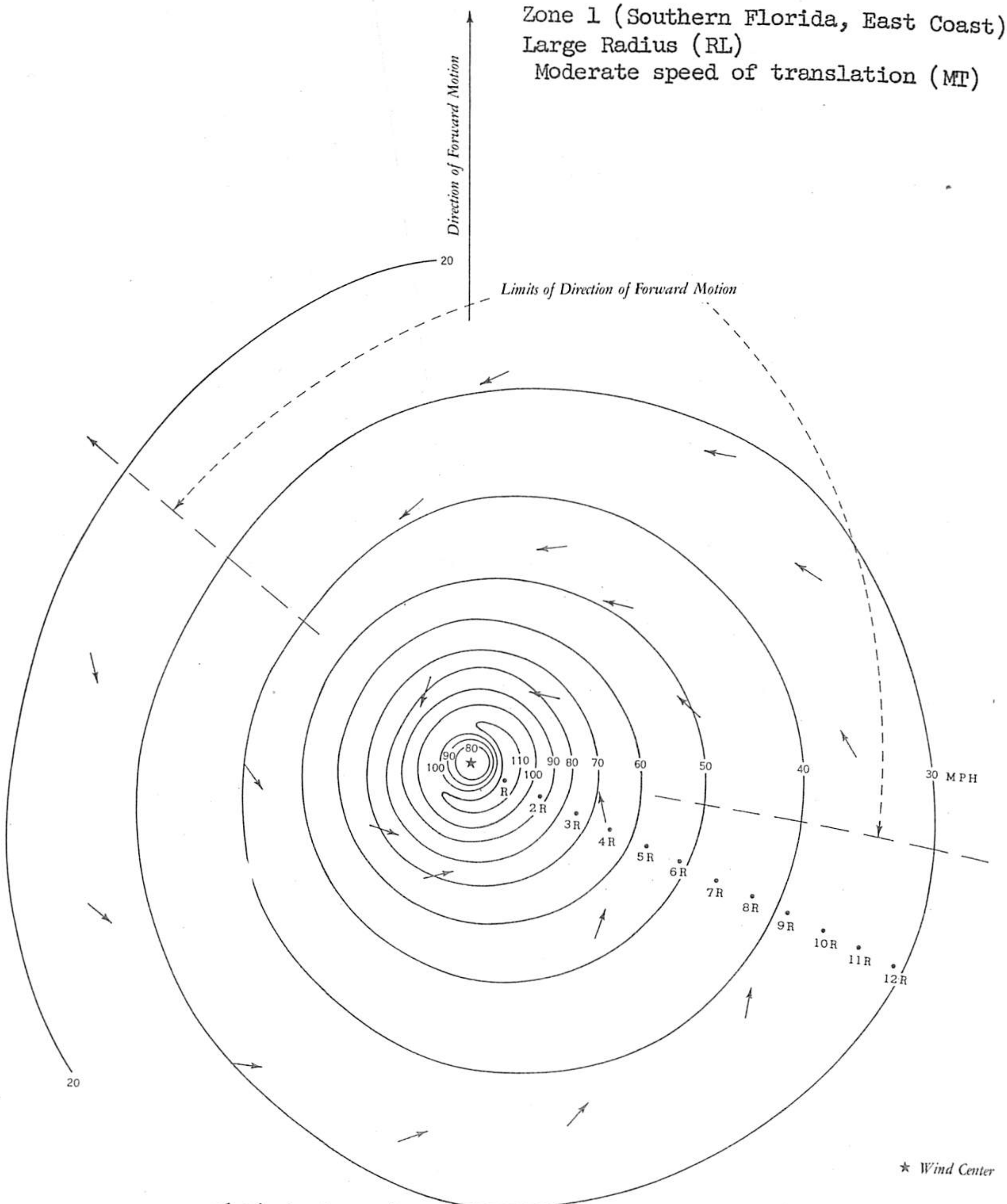
Zone 1 (Southern Florida, East Coast)
Mean Radius (RM)
High speed of translation (HT)



Note: For CPI of 26.74 inches, to adjust CPI, see table 3.

Figure 24. - Standard Project Hurricane 30-ft. over-water isovel pattern.

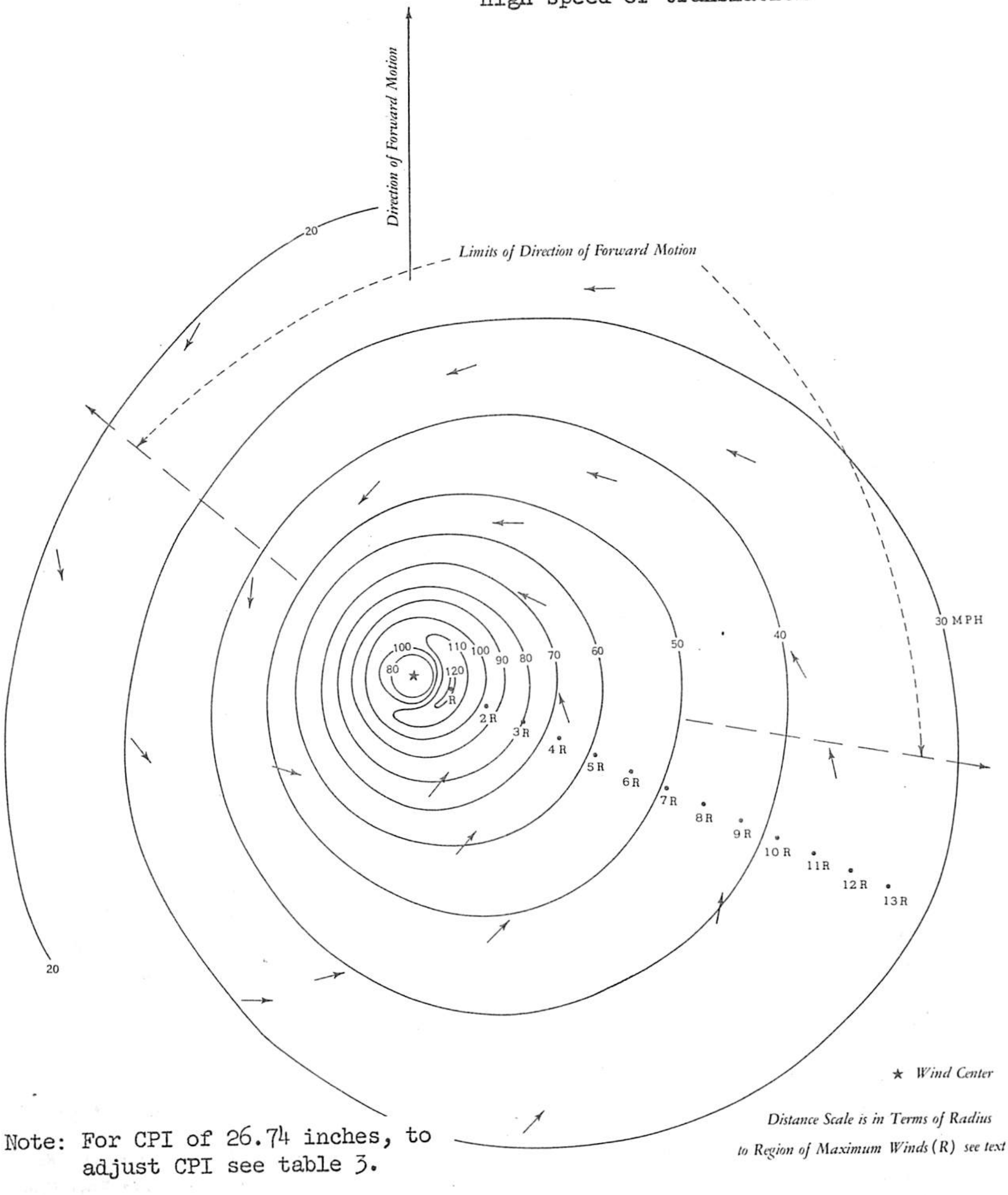
Zone 1 (Southern Florida, East Coast)
Large Radius (RL)
Moderate speed of translation (MT)



Note: For CPI of 26.74 inches, to adjust CPI see table 3.

Figure 25. - Standard Project Hurricane 30-ft. over-water isovel pattern.

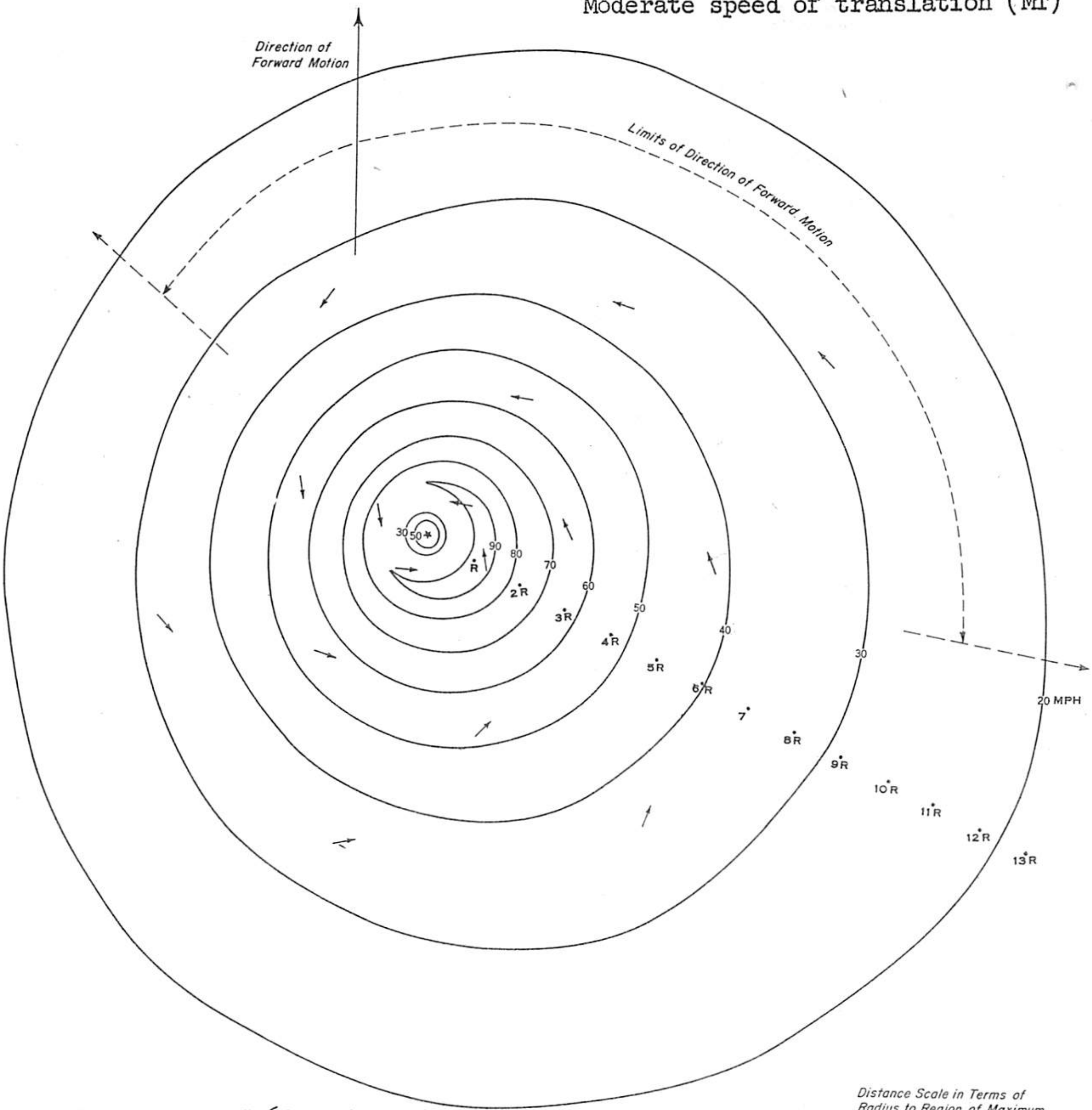
Zone 1 (Southern Florida, East Coast)
High speed of translation



Note: For CPI of 26.74 inches, to
adjust CPI see table 3.

Figure 26. - Standard Project Hurricane 30-ft. over-water isovel pattern.

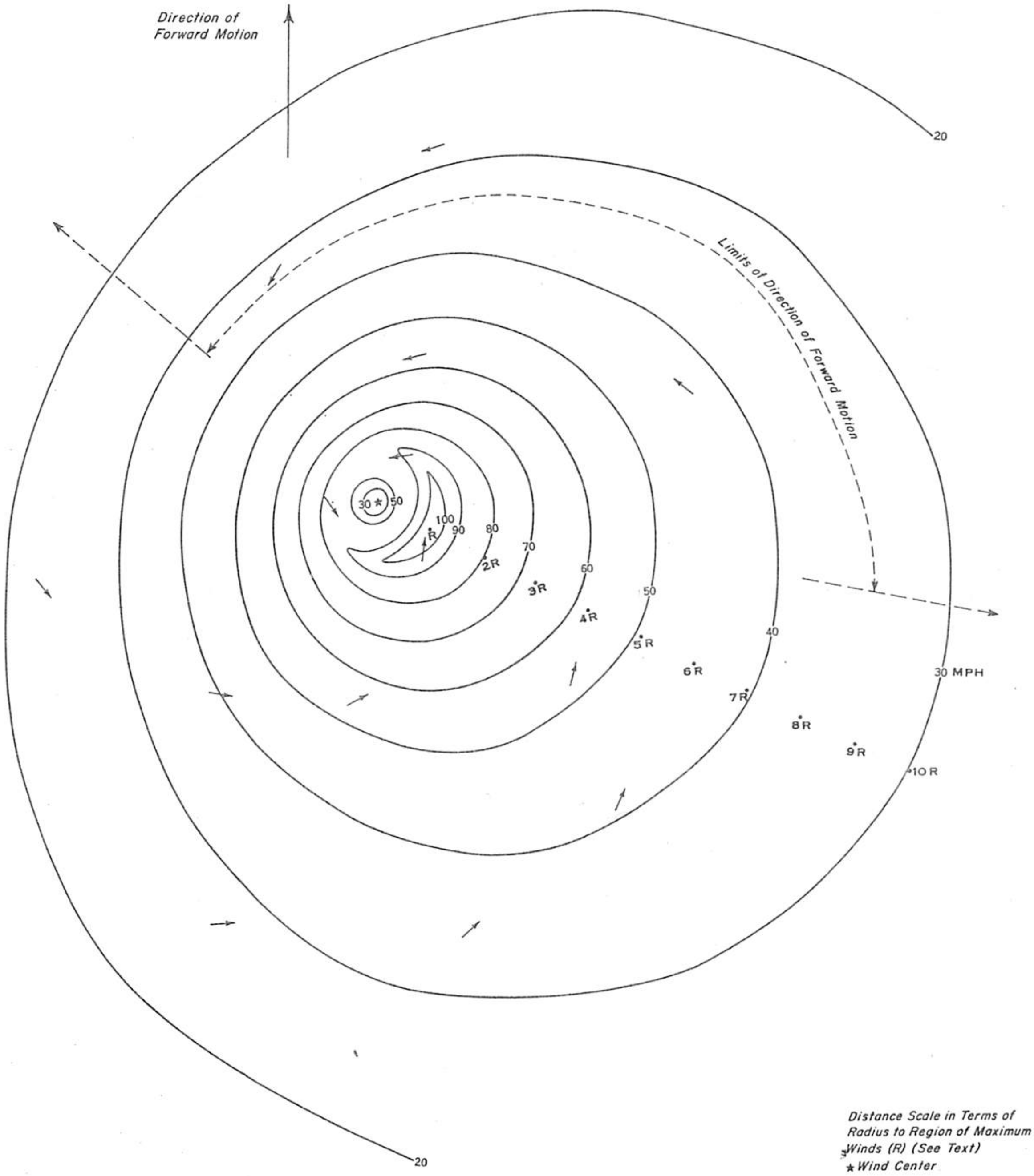
Zone 2 (Northern Florida to South Carolina)
Mean Radius (RM)
Moderate speed of translation (MT)



Note: For CPI of 27.65 inches, to adjust CPI see table 3.

Figure 27. - Standard Project Hurricane 30-ft. over-water isovel pattern.

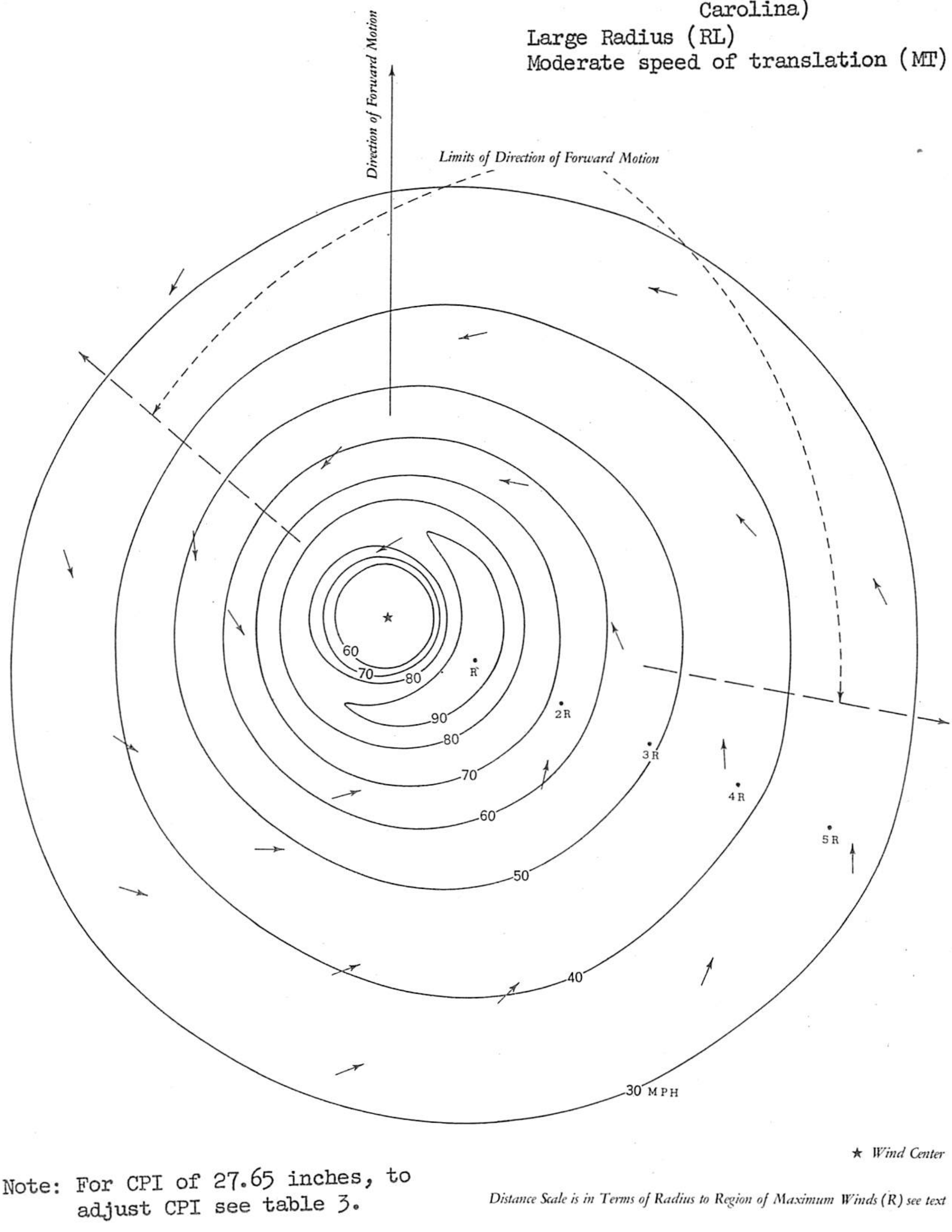
Zone 2 (Northern Florida to South Carolina)
Mean Radius (RM)
High speed of translation (HT)



Note: For CPI of 27.65 inches, to adjust CPI see table 3.

Figure 28. - Standard Project Hurricane 30-ft. over-water isovel pattern.

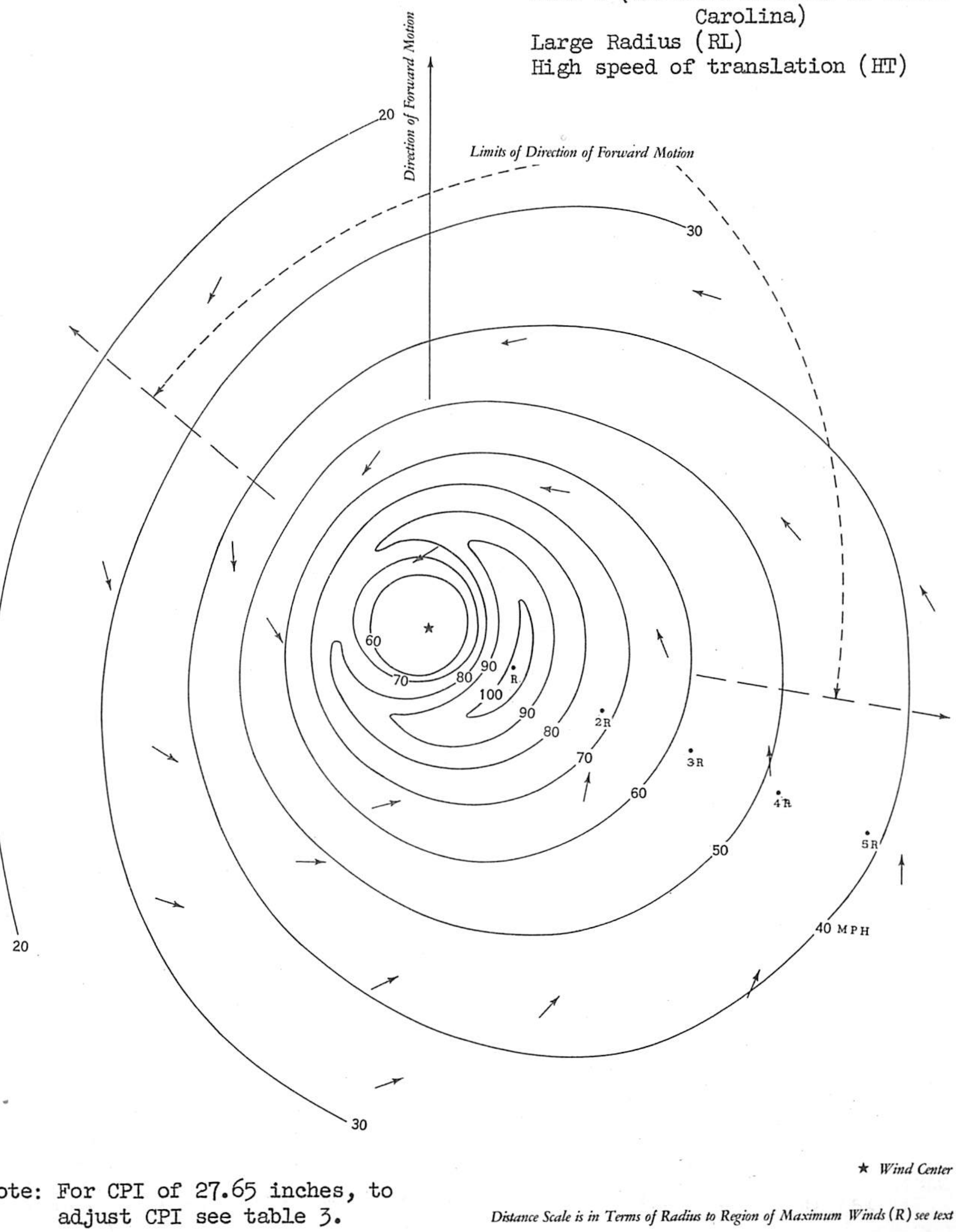
Zone 2 (Northern Florida to South Carolina)
Large Radius (RL)
Moderate speed of translation (MT)



Note: For CPI of 27.65 inches, to adjust CPI see table 3.

Figure 29. - Standard Project Hurricane 30-ft. over-water isovel pattern.

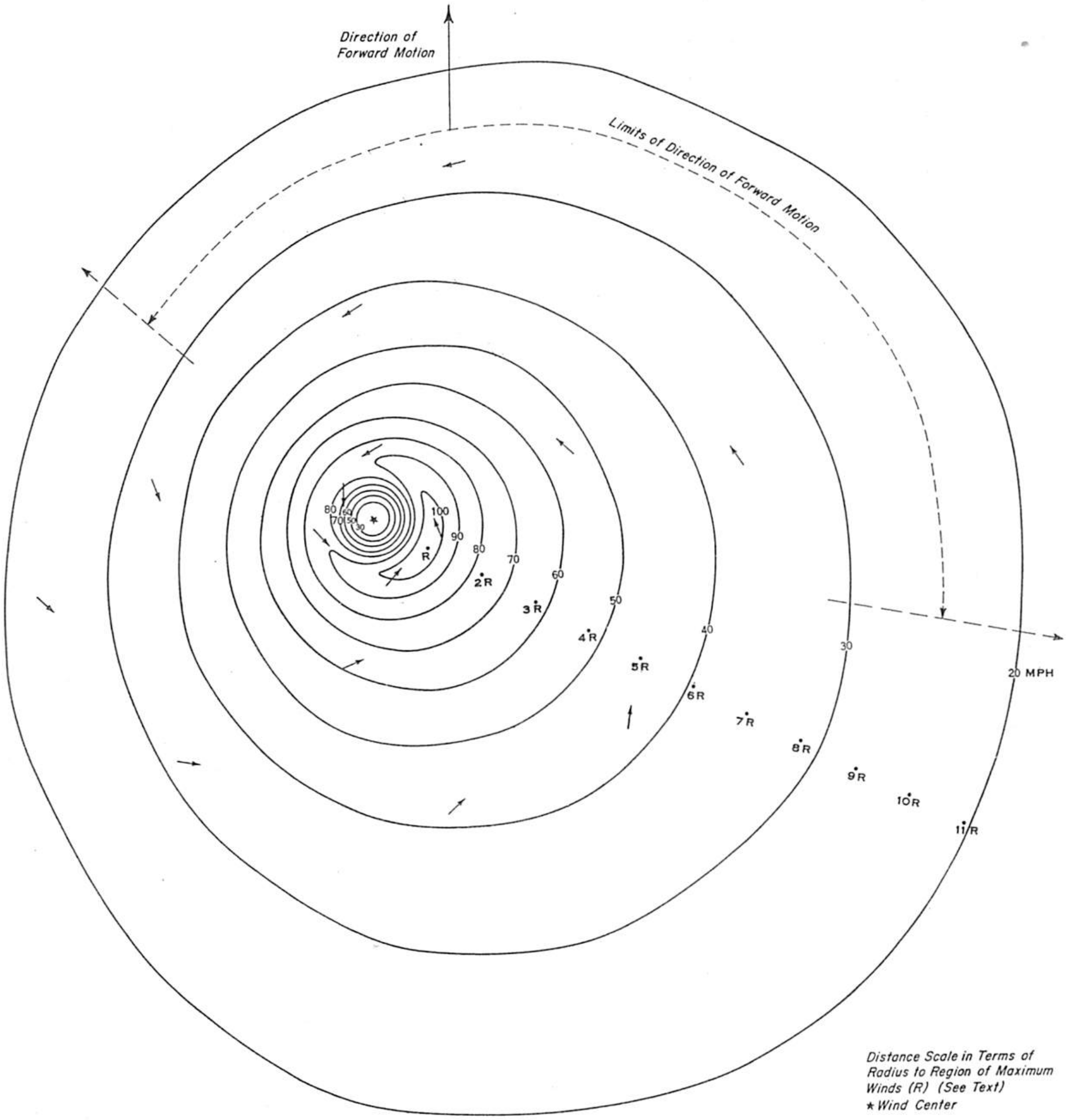
Zone 2 (Northern Florida to South Carolina)
Large Radius (RL)
High speed of translation (HT)



Note: For CPI of 27.65 inches, to adjust CPI see table 3.

Figure 30. - Standard Project Hurricane 30-ft. over-water isovel pattern.

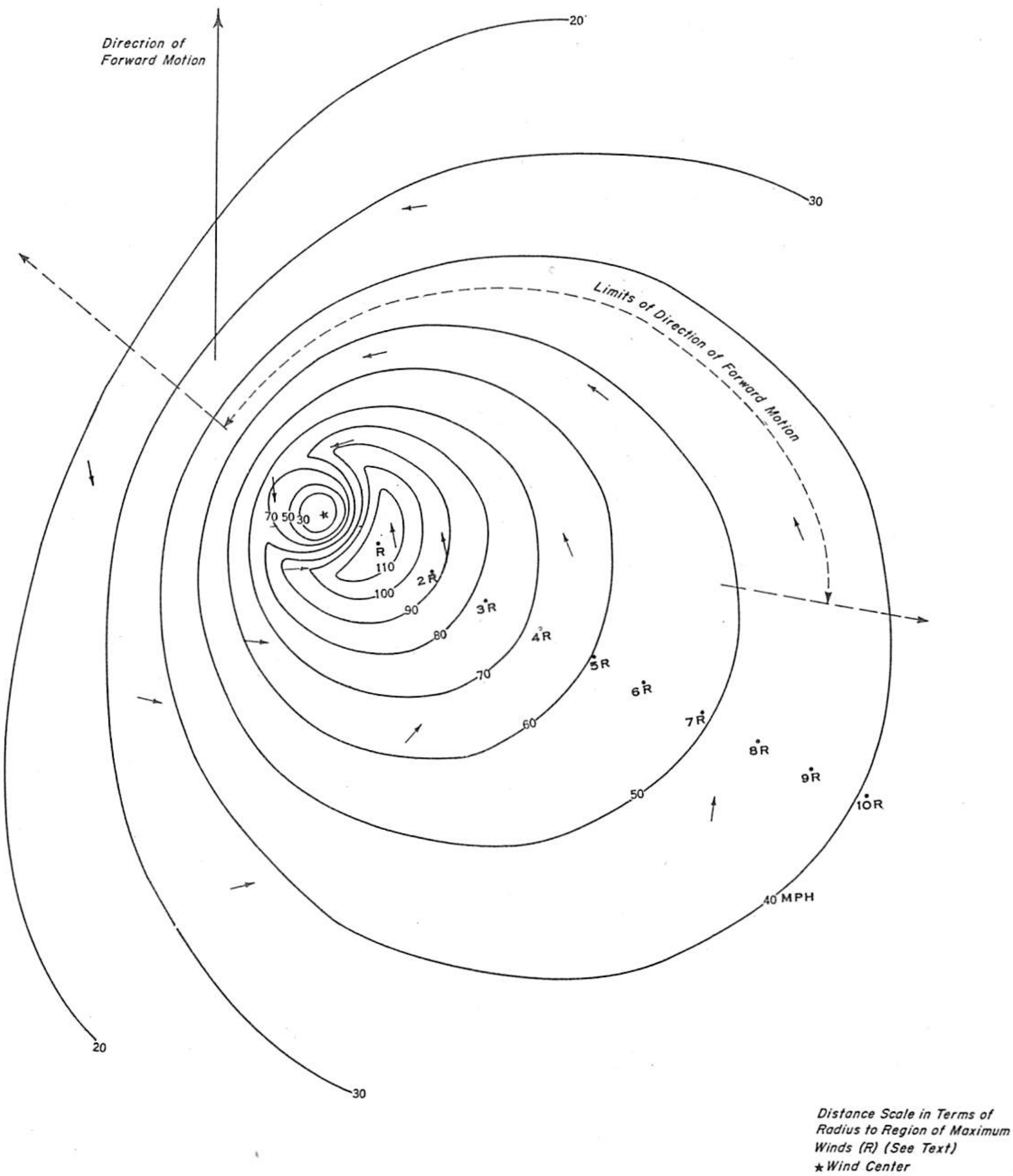
Zone 3 (South Carolina through southern Maryland)
Mean Radius (RM)
Moderate speed of translation (MT)



Note: For CPI of 27.55 inches, to adjust CPI see table 3.

Figure 31. - Standard Project Hurricane 30-ft. over-water isovel pattern.

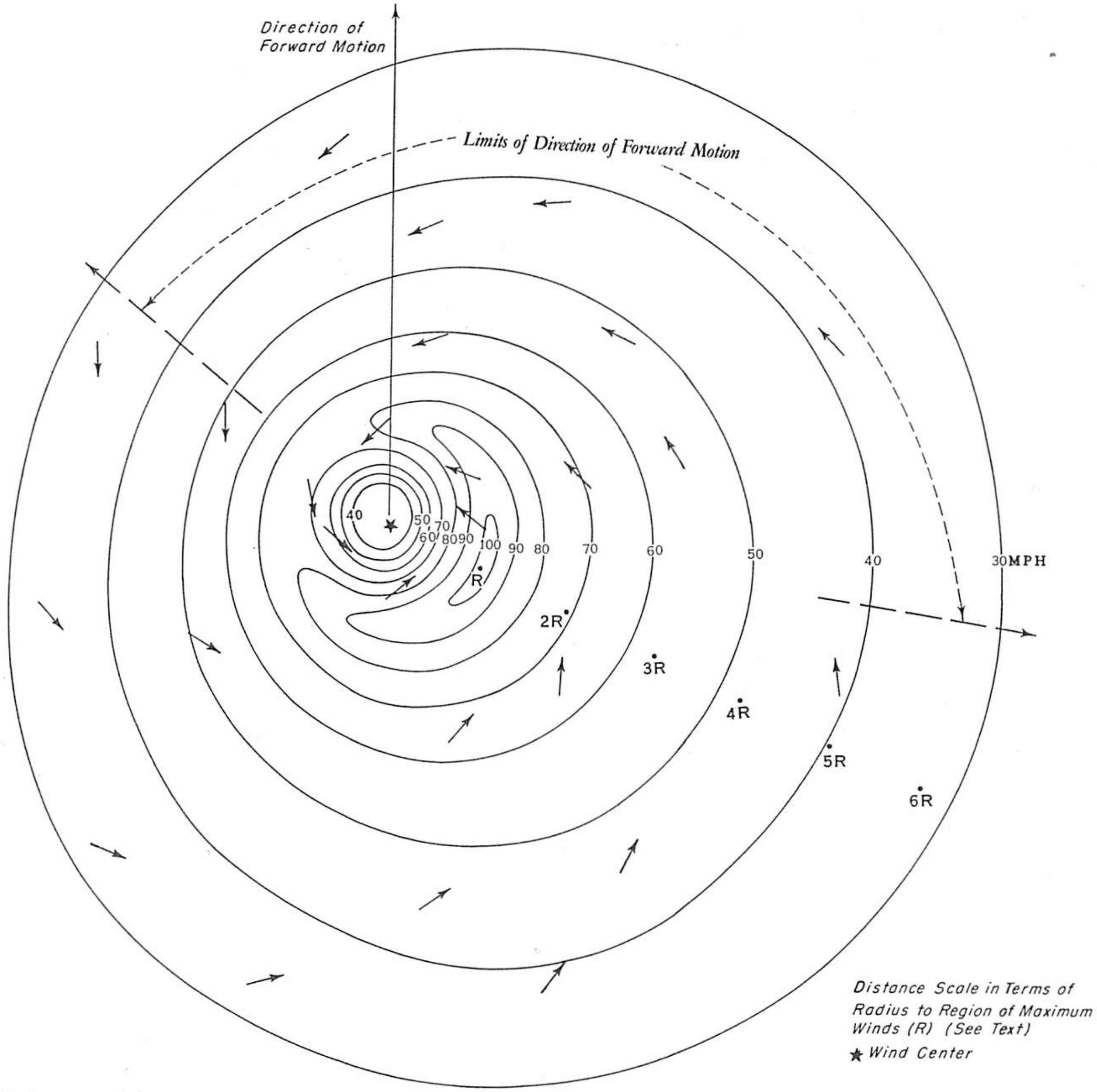
Zone 3 (South Carolina through southern Maryland)
Mean Radius (RM)
High speed of translation (HT)



Note: For CPI of 27.55 inches, to adjust CPI see table 3.

Figure 32. - Standard Project Hurricane 30-ft. over-water isovel pattern.

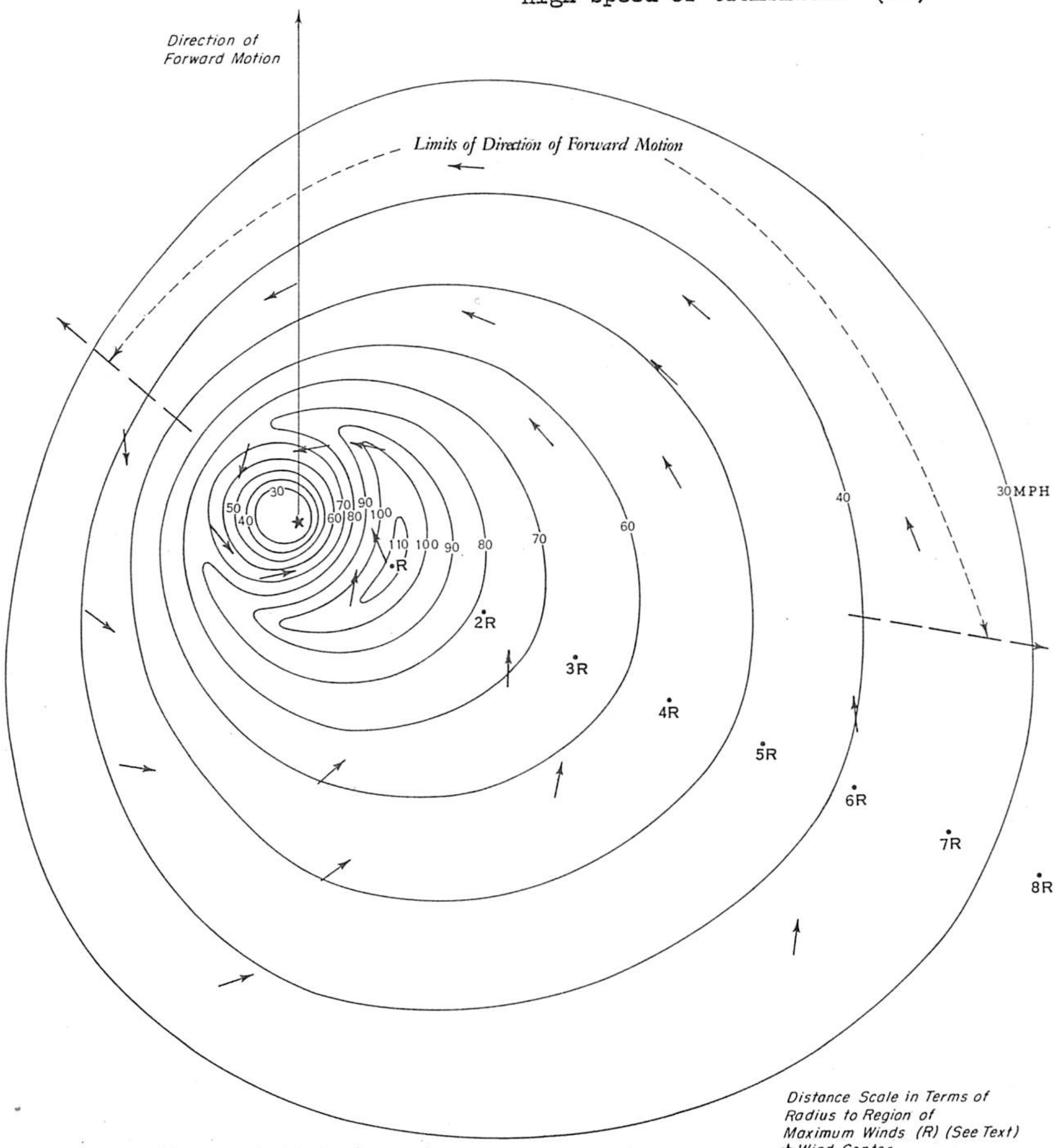
Zone 3 (South Carolina through southern Maryland)
Large Radius (RL)
Moderate speed of translation (MT)



Note: For CPI of 27.55 inches, to adjust CPI see table 3.

Figure 33. - Standard Project Hurricane 30-ft. over-water isovel pattern.

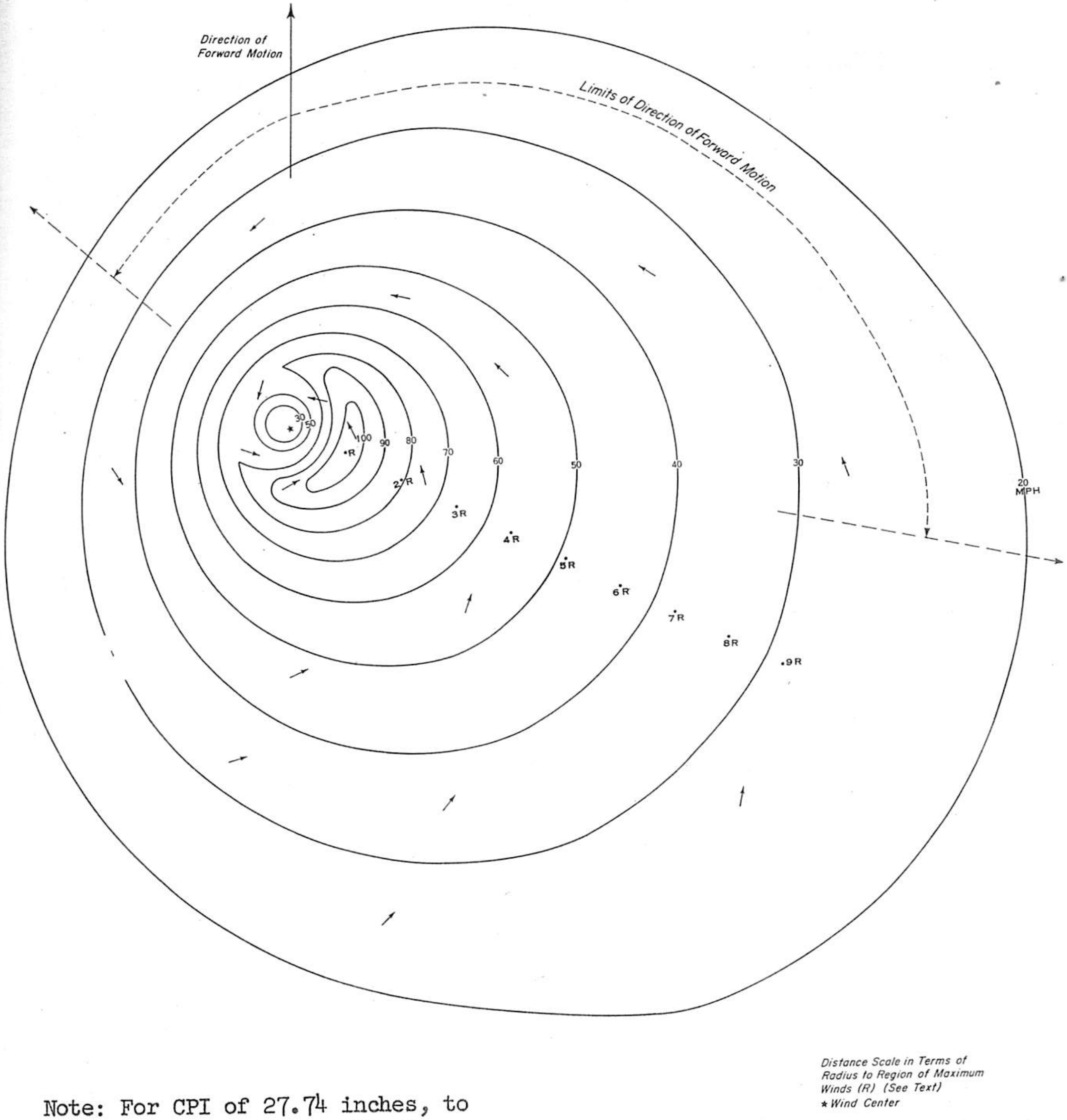
Zone 3 (South Carolina through southern Maryland)
Large Radius (RL)
High speed of translation (HT)



Note: For CPI of 27.55 inches, to adjust CPI see table 3.

Figure 34. - Standard Project Hurricane 30-ft. over-water isovel pattern.

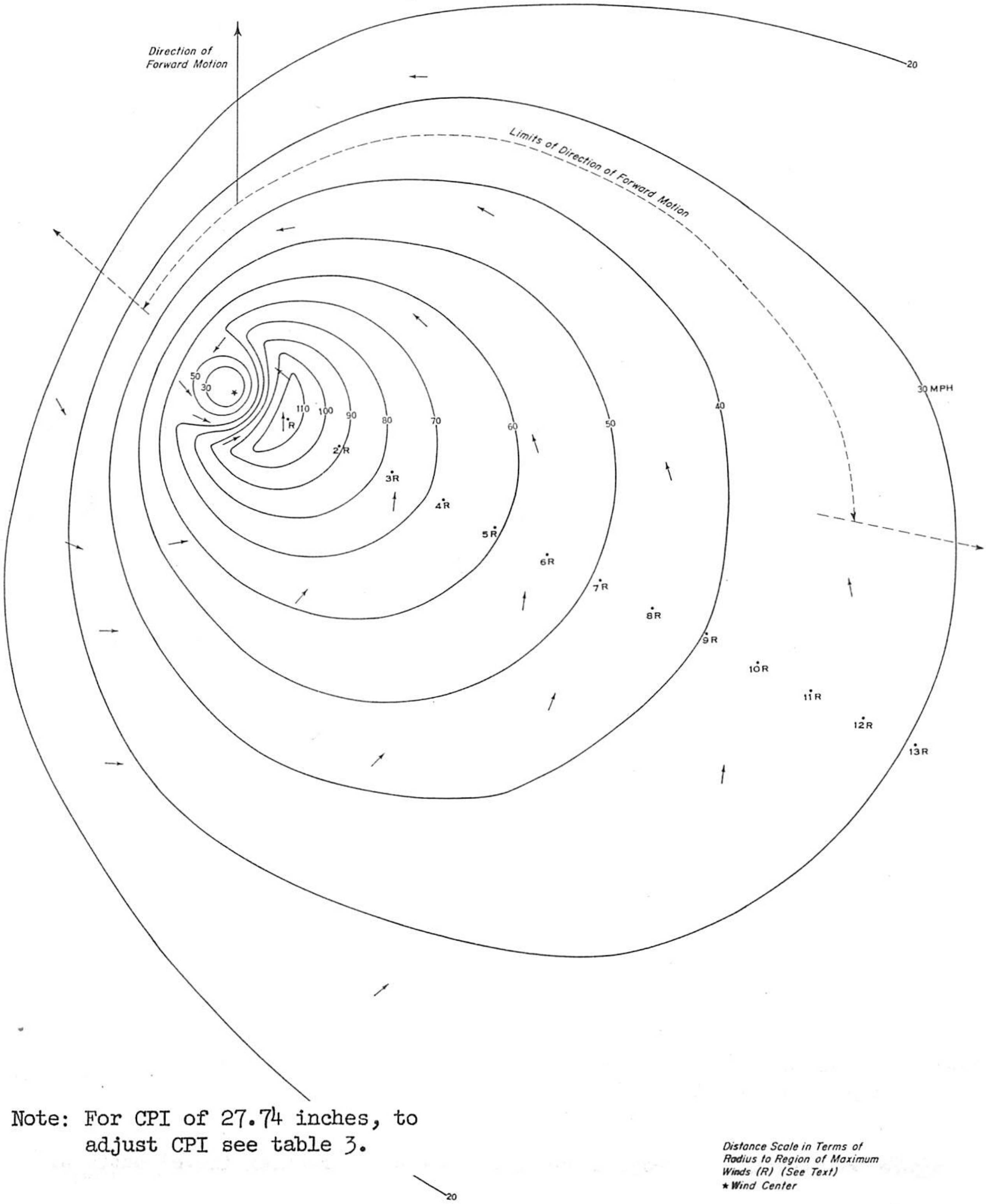
Zone 4 (Maryland to Maine)
Mean Radius (RM)
Moderate speed of translation (MT)



Note: For CPI of 27.74 inches, to adjust CPI see table 3.

Figure 35. - Standard Project Hurricane 30-ft. over-water isovel pattern.

Zone 4 (Maryland to Maine)
Mean Radius (RM)
High speed of translation (HT)

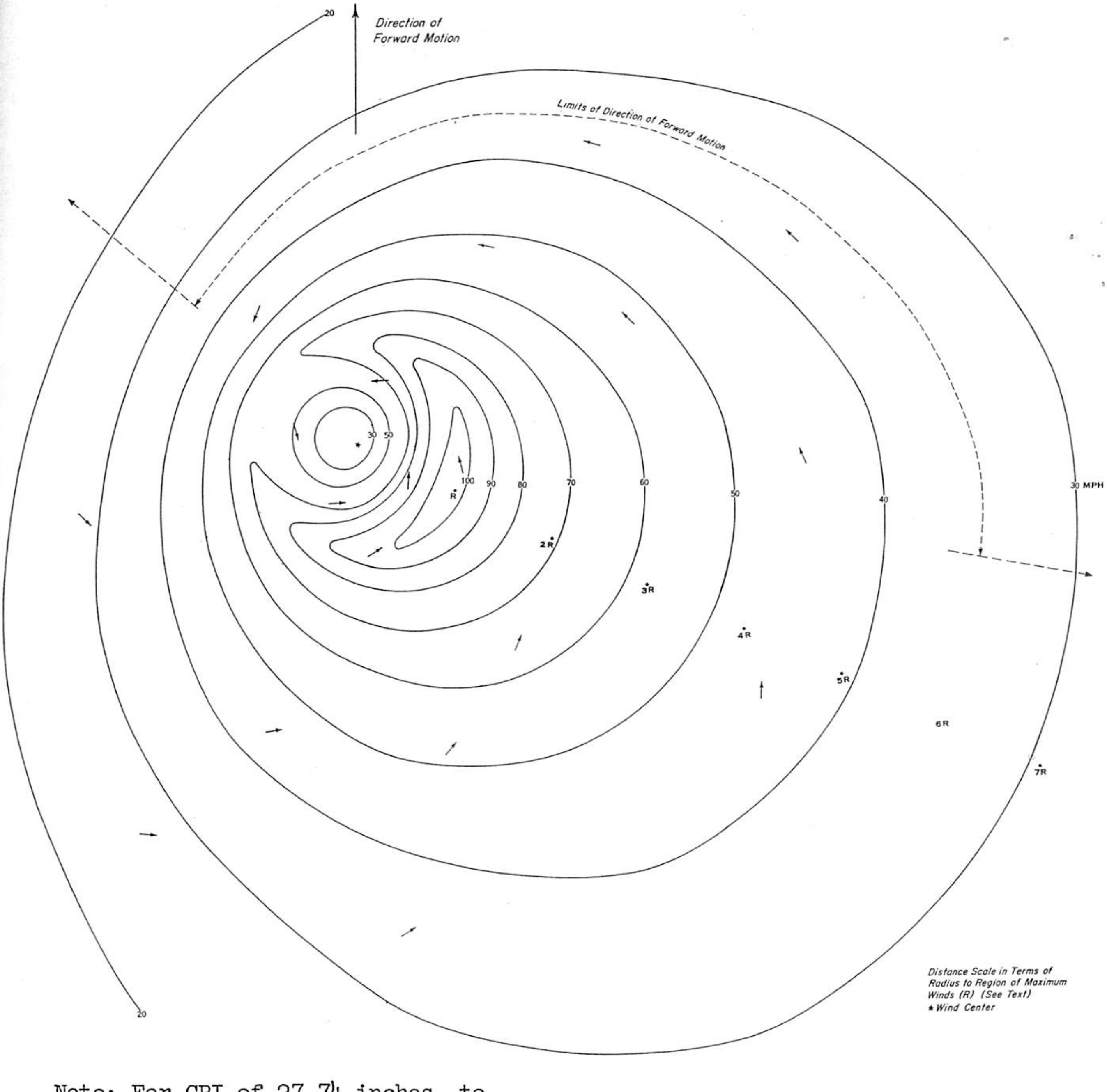


Note: For CPI of 27.74 inches, to adjust CPI see table 3.

Distance Scale in Terms of Radius to Region of Maximum Winds (R) (See Text)
★ Wind Center

Figure 36. - Standard Project Hurricane 30-ft. over-water isovel pattern.

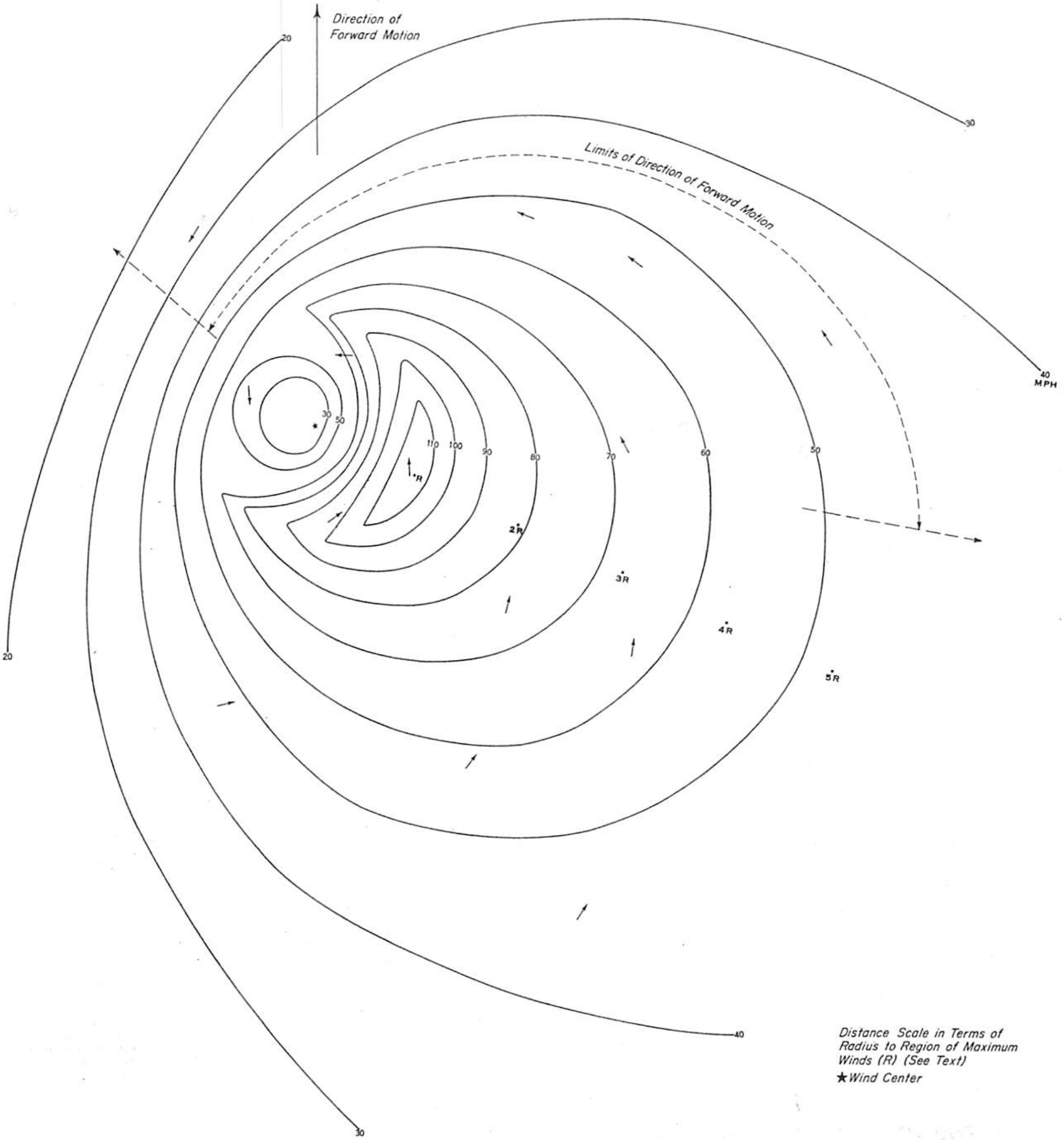
Zone 4 (Maryland to Maine)
Large Radius (RL)
Moderate speed of translation (MT)



Note: For CPI of 27.74 inches, to
adjust CPI see table 3.

Figure 37. - Standard Project Hurricane 30-ft. over-water isovel pattern.

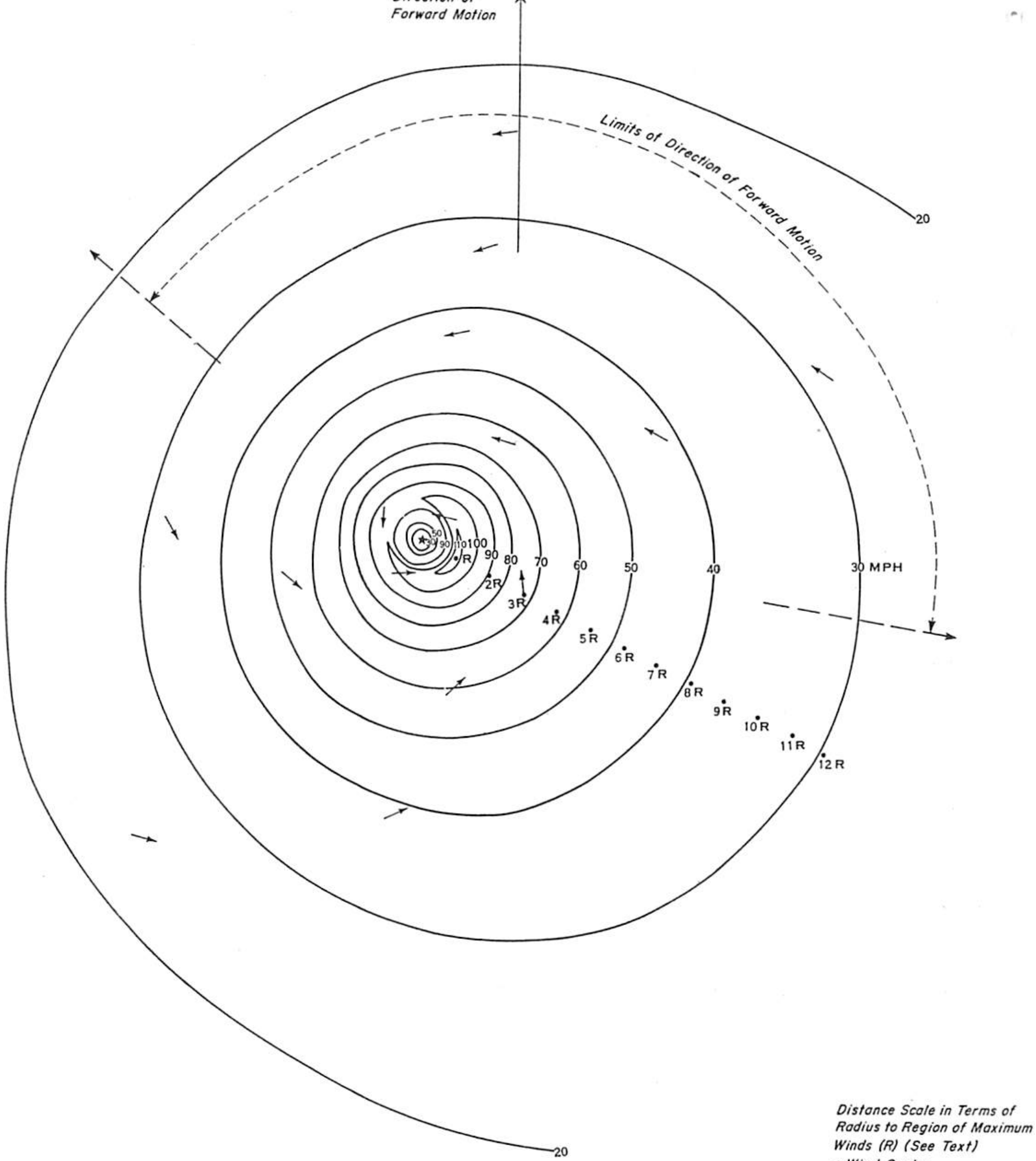
Zone 4 (Maryland to Maine)
Large Radius (RL)
High speed of translation (HT)



Note: For CPI of 27.74 inches, to adjust CPI see table 3.

Figure 38. - Standard Project Hurricane 30-ft. over-water isovel pattern.

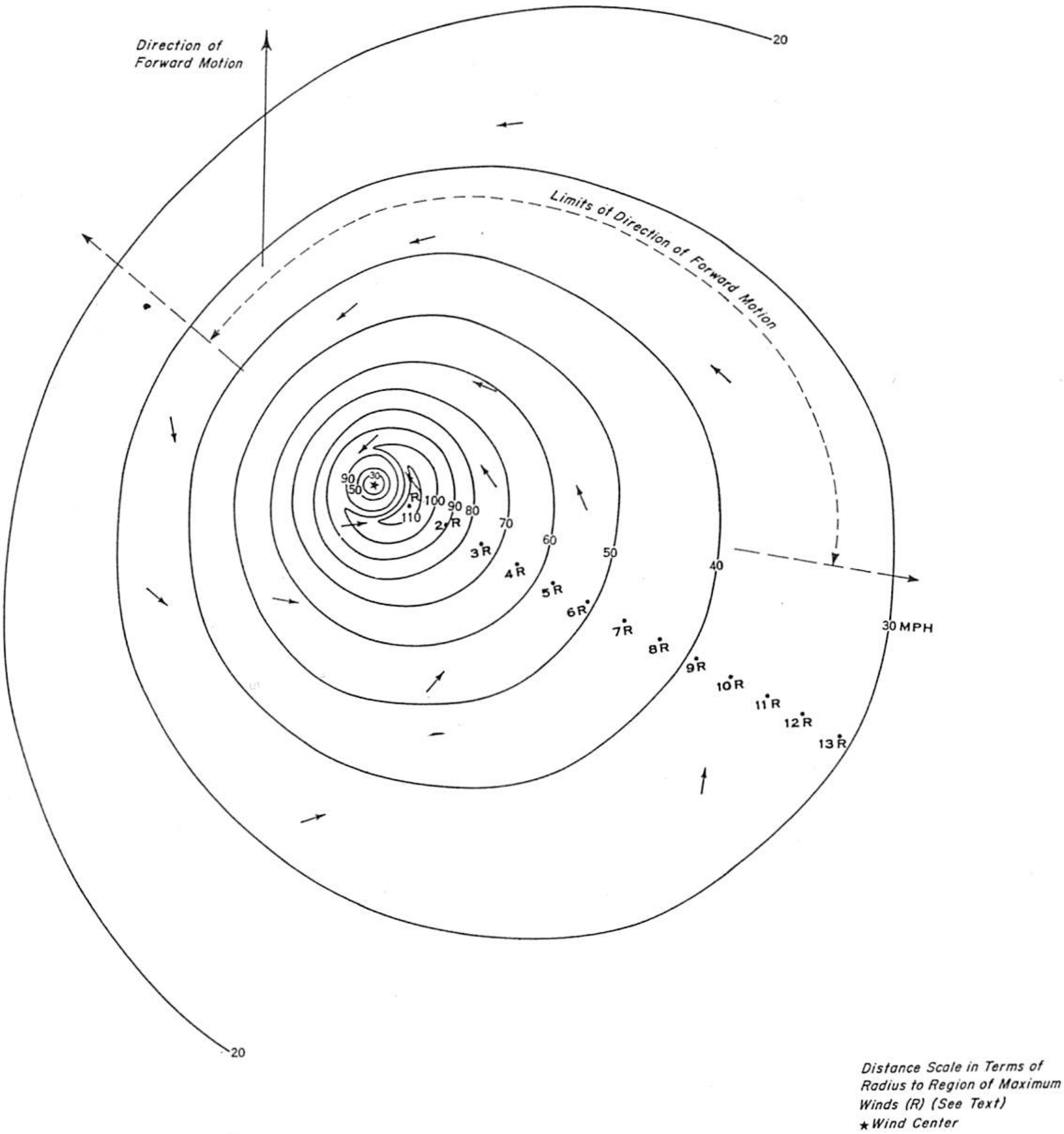
Zone A (Florida, West Coast)
Mean Radius (RM)
Moderate speed of translation (MT)



Note: For CPI of 27.06 inches, to adjust CPI see table 3.

Figure 39. - Standard Project Hurricane 30-ft. over-water isovel pattern.

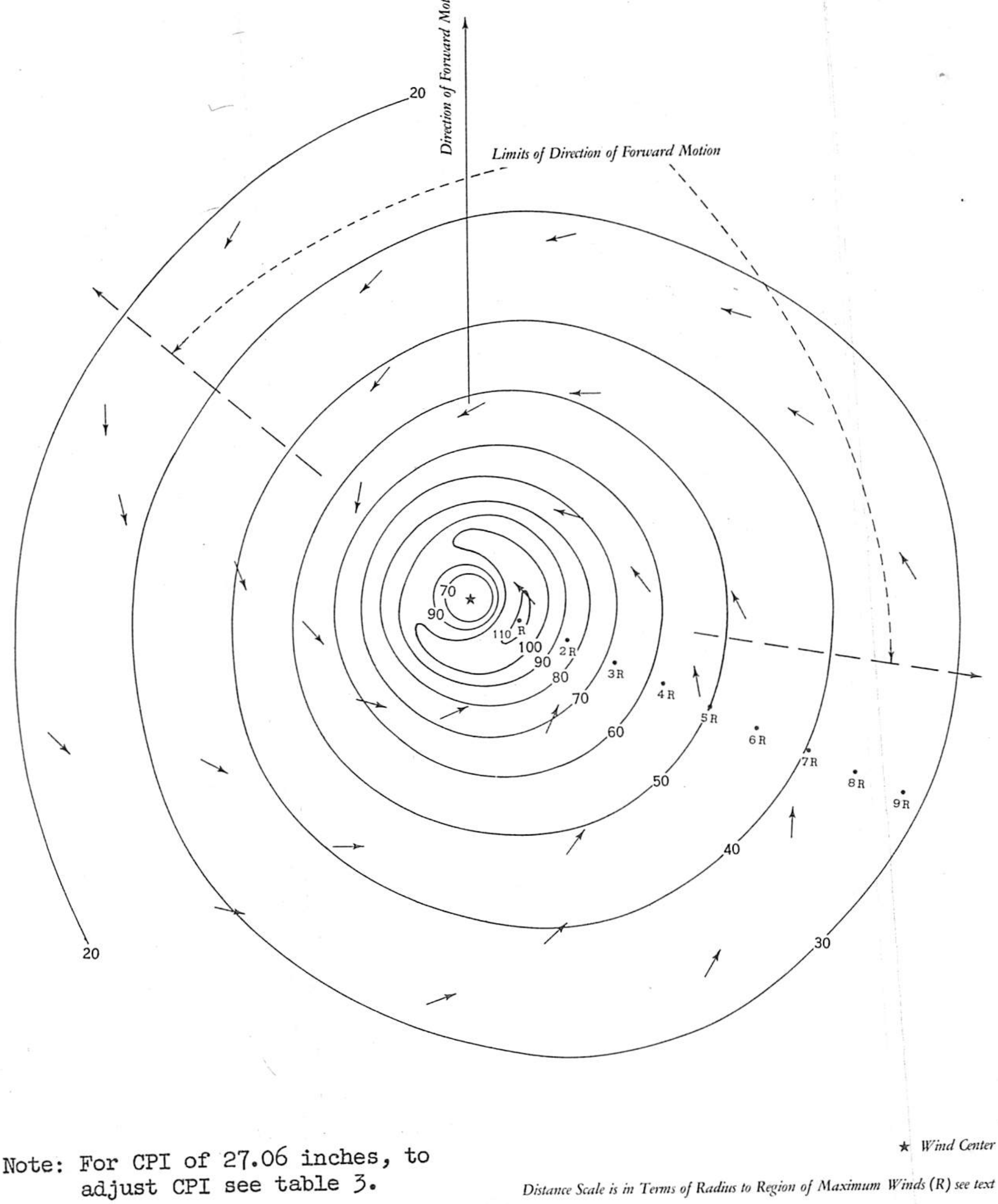
Zone A (Florida, West Coast)
Mean Radius (RM)
High speed of translation (HT)



Note: For CPI of 27.06 inches, to
adjust CPI see table 3.

Figure 40. - Standard Project Hurricane 30-ft. over-water isovel pattern.

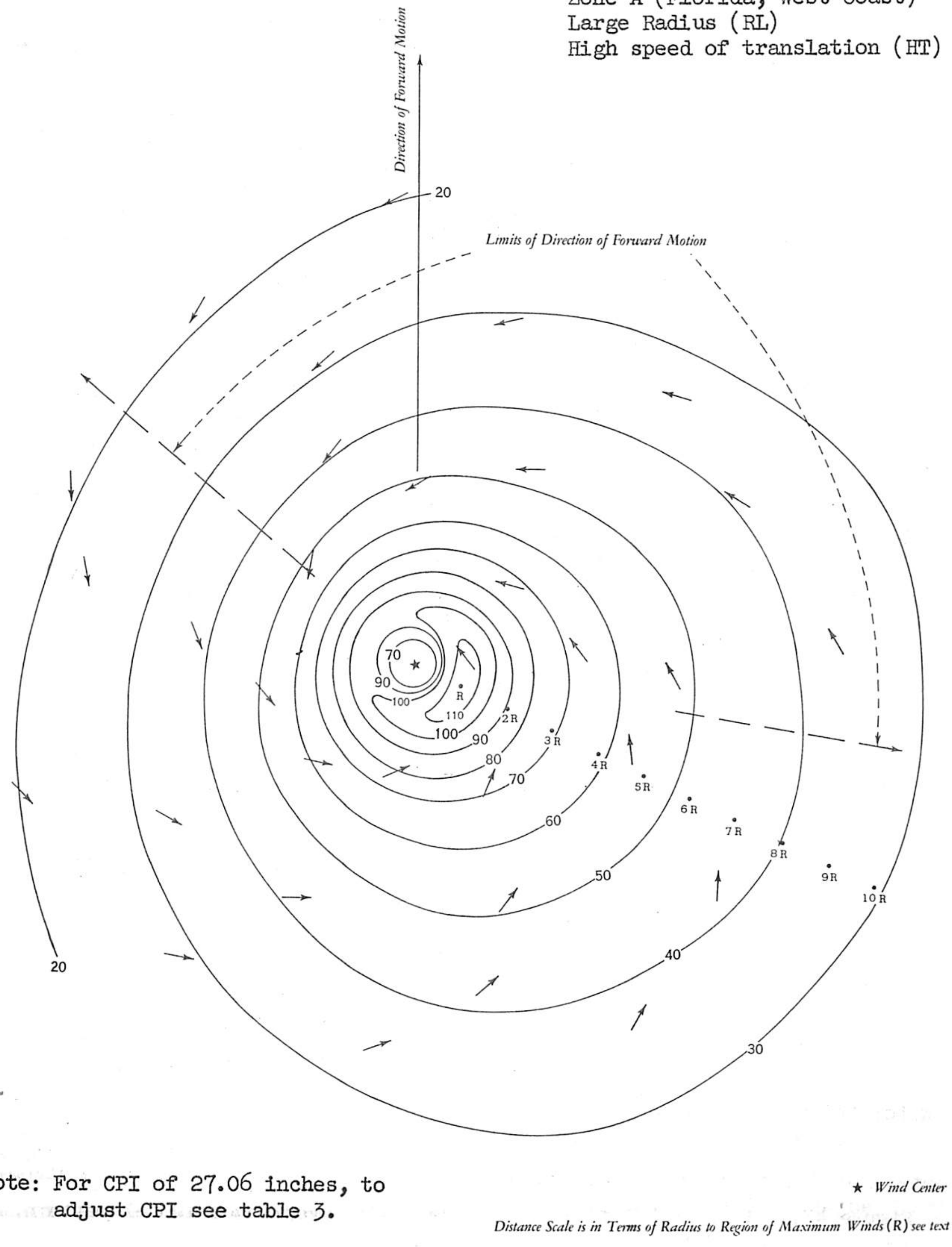
Zone A (Florida, West Coast)
Large Radius (RL)
Moderate speed of translation (MT)



Note: For CPI of 27.06 inches, to adjust CPI see table 3.

Figure 41. - Standard Project Hurricane 30-ft. over-water isovel pattern.

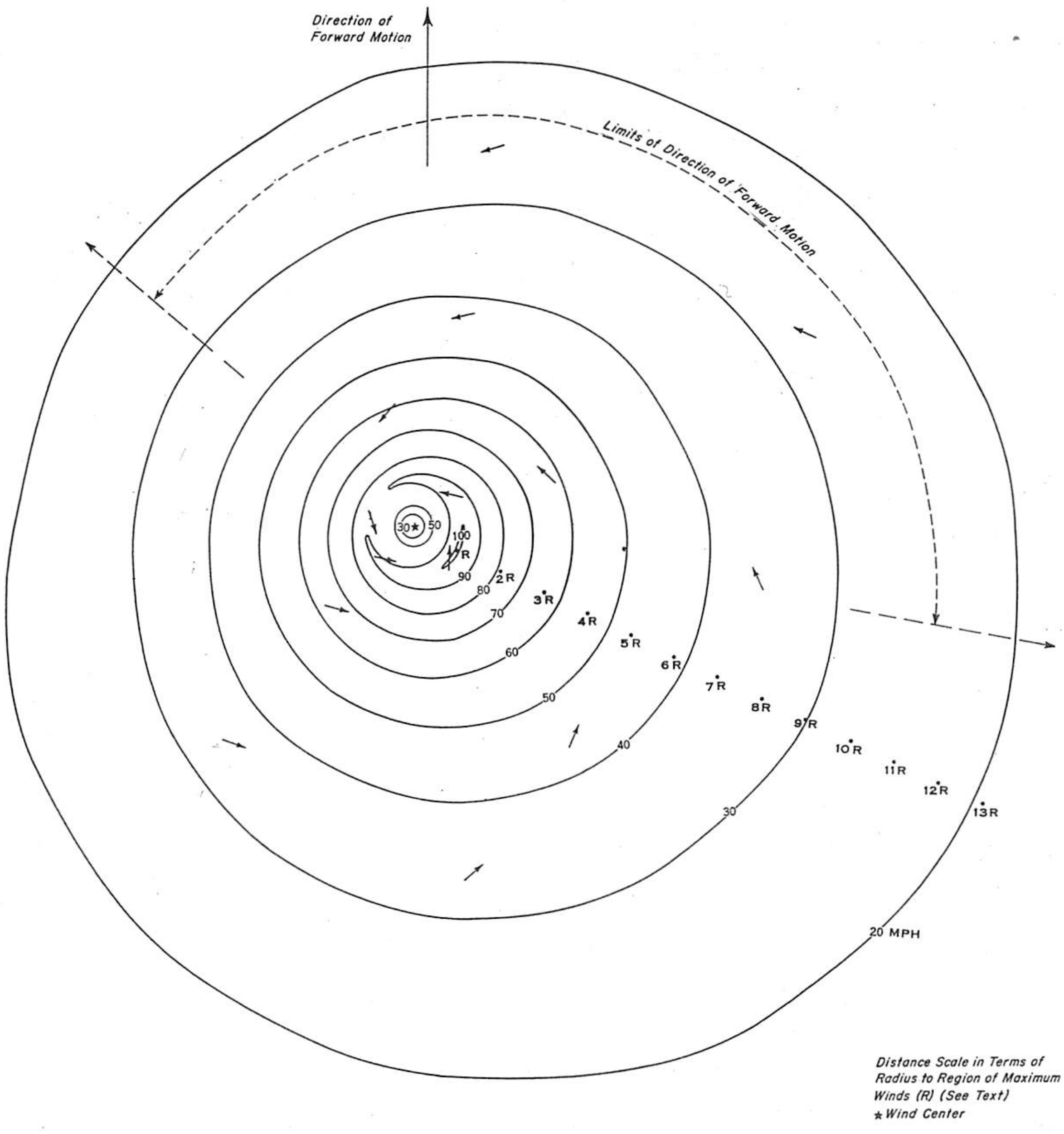
Zone A (Florida, West Coast)
Large Radius (RL)
High speed of translation (HT)



Note: For CPI of 27.06 inches, to
adjust CPI see table 3.

Figure 42. - Standard Project Hurricane 30-ft. over-water isovel pattern.

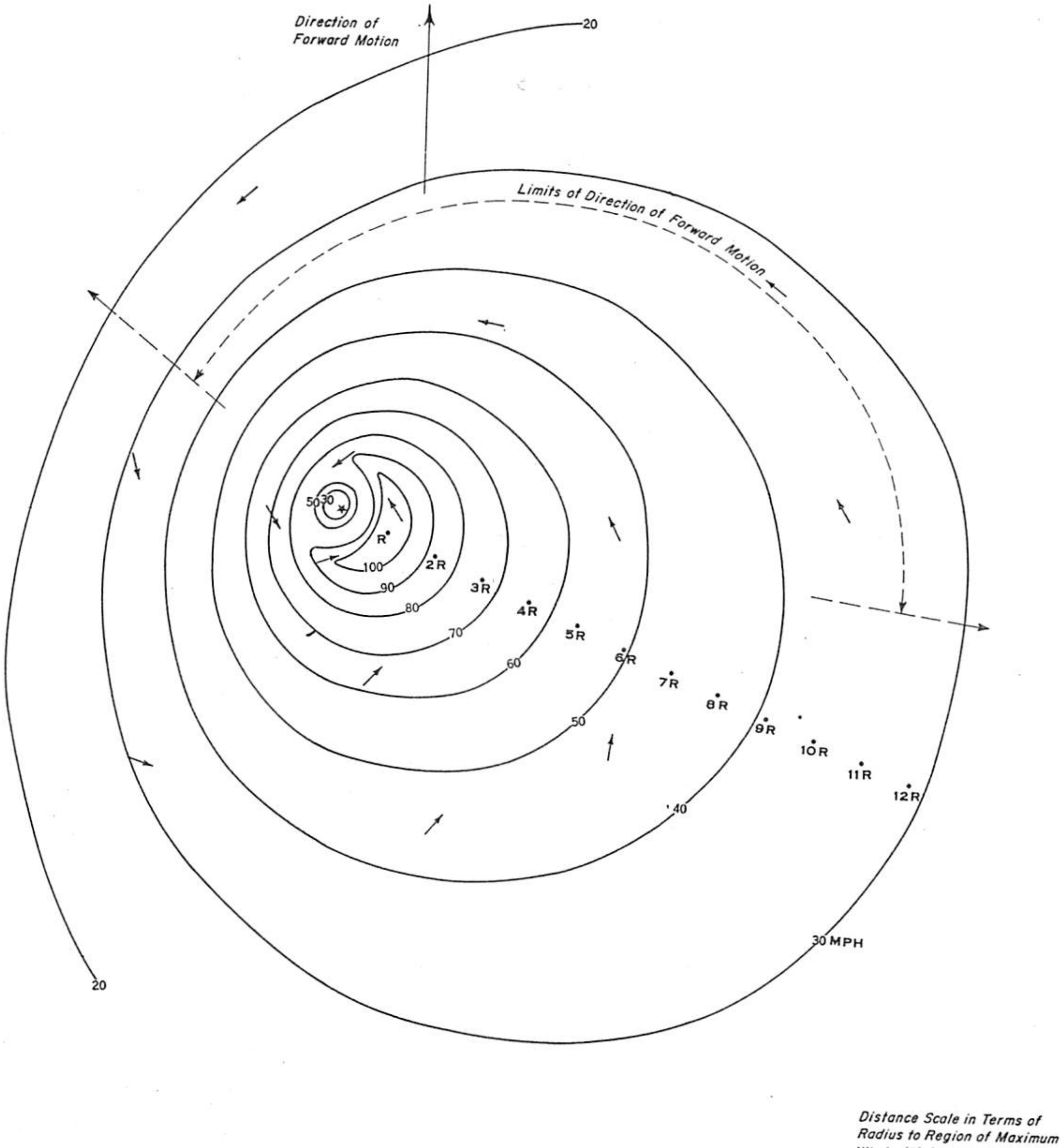
Zones B and C
Mean Radius (RM)
Moderate speed of translation (MT)



Note: For CPI of 27.55 inches, to
adjust CPI see table 3.

Figure 43. - Standard Project Hurricane 30-ft. over-water isovel pattern.

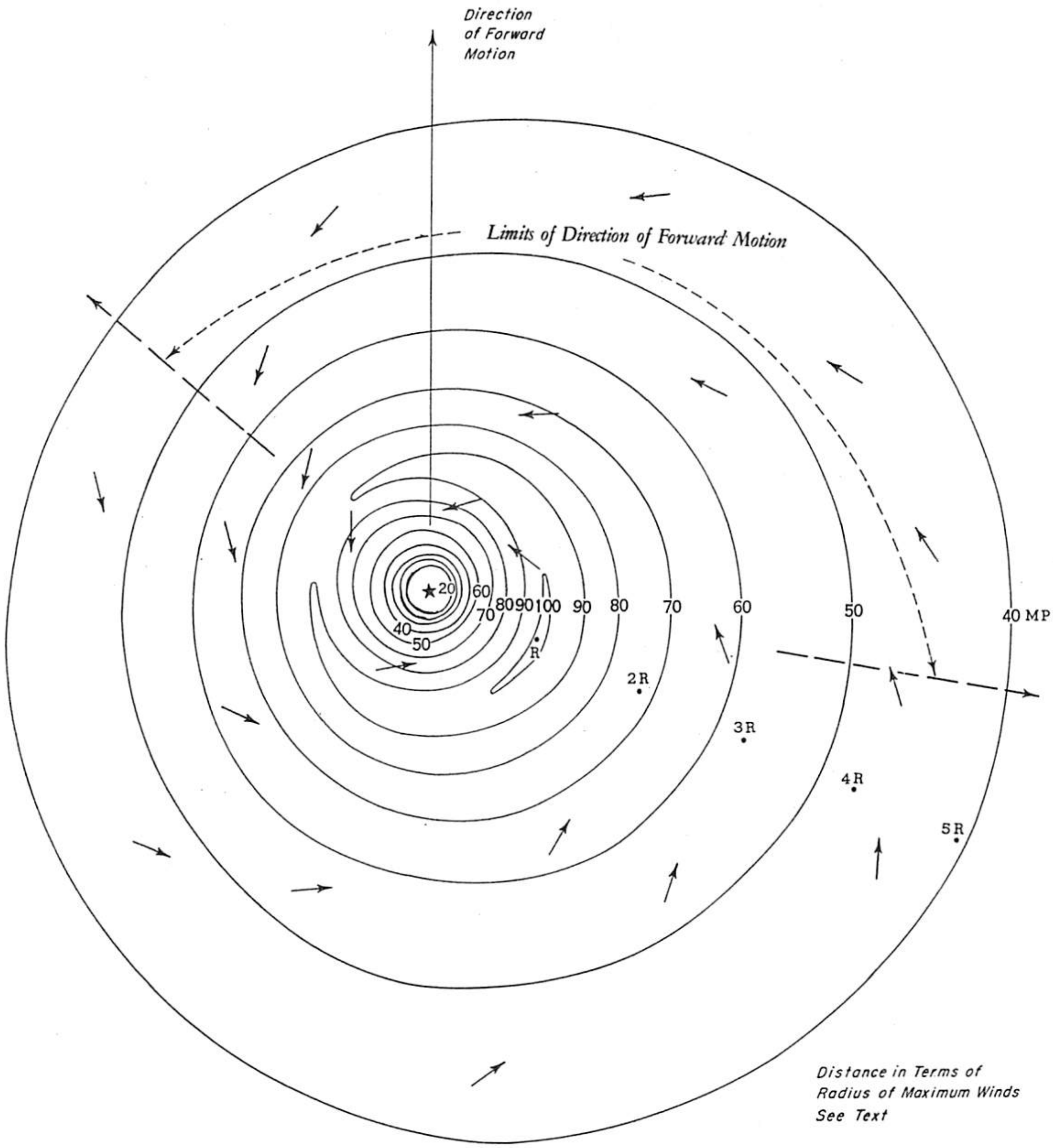
Zones B and C
Mean Radius (RM)
High Speed of Translation (HT)



Note: For CPI of 27.55 inches, to adjust CPI see table 3.

Figure 44. - Standard Project Hurricane 30-ft. over-water isovel pattern.

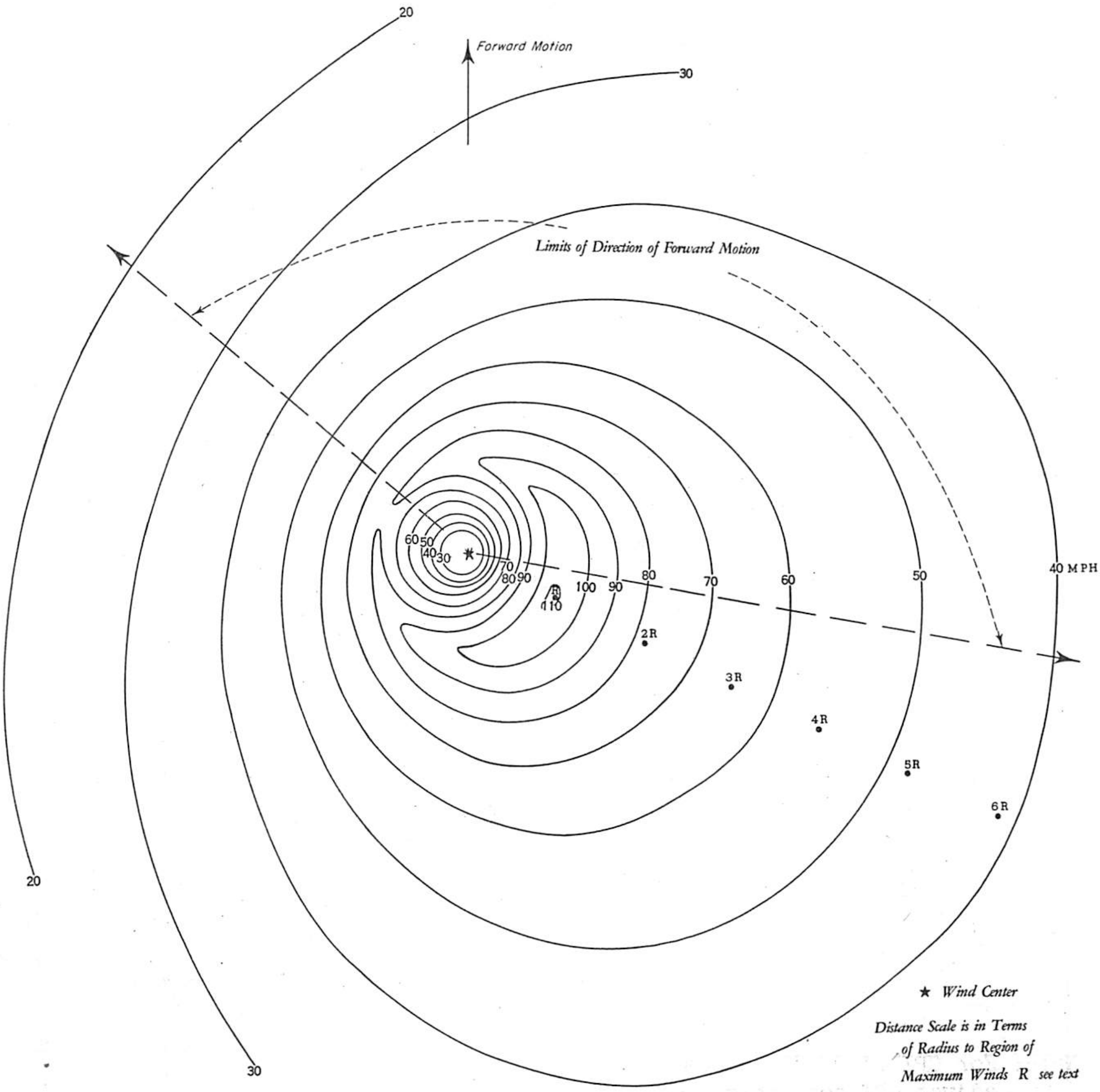
Zones B and C
Large Radius (RL)
Moderate speed of translation (MT)



Note: For CPI of 27.55 inches, to adjust CPI see table 3.

Figure 45. - Standard Project Hurricane 30-ft. over-water isovel pattern.

Zones B and C
Large Radius (RL)
High speed of translation (HT)



Note: For CPI of 27.55 inches, to adjust CPI see table 3.

Figure 46. - Standard Project Hurricane 30-ft. over-water isovel pattern.

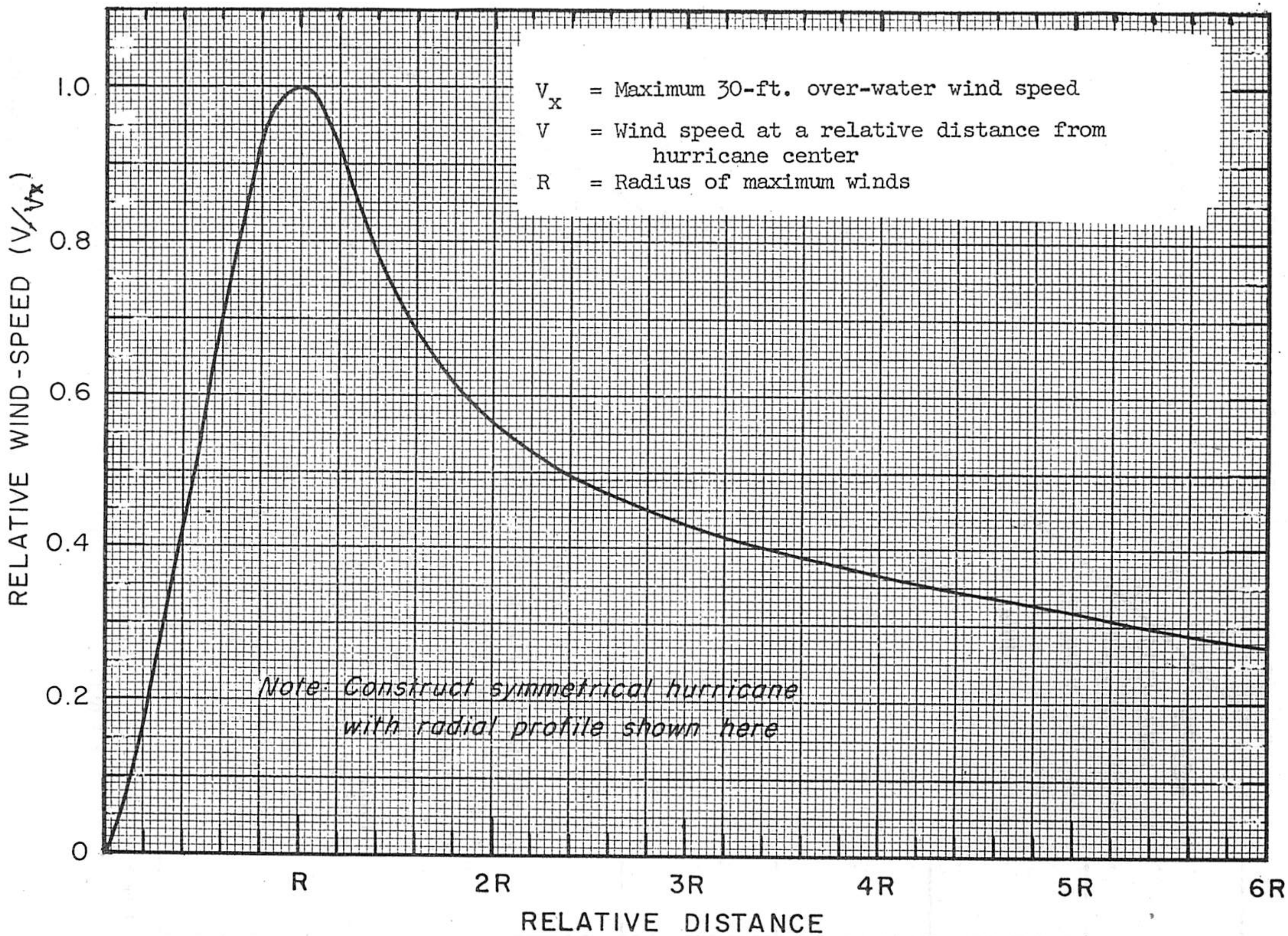


Figure 47. - Standard Project Hurricane 30-ft. wind-speed profile, small radius (RS) hurricanes, all zones.

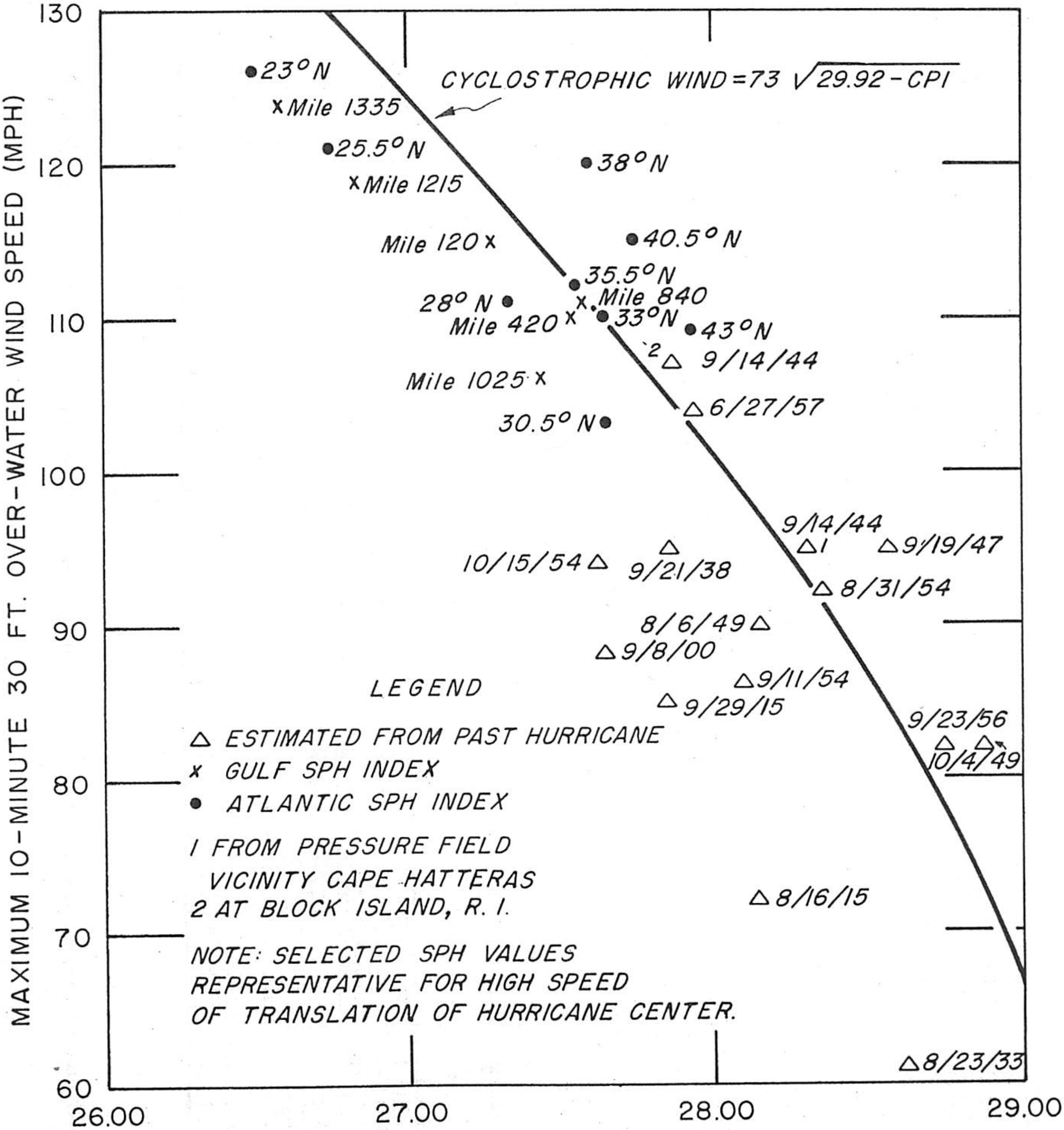


Figure 48. - Relation of central pressure index to maximum 30-ft. wind, Atlantic and Gulf Coasts.

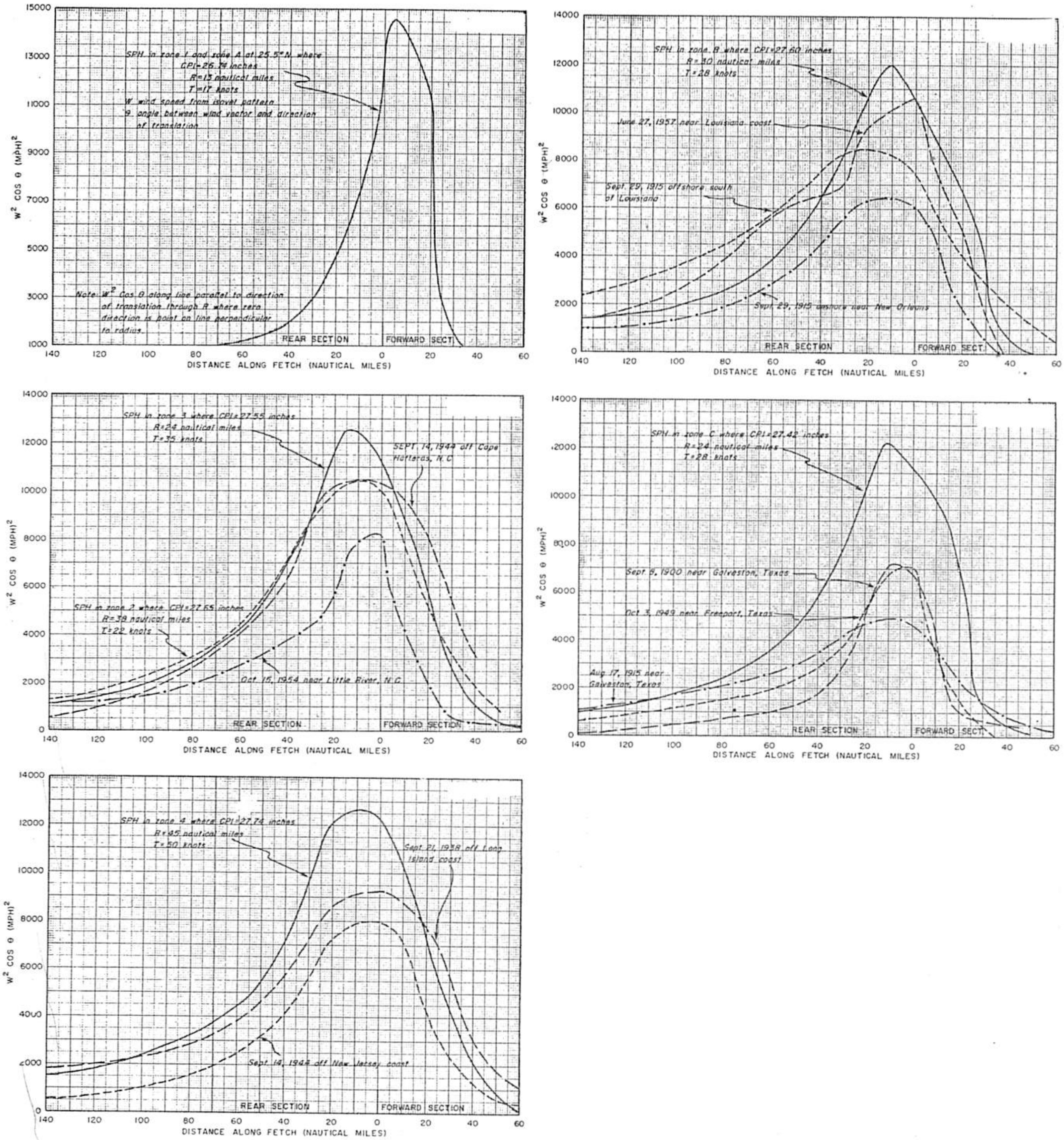


Figure 49. - Comparison of storm surge producing potential for various standard project hurricane isovel patterns and observed hurricanes.

APPENDIX

TABLE A. - HURRICANES WITH CENTRAL PRESSURE INDEX LESS THAN 29.00 INCHES (1900-1956) RANKED BY CPI

EAST COAST UNITED STATES

Date	CPI (inches)	R (n.mi.)	V_{gx} (m.p.h.)	Lat. (deg. N.)	F (kt.)	Max. 30-ft. wind speed estimated from analyses of data
ZONE 1						
Sept. 2, 1935	26.35	6	137	24.8	9	
Sept. 9, 1919	27.44	15	108	24.8	8	
Oct. 20, 1926	27.52	21	98	24.6	16	
Sept. 18, 1926	27.59	24	110	25.8	17	
Sept. 16, 1928	27.62	53	117	26.7	13	
Sept. 17, 1947	27.76	34	102	26.2	10	
Sept. 4, 1933	27.98	29	101	26.9	11	
Sept. 15, 1945	28.09	24	99	25.5	10	
Sept. 28, 1929	28.15	28	98	24.9	10	
Aug. 26, 1949	28.16	23	99	26.7	14	90**
Oct. 17, 1950	28.20	-	-	25.8	6	
Oct. 11, 1909	28.30	22	94	24.5	10	
July 28, 1926	28.34	14	89	28.0	-	
Sept. 22, 1948	28.41	16	85	26.8	11	
Nov. 4, 1935	28.73	-	79	-	-	
Oct. 20, 1924	28.83	25	62	25.8	6	
Sept. 11, 1903	28.84	43	76	25.8	8	
Oct. 18, 1906	28.84	35	67	26.9	6	
Oct. 5, 1948	28.85	31	67	25.8	13	
June 17, 1906	28.91	26	72	26.9	12	
ZONE 2						
Oct. 15, 1954	27.66	36	92	32.0	-	94
July 28, 1926	28.34	14	89	28.4	8	
Aug. 30, 1954	28.35	-	-	-	-	
Sept. 19, 1955	28.51	50	78	32.8	10	
Aug. 12, 1955	28.40	45	72	32.5	7	
Oct. 15, 1947	28.59	13	73	32.1	17	
Sept. 16, 1928	28.75	-	-	29.5	-	
Aug. 11, 1940	28.78	27	77	32.0	12	
Oct. 25, 1921	28.91	-	-	29.0	10	
Sept. 15, 1945	28.91	-	-	29.0	-	
Aug. 28, 1911	28.92	27	73	32.1	8	

Date	CPI (inches)	R (n.mi.)	V_{gx} (m.p.h.)	Lat. (deg. N.)	F (kt.)	Max. 30-ft. wind speed estimated from analyses of data
ZONE 3						
Oct. 15, 1954	27.66	36	92	33.0	26	94
Sept. 21, 1938	27.86	50	83	33.7	-	
Sept. 14, 1944	27.88	17	113	35.2	23	
Sept. 10, 1954	27.97	-	-	-	-	
Sept. 16, 1933	28.25	42	84	35.2	9	
Aug. 30, 1954	28.35	-	-	33.4	-	
Aug. 12, 1955	28.40	45	72	34.5	7	
Sept. 19, 1955	28.51	50	78	35.0	9	
Sept. 18, 1936	28.53	34	63	35.2	16	
Aug. 23, 1933	28.63	36	58	36.9	18	61
Aug. 25, 1924	28.70	34	78	35.2	22	
Sept. 3, 1913	28.81	41	72	35.8	16	
Aug. 24, 1949	28.86	24	80	33.5	22	
Dec. 2, 1925	28.95	54	62	34.2	14	
Sept. 17, 1906	28.98	61	72	34.0	16	
ZONE 4						
Sept. 21, 1938	27.86	50	83	41.8	47	95
Sept. 11, 1954	27.97	-	-	41.3	40	
Sept. 16, 1933	28.25	-	84	-		
Sept. 14, 1944	28.31	48	71	41.4	30	95
Aug. 31, 1954	28.38	22	-	41.8	33	
Sept. 18, 1936	28.53	34	63	38.0	-	
Aug. 26, 1924	28.70	66	59	41.3	29	

**From an analysis of observed winds at Lake Okeechobee (central pressure 28.20 in.)

TABLE A. - Continued

GULF COAST UNITED STATES

Date	CPI (inches)	R (n.mi.)	V_{gx} (m.p.h.)	F (kt.)	Lat. (deg. N.)	Long. (deg. W.)
			ZONE A			
Sept. 2, 1935	26.35	6	137	9	24.8	80.9
Sept. 9, 1919	27.44	15	108	8	24.6	82.9
Oct. 20, 1926	27.52	21	112	16	23.8	81.3
Sept. 21, 1948	27.62	7	102	8	24.5	81.8
Oct. 17, 1910	27.80	16	84	11	24.5	82.5
Oct. 18, 1944	28.02	27	93	13	24.6	82.8
Sept. 17, 1947	28.03	34	--	-	26.4	81.3
Sept. 18, 1926	28.05	24	--	17	26.5	81.0
Sept. 28, 1929	28.15	28	--	10	24.8	81.1
Oct. 25, 1921	28.29	18	80	10	28.1	82.8
Oct. 11, 1909	28.30	22	94	10	24.3	81.7
Sept. 16, 1928	28.30	53	--	-	27.7	81.4
Sept. 4, 1950	28.30	--	--	-	29.1	83.1
Aug. 26, 1949	28.37	23	--	14	27.2	81.2
Sept. 15, 1945	28.39	24	--	10	25.5	81.0
Sept. 4, 1933	28.48	29	--	11	27.8	81.6
Oct. 19, 1924	28.70	19	--	8	25.0	83.0
Nov. 4, 1935	28.73	--	79	-	25.0	81.0
Sept. 11, 1903	28.84	43	76	7	27.0	81.5
Oct. 18, 1906	28.84	35	67	6	25.0	81.0
Oct. 5, 1948	28.85	31	67	13	24.0	81.2
Oct. 18, 1950	28.88	--	--	-	28.0	81.6
June 17, 1906	28.91	26	72	-	25.1	80.9
Oct. 7, 1941	28.98	18	78	11	29.8	84.7

Date	CPI (inches)	R (n.mi.)	V_{gx} (m.p.h.)	F (kt)	Lat. (deg.N.)	Long. (deg.W.)	Max. 30-ft. wind speed estimated from analyses of data
			ZONE B				
Sept. 8, 1900	27.64	--	104	--	27.0	90.5	88
Sept. 29, 1915	27.87	29	106	10	29.9	90.1	85
Sept. 14, 1919	28.00	--	--	20	26.9	90.2	
Sept. 20, 1926	28.20	17	98	7	30.5	87.5	
July 21, 1909	28.31	19	99	--	26.8	91.0	
Aug. 25, 1926	28.31	27	100	10	29.6	90.7	
July 5, 1916	28.38	50	81	25	30.7	88.0	
July 31, 1936	28.46	19	80	9	30.5	86.5	
Sept. 28, 1917	28.48	33	81	13	30.4	87.2	
Sept. 27, 1906	28.50	73	83	16	30.6	88.5	
June 16, 1934	28.52	37	80	16	29.9	91.7	
Sept. 19, 1947	28.57	33	72	16	29.9	90.1	95
Aug. 14, 1901	28.72	33	83	14	29.9	90.1	
Oct. 18, 1916	28.76	19	81	21	30.4	87.2	
Aug. 7, 1940	28.76	11	71	8	29.0	92.8	
Sept. 23, 1956	28.76	*22	--	*10	30.0	86.5	82
July 27, 1943	28.78	16	78	8	28.2	92.0	
Sept. 30, 1929	28.80	65	70	6	30.1	85.7	
Aug. 30, 1950	28.92	21	64	23	30.2	88.0	
Sept. 21, 1920	28.93	28	67	28	29.6	90.7	
Sept. 20, 1909	28.94	88	73	11	29.9	90.1	
Oct. 7, 1941	28.98	18	78	11	29.9	84.7	
June 27, 1957*	27.95	19	--	14	29.8	93.6	104
			ZONE C				
Sept. 8, 1900	27.64	14	104	10	29.2	95.9	88
Aug. 13, 1932	27.83	12	108	15	29.1	95.6	
Aug. 18, 1916	28.00	35	116	11	27.5	97.5	
Sept. 14, 1919	28.00	--	---	20	27.7	97.5	
Sept. 5, 1933	28.02	20	105	8	25.9	97.5	
Aug. 30, 1942	28.07	18	88	14	28.5	96.7	
Aug. 16, 1915	28.14	32	83	11	29.8	95.0	72
June 22, 1921	28.17	17	97	11	29.7	95.4	
July 21, 1909	28.31	19	99	12	29.0	96.0	
Sept. 23, 1941	28.31	21	81	13	29.7	95.4	
Aug. 27, 1945	28.57	18	88	4	29.0	96.2	
June 28, 1929	28.62	13	82	15	28.5	96.5	
Aug. 7, 1940	28.76	11	71	8	29.9	93.9	
July 27, 1943	28.78	16	78	8	29.5	95.0	
Aug. 4, 1933	28.80	25	76	10	25.9	97.5	
Oct. 4, 1949	28.88	28	78	11	28.9	95.4	82

Legend

CPI - central pressure index
R - radius of maximum winds
V_{gx} - maximum gradient wind speed from table 3-1, reference [4]
F - forward speed of the storm

*Not used in frequency analysis for zone B. Parameters determined subsequent to preparation of frequency analyses.

TABLE B. - AVERAGE DIRECTION OF CENTER MOVEMENT OF ALL TROPICAL STORMS IN THE ZONE WHICH REACHED HURRICANE INTENSITY AT ANY TIME (1887-1956)

EAST COAST UNITED STATES

Date	Avg. direction of movement within zone (degrees from)	Date	Avg. direction of movement within zone (degrees from)	Date	Avg. direction of movement within zone (degrees from)	Date	Avg. direction of movement within zone (degrees from)
ZONE 1				ZONE 2			
Aug. 18, 1887	126	Sept. 17, 1926	125	Aug. 20, 1887	198	July 26, 1926	155
Aug. 15, 1888	122	Aug. 12, 1928	129	Aug. 22, 1887	173	Sept. 17, 1928	202
Sept. 3, 1888	002	Aug. 6, 1928	138	Oct. 10, 1888	232	Sept. 9, 1930	227
Sept. 7, 1888	92	Sept. 15, 1928	123	Sept. 9, 1888	211	Sept. 6, 1934	185
Aug. 23, 1891	109	Sept. 25, 1929	55	Oct. 12, 1893	175	July 21, 1934	035
Oct. 11, 1893	138	Aug. 28, 1932	117	Aug. 26, 1893	166	Aug. 10, 1940	124
Aug. 26, 1893	143	Sept. 5, 1932	168	Sept. 25, 1894	191	Aug. 2, 1940	54
Sept. 25, 1894	185	Oct. 4, 1933	236	Oct. 8, 1894	230	Sept. 18, 1941	209
Oct. 20, 1895	210	Aug. 31, 1933	106	Oct. 9, 1896	223	Oct. 8, 1941	287
Sept. 4, 1896	227	Sept. 2, 1933	119	Aug. 30, 1898	152	Oct. 19, 1944	196
Oct. 8, 1896	229	July 29, 1933	113	Oct. 1, 1898	120	Aug. 1, 1944	170
Aug. 1, 1898	110	Sept. 6, 1934	148	Oct. 30, 1899	180	June 24, 1945	220
Oct. 28, 1899	201	Aug. 31, 1935	107	Aug. 13, 1899	197	Sept. 16, 1945	196
Aug. 11, 1899	144	Sept. 28, 1935	217	Oct. 20, 1904	138	July 5, 1946	174
Aug. 9, 1901	116	Nov. 3, 1935	57	Sept. 13, 1904	127	Oct. 14, 1947	94
Aug. 10, 1903	111	July 27, 1936	107	Oct. 19, 1906	33	Sept.22, 1948	238
Sept. 11, 1903	113	Oct. 5, 1941	107	June 17, 1906	122	Sept. 5, 1950	165
Oct. 15, 1904	190	Sept. 17, 1941	183	July 28, 1908	181	May 16, 1951	199
June 16, 1906	212	Sept. 14, 1945	126	Oct. 18, 1910	195	Oct. 2, 1951	122
Oct. 17, 1906	216	Sept. 12, 1946	205	Aug. 26, 1911	115	Aug. 29, 1952	142
Sept. 30, 1908	182	Oct. 11, 1947	231	July 13, 1916	146	Sept. 27, 1953	248
July 27, 1908	156	Sept. 16, 1947	081	Oct, 25, 1921	255	Oct. 14, 1954	274
Oct. 11, 1909	232	Sept. 21, 1948	231	Sept. 29, 1920	223	Aug. 29, 1954	201
Nov. 21, 1912	214	Oct. 5, 1948	224	Sept. 22, 1920	134	Aug. 16, 1955	138
Nov. 15, 1916	242	Aug. 25, 1949	119	Sept. 16, 1924	240	Aug. 11, 1955	168
Sept. 7, 1919	90	Oct. 17, 1950	159	Nov. 30, 1925	215	Sept. 19, 1955	169
Oct. 20, 1924	256	Oct. 2, 1951	233				
Oct. 20, 1926	236	May 17, 1951	305				
July 26, 1926	144	Oct. 24, 1952	232				

TABLE B. - Continued

EAST COAST UNITED STATES

ZONE 3

Date	Avg. direction of movement within zone (degrees from)	Date	Avg. direction of movement within zone (degrees from)
Aug. 20, 1887	227	Sept. 17, 1928	126
Oct. 20, 1887	215	Sept. 11, 1930	124
Oct. 11, 1888	218	Aug. 22, 1933	142
Nov. 25, 1888	204	Sept. 15, 1933	196
Sept. 24, 1889	237	July 21, 1934	067
Sept. 11, 1889	134	Sept. 7, 1934	203
July 8, 1891	249	Sept. 5, 1935	246
Oct. 11, 1891	195	Sept. 17, 1936	159
Aug. 23, 1893	178	Sept. 20, 1938	093
Oct. 4, 1893	284	Aug. 31, 1940	205
Oct. 13, 1893	186	Aug. 16, 1940	217
Sept. 26, 1894	223	Sept. 22, 1941	209
Oct. 9, 1894	221	Oct. 8, 1941	288
Oct. 30, 1899	184	Oct. 19, 1944	202
Aug. 15, 1899	214	Aug. 1, 1944	178
July 10, 1901	076	Sept. 13, 1944	188
Oct. 10, 1903	202	June 25, 1945	217
Sept. 15, 1903	167	Sept. 17, 1945	195
Sept. 14, 1904	149	July 5, 1946	225
Sept. 16, 1906	112	Oct. 9, 1946	266
July 30, 1908	216	Aug. 23, 1949	215
Oct. 19, 1910	238	Aug. 19, 1950	213
Oct. 5, 1912	061	Oct. 3, 1951	220
Sept. 1, 1913	135	May 20, 1951	205
July 19, 1916	192	Aug. 13, 1953	193
July 13, 1916	140	Sept. 27, 1953	238
Sept. 22, 1920	135	Oct. 15, 1954	182
Sept. 30, 1920	205	Aug. 30, 1954	209
Oct. 23, 1923	168	Sept. 10, 1954	204
Sept. 16, 1924	133	Aug. 11, 1955	192
Aug. 25, 1924	104	Sept. 18, 1955	195
Dec. 1, 1925	104	Aug. 16, 1955	144
Aug. 23, 1927	183	Sept. 27, 1956	230

ZONE 4

Date	Avg. direction of movement within zone (degrees from)	Date	Avg. direction of movement within zone (degrees from)
Oct. 20, 1887	197	Aug. 25, 1924	208
Aug. 21, 1888	248	Dec. 3, 1925	248
Sept. 10, 1888	224	Aug. 23, 1927	214
Oct. 11, 1888	225	Sept. 16, 1933	224
Nov. 26, 1888	214	Sept. 8, 1934	197
Sept. 10, 1889	98	June 19, 1934	237
Sept. 24, 1889	225	Sept. 6, 1935	249
Oct. 12, 1891	220	Sept. 18, 1936	226
July 8, 1891	246	Sept. 24, 1936	195
Aug. 23, 1893	183	Sept. 21, 1938	187
Oct. 9, 1894	212	Sept. 1, 1940	207
Sept. 9, 1896	177	Oct. 17, 1943	187
Aug. 19, 1899	244	Oct. 20, 1944	227
June 29, 1902	278	Aug. 2, 1944	241
Oct. 12, 1902	246	Sept. 14, 1944	213
Sept. 15, 1903	152	June 26, 1945	226
Oct. 11, 1903	239	Sept. 11, 1950	222
Sept. 14, 1904	219	Aug. 14, 1953	226
Sept. 15, 1912	258	Sept. 6, 1953	199
July 20, 1916	208	Aug. 30, 1954	195
Sept. 6, 1918	200	Sept. 10, 1954	210
Sept. 30, 1920	202	Aug. 18, 1955	254
		Sept. 27, 1956	235

TABLE B. - Continued

GULF COAST UNITED STATES

ZONE A

Date	Avg. direction of movement within zone (degrees from)	Date	Avg. direction of movement within zone (degrees from)
Sept. 5, 1900	137	Sept. 1, 1933	104
Aug. 10, 1901	110	Oct. 4, 1933	208
Sept. 11, 1903	112	Sept. 3, 1933	145
Sept. 17, 1904	005	July 22, 1934	67
June 16, 1906	170	Sept. 2, 1935	155
Oct. 16, 1906	218	Nov. 4, 1935	90
Oct. 10, 1909	200	Nov. 7, 1935	264
Oct. 17, 1910	182	July 28, 1936	123
Aug. 9, 1911	145	Aug. 2, 1938	70
Sept. 11, 1912	114	Sept. 16, 1941	92
Sept. 2, 1915	157	Oct. 6, 1941	140
Nov. 15, 1916	235	Oct. 18, 1944	190
Nov. 9, 1919	95	June 23, 1945	239
Sept. 29, 1920	245	Sept. 15, 1945	180
Oct. 24, 1921	230	Oct. 7, 1946	190
Oct. 19, 1924	240	Sept. 17, 1947	109
Nov. 30, 1925	221	Aug. 18, 1947	96
July 28, 1926	131	Oct. 11, 1947	218
Sept. 18, 1926	120	Oct. 4, 1948	220
Sept. 16, 1928	150	Sept. 20, 1948	190
Aug. 8, 1928	130	Aug. 26, 1949	145
Aug. 12, 1928	141	Oct. 20, 1950	210
Sept. 27, 1929	135	Sept. 2, 1950	198
Sept. 7, 1930	227	Oct. 18, 1950	158
Aug. 29, 1932	116	Oct. 1, 1951	270
July 30, 1933	90		

Zone B

Date	Avg. direction of movement within zone (degrees from)	Date	Avg. direction of movement within zone (degrees from)
Sept. 7, 1900	112	Aug. 13, 1928	164
Aug. 12, 1901	145	Sept. 29, 1929	180
Oct. 9, 1902	200	Aug. 31, 1932	135
Sept. 12, 1903	170	Aug. 2, 1933	89
Sept 26, 1906	152	July 23, 1934	90
Aug. 10, 1911	138	June 15, 1934	179
Sept. 11, 1912	135	Aug. 26, 1934	115
June 12, 1912	230	Sept. 4, 1935	180
Sept. 3, 1915	180	Nov. 7, 1935	255
Sept. 28, 1915	175	July 30, 1936	147
Oct. 17, 1916	185	Aug. 4, 1938	116
July 4, 1916	170	Oct. 6, 1941	180
Sept. 27, 1917	205	Aug. 18, 1942	124
Aug. 6, 1918	148	July 25, 1943	93
Nov. 12, 1919	100	Sept. 19, 1943	212
Sept. 21, 1920	170	Sept. 18, 1947	123
Sept. 29, 1920	240	Aug. 22, 1947	135
Oct. 15, 1923	190	Sept. 3, 1948	200
Sept. 13, 1924	215	Oct. 18, 1950	31
Sept 19, 1926	128	Aug. 29, 1950	185
Aug. 24, 1926	180	Sept. 25, 1953	221
Aug. 9, 1928	130		

ZONE C

Date	Avg. direction of movement within zone (degrees from)	Date	Avg. direction of movement within zone (degrees from)
Sept. 7, 1900	125	July 6, 1933	60
June 24, 1902	185	Sept. 3, 1933	98
July 20, 1909	96	July 24, 1934	90
Aug. 27, 1909	112	Aug. 26, 1934	32
Sept. 13, 1910	180	Aug. 17, 1936	56
June 11, 1912	198	June 26, 1936	138
Oct. 15, 1912	139	Aug. 14, 1938	160
June 27, 1913	115	Aug. 27, 1938	90
Aug. 16, 1915	165	Aug. 6, 1938	127
Aug. 18, 1916	110	Sept. 22, 1941	166
Aug. 6, 1918	145	Aug. 20, 1942	119
Nov. 13, 1919	90	Aug. 29, 1942	133
Sept. 6, 1921	140	July 26, 1943	122
June 20, 1921	166	Sept. 15, 1943	215
June 15, 1922	125	Aug. 24, 1945	180
June 28, 1929	140	Oct. 22, 1947	128
Aug. 12, 1932	149	Oct. 3, 1949	180
Aug. 3, 1933	75	June 24, 1954	136
		Sept. 4, 1955	100