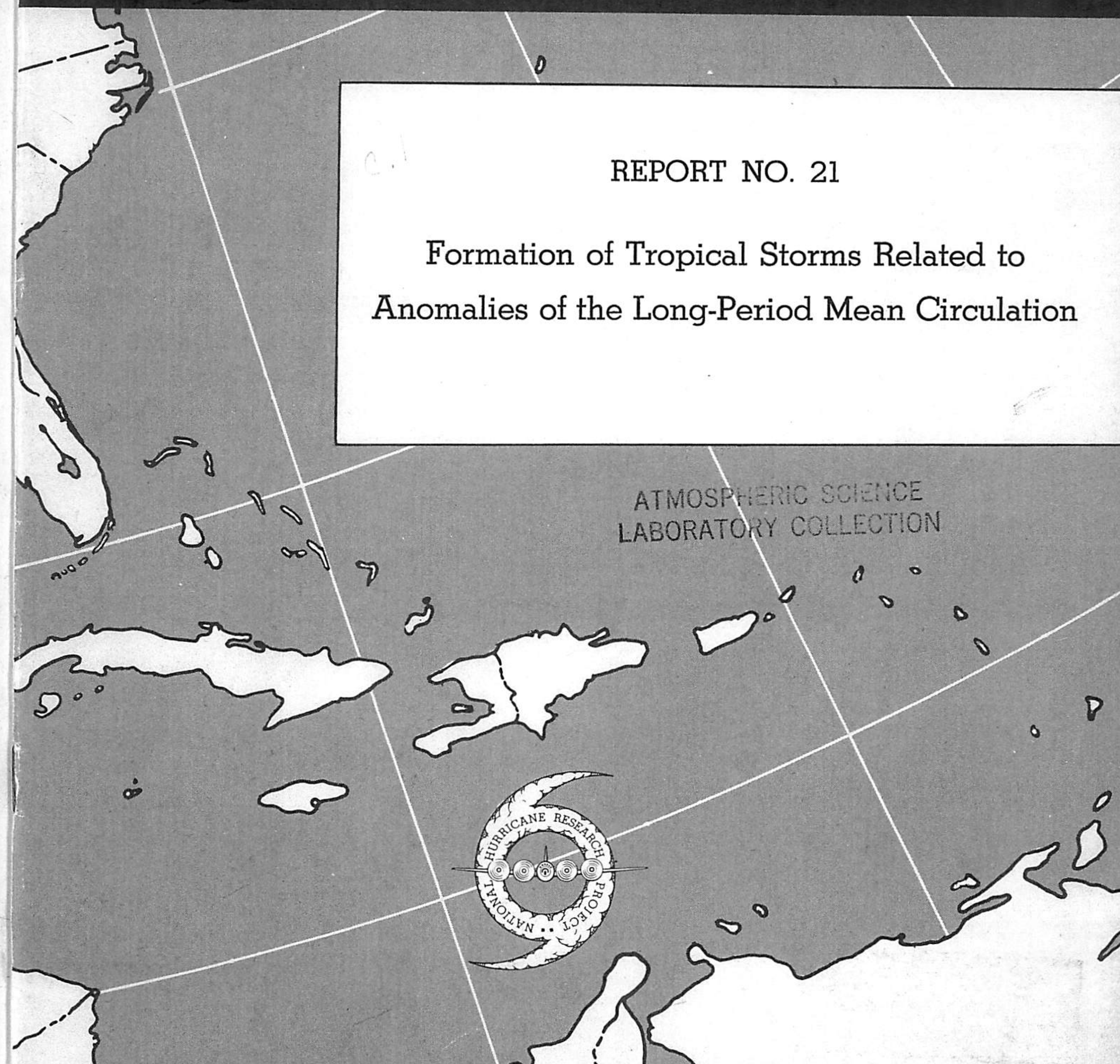
NATIONAL HURRICANE RESEARCH PROJECT

REPORT NO. 21

Formation of Tropical Storms Related to Anomalies of the Long-Period Mean Circulation



U. S. DEPARTMENT OF COMMERCE
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WEATHER BUREAU
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NATIONAL HURRICANE RESEARCH PROJECT

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Formation of Tropical Storms Related to Anomalies of the Long-Period Mean Circulation

by
Emanuel M. Ballenzweig
U. S. Weather Bureau, Washington, D. C.

Washington, D. C.
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NATIONAL HURRICANE RESEARCH PROJECT REPORTS

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FORMATION OF TROPICAL STORMS RELATED TO ANOMALIES OF THE LONG-PERIOD MEAN CIRCULATION

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ABSTRACT

By using composite charts of time-averaged means many details of the role of the large-scale circulation in influencing the generation of tropical cyclones are brought into focus. First, a contrast is shown between generally propitious and inhibiting conditions for genesis in the broad area of the North Atlantic. Next, the formation of tropical storms is shown to be concentrated in five areas in the Atlantic and the longer-period circulation features accompanying tropical cyclogenesis in these areas is discussed with the help of a series of charts containing rather clear-cut anomalous features. Conditions favorable for the formation of tropical storms are found to differ among the different areas. The composite charts appear to be useful as guides in the preparation of long-range forecasts of hurricane formation, once the mean circulation has been predicted.

1. INTRODUCTION

Tropical cyclones usually originate in easterly waves, along the intertropical convergence zone, or sometimes on trailing portions of polar troughs. However, to date no generally accepted description of the synoptic conditions necessary and sufficient for hurricane development has been presented. For this reason short-range forecasting of hurricane formation is rarely done despite its importance. It is especially desirable to forecast genesis in the northern Gulf of Mexico and the Bahamas where a storm can become a threat shortly after formation. Certain interests, for example, offshore oil operations and shipping, have a need for such forecasts as well as for longer-range predictions.

Successful long-range prediction of tropical cyclogenesis is dependent upon an understanding of the nature of the variable frequency of these storms from one season to another (Ballenzweig [2]). Though the cause of these fluctuations is still a matter of conjecture, the most likely one is the variation in the general circulation in middle latitudes (Namias [8]).

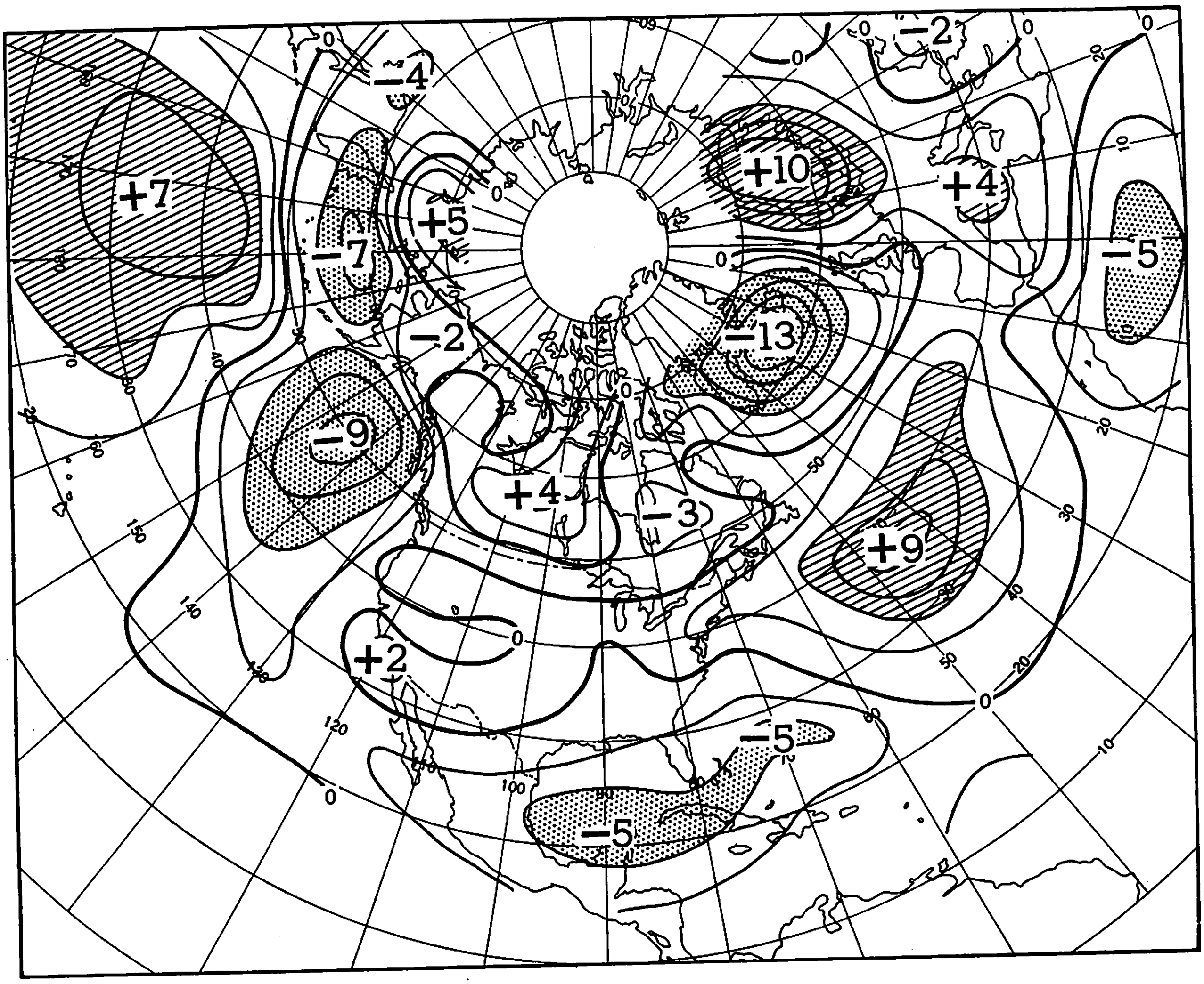

Figure 1. - Composite chart of the average departures from normal (in tens of feet) of 700-mb. height for the 17 monthly periods (August through October, 1933-1956) when at least 5 tropical storms formed in the North Atlantic. (Areas of positive anomaly of at least 40 feet are hatched, and areas of negative anomaly of at least 40 feet are dotted.)

2. FORMATION IN THE ENTIRE NORTH ATLANTIC

In previous reports [2, 3, 4] the seasonal relationship of mean 700-mb. height to tropical storm frequency over the entire North Atlantic was investigated by contrasting composite charts for seasons (August-October) of maximum with those of minimum storm occurrence. Large differences were apparent which one could relate in a physical manner to tropical storm generation. The most significant differences were probably those over the Atlantic where easterly anomalous flow and strong anticyclonic shear were observed to the north of the zones of storm formation in seasons of high occurrence.

It was suggested in two of these reports [2, 4] that these relationships should be equally applicable on a monthly basis (and perhaps even for medium-

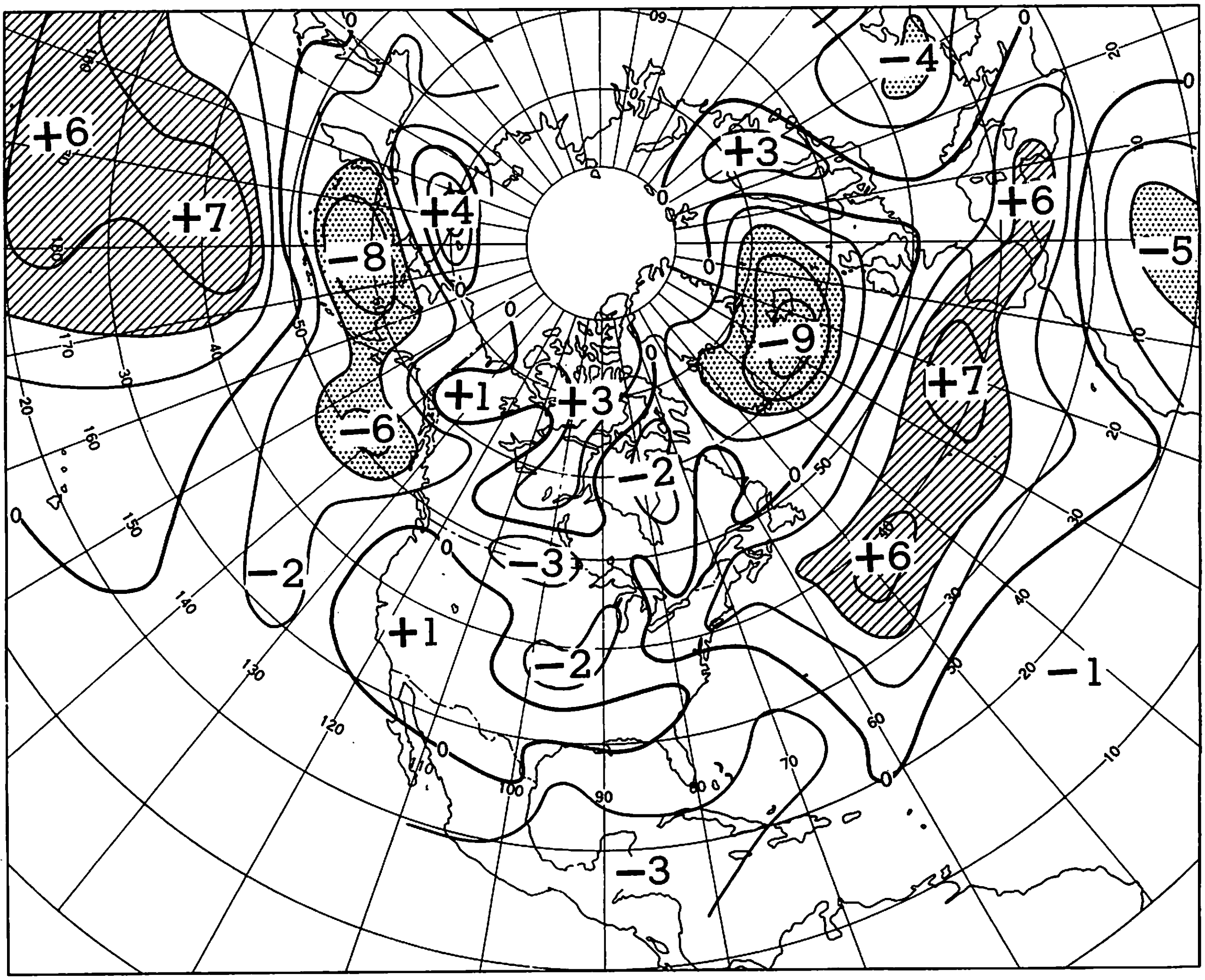

Figure 2. - Composite chart of the average departures from normal (in tens of feet) of 700-mb. height for the five seasons (August-October) of maximum tropical cyclone incidence in the North Atlantic.

range periods). To investigate this possibility, all months from 1933 to 1956 were investigated; and the months when at least 5 tropical storms formed were tabulated and the height anomalies for these months averaged at points 5° of latitude and 10° of longitude apart on a diamond grid. The resulting composite chart (fig. 1), composed of 17 monthly periods, bore a striking resemblence to the composite for seasons of high frequency (fig.2).

A composite chart of mean 700-mb. height was prepared for the 16 monthly periods during August to October when one storm or less formed in the years 1933-1956 (fig. 3). To include other months of the year would bias the sample, as one storm per month is greater than the median value in other months. One would not expect great homogeneity in this sample, as many factors may limit the frequency. A large well-defined negative area dips far southward in the eastern Atlantic with a double center, one over Scandinavia and the

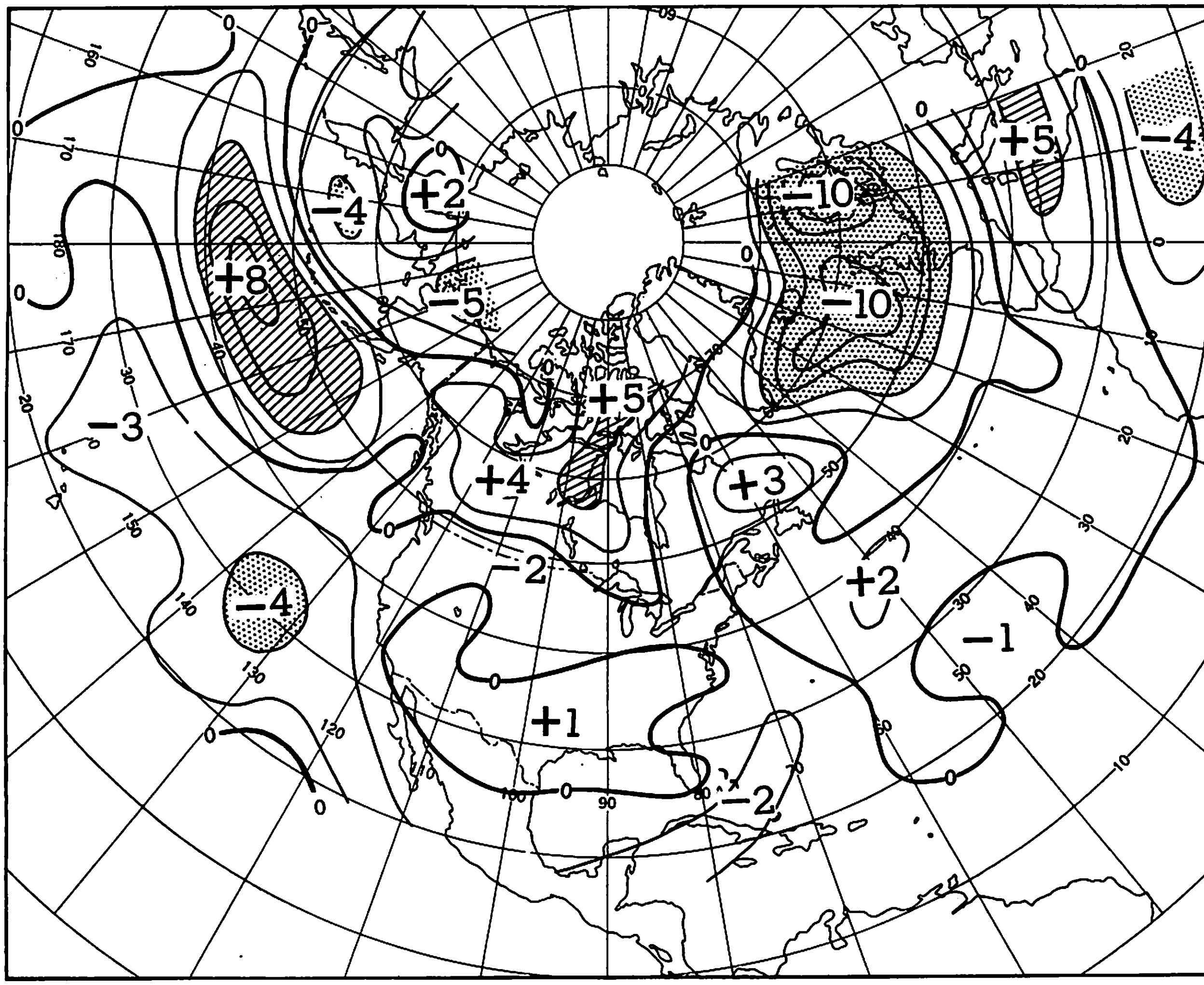

Figure 3. - Composite chart of the average departures from normal (in tens of feet) of 700-mb. height for those 16 monthly periods (August through October, 1933-1956) when no more than one tropical storm formed in the North Atlantic.

other between Iceland and Great Britain. The anomaly field in the Atlantic south of 45°N. is weak and poorly defined and the 16 months included showed no consistent sign of the anomaly in this area, whereas in maximal months the positive anomalies in the Atlantic were very highly consonant. The basic difference between these two patterns is readily seen in figure 4A where the zonal wind speed profiles for the two groups of months are presented. The westerlies are weaker in months of high frequency than in months of low frequency in latitudes south of about 45°N. and the anticyclonic wind shear is greater in the middle latitudes of the Atlantic and eastern North America (0°-100°W.). This is essentially the same information gained from the seasonal study, with one exception: the westerly wind maximum is at about the same latitude in both groups of months, whereas the seasonal study showed a southward displacement in minimal seasons.

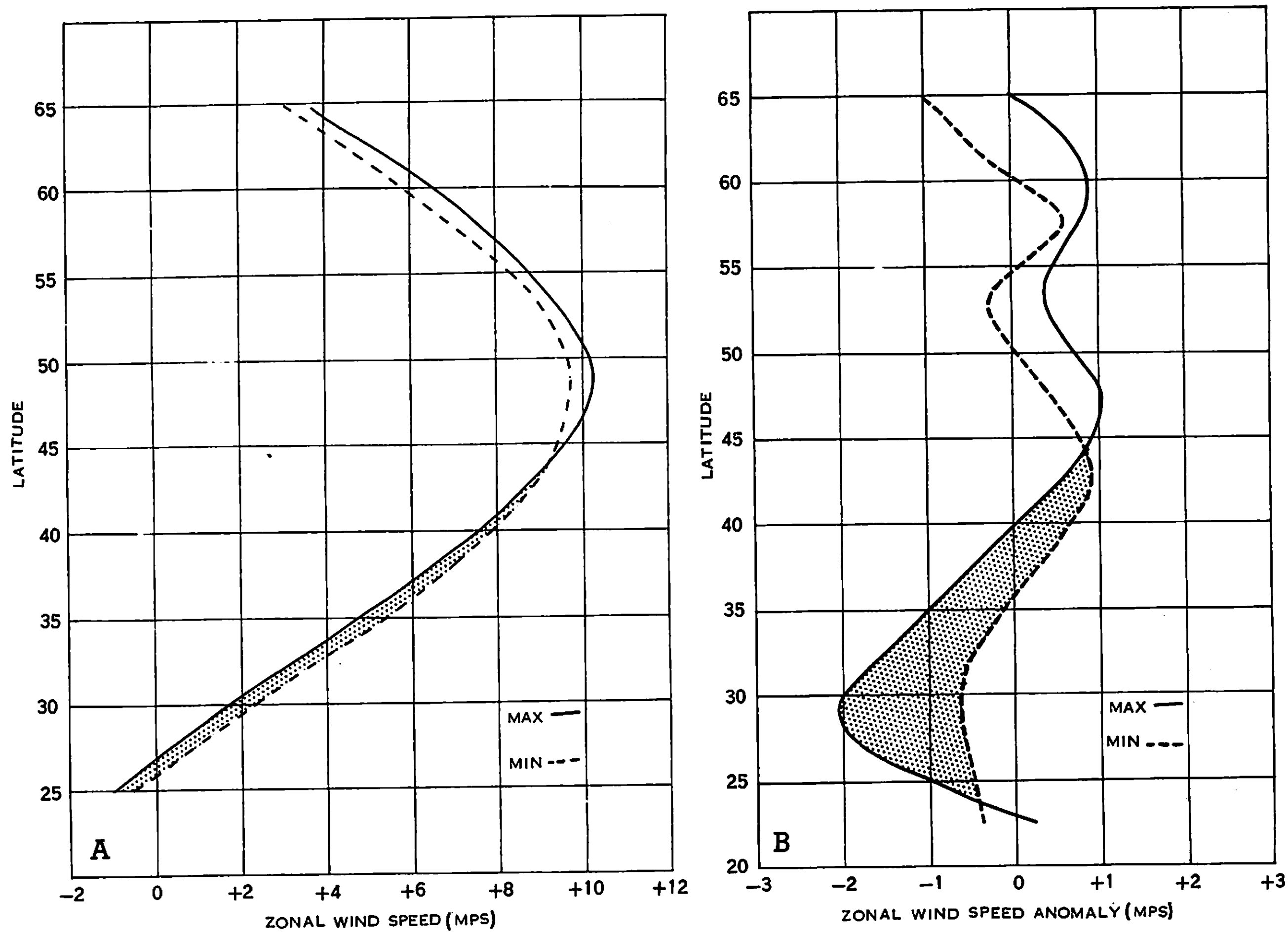

Figure 4. - (A) Composite 700-mb. zonal geostrophic wind speed profiles averaged between 0° and 100°W. for the months of maximum (solid curve) and minimum (dashed curve) tropical storm formation in the North Atlantic. Note the weaker westerlies south of 45°N. in maximal contrasted with minimal months (stippled area indicates the difference) and the greater anticyclonic shear in middle latitudes in those months. (B) Departure from normal of the zonal wind speed profiles shown in (A). Note the large area of easterly anomalous flow in maximal months especially when contrasted with minimal months (difference is stippled). Note the anomalous cyclonic shear in low latitudes with stronger than normal anticyclonic shear to its north in maximal months.

In order to emphasize the differences between these two contrasting samples and remove any possible bias introduced by the different frequency distribution of Augusts, Septembers, and Octobers in both groups of months, profiles of the departure from normal component of the wind were plotted for each group of months (fig.4B). The following relevant features are evident: Months of maximum frequency show a broad band of easterly anomalous flow south of about 40°N. and greater anticyclonic shear than normal between 45°N. and 30°N., both in excess of that observed in minimal months; more cyclonic

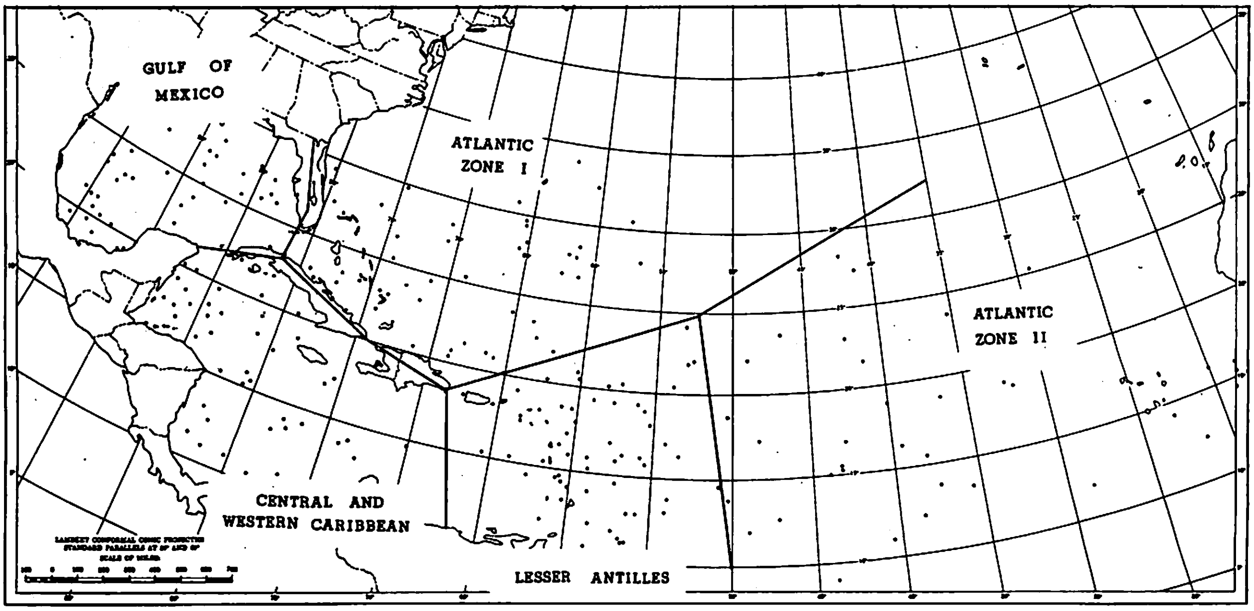

Figure 5. - Areas of formation of tropical storms. The circles are the positions where the storms were first detected.

shear than normal is also observed in latitudes south of 30°N. in maximal months whereas there is no significant anomalous cyclonic shear indicated in minimal months.

The stronger anticyclonic wind shear in lower middle latitudes may be a pertinent physical factor. Such a distribution of zonal winds is often associated with the shearing of planetary waves wherein the northern portions move eastward more rapidly than the southern portions which tend to fracture. Break-off troughs, thus formed, may move westward as easterly waves. Riehl and Burgner [12] found that tropical depressions tend to intensify following fracture of the extended trough that produced the initial deepening, and Bath et al.[6] showed an excellent synoptic example of this type of situation in the Australian region. The easterly anomalous flow south of 40°N. presents a favorable background for formation, and at this level cyclonic shear in lower latitudes should aid the growth of cyclonic vortices.

3. STORM FORMATION IN INDIVIDUAL AREAS

Procedure - Although a general forecast of the frequency of tropical storm activity in the Atlantic is valuable, it is of more importance to specify which portion(s) of the Atlantic will be the preferred site(s) of storm formation. Their development seems to show signs of concentration in five general areas (several of which could be sub-divided further): the Gulf of Mexico, western Caribbean Sea, vicinity of the Bahamas, near the Lesser Antilles, and the eastern North Atlantic. Figure 5 illustrates the positions where the storms used in this study (1933-1955) were first detected, that is, the points where the cyclonic circulation first became discernible with the data available. The bold lines arbitrarily outline the areas which were partially delineated by the scatter of points of the 23-year sample.

Figures 6-10 illustrate the circulation features which accompany storm formation in these particular areas of the Atlantic. These charts are averages of monthly mean 700-mb. height anomalies for those Augusts, Septembers, or Octobers between 1933 and 1955 when two or more tropical storms formed in the indicated areas of the Atlantic. Of course, such a study is subject to possible errors arising from the occasional uncertainty as to whether a storm actually formed in the area where it was first detected. Also, classification of storms on the basis of formation in certain small areas in a given month may result in excessive subdivision of the data. While it might seem that the appearance of two storms in a month hardly indicates that the given area is a preferred site for formation, cases with any more than two per month in the areas chosen are quite rare. Despite these apparent restrictions, the charts contain some rather clear-cut anomaly fields which seem physically reasonable.

Formation in the Eastern Atlantic (Atlantic Zone II) - Figure 6 indicates that formation in this area is associated with heights below normal over most of the Atlantic south of latitude 30°N., the greatest negative anomalies being centered over the area of formation. A belt of pronounced positive height anomaly stretches across the Atlantic near latitude 40°N. and continues west-southwestward across the United States. This feature means that the subtropical Highs are extremely well developed, zonally oriented, and north of normal. In combination with the negative anomalies to the south a fairly strong easterly flow (as strong as 5 m.p.s.) relative to normal prevails over the subtropical Atlantic and southern United States. This large zone of easterly anomalous flow may provide the climate favorable to their growth.

Negative height anomalies are discernable at higher latitudes over northeastern Canada and the Atlantic with an intense negative center near Iceland. This, in combination with the positive anomalies to the south, illustrates the tendency for stronger-than-normal westerlies to prevail from eastern Canada to just west of the British Isles. The distribution of zonal winds produced by these anomalies is one of extreme shear. Along the 45th meridian the wind speed is 15 m.p.s. from the west at about 48°N. and 2 m.p.s. from the east at 30°N., a shear of 17 m.p.s. contrasted with a normal value of only 8 m.p.s. Perhaps this zone of strong anticyclonic shear is also of importance in the development of tropical cyclones; e. g., by fracture of extended troughs due to relative motion.

Namias and Dunn [9] hypothesized that the frequency of tropical storms of the Cape Verde type depends on the degree of development of the Azores ridge to the north. They stated that when the ridge of the Azores upper-level anticyclone is thrust strongly northeastward into Europe, cyclonic vorticity is injected into a trough in the vicinity of the northwestern coast of Africa. They cited the antecedent conditions associated with hurricane Connie in August 1955 as an example of this type of development; and this writer [5] found similar conditions prior to the formation of hurricane Carrie in September 1957. Perhaps the positive anomalies near western Europe during seasons of frequent

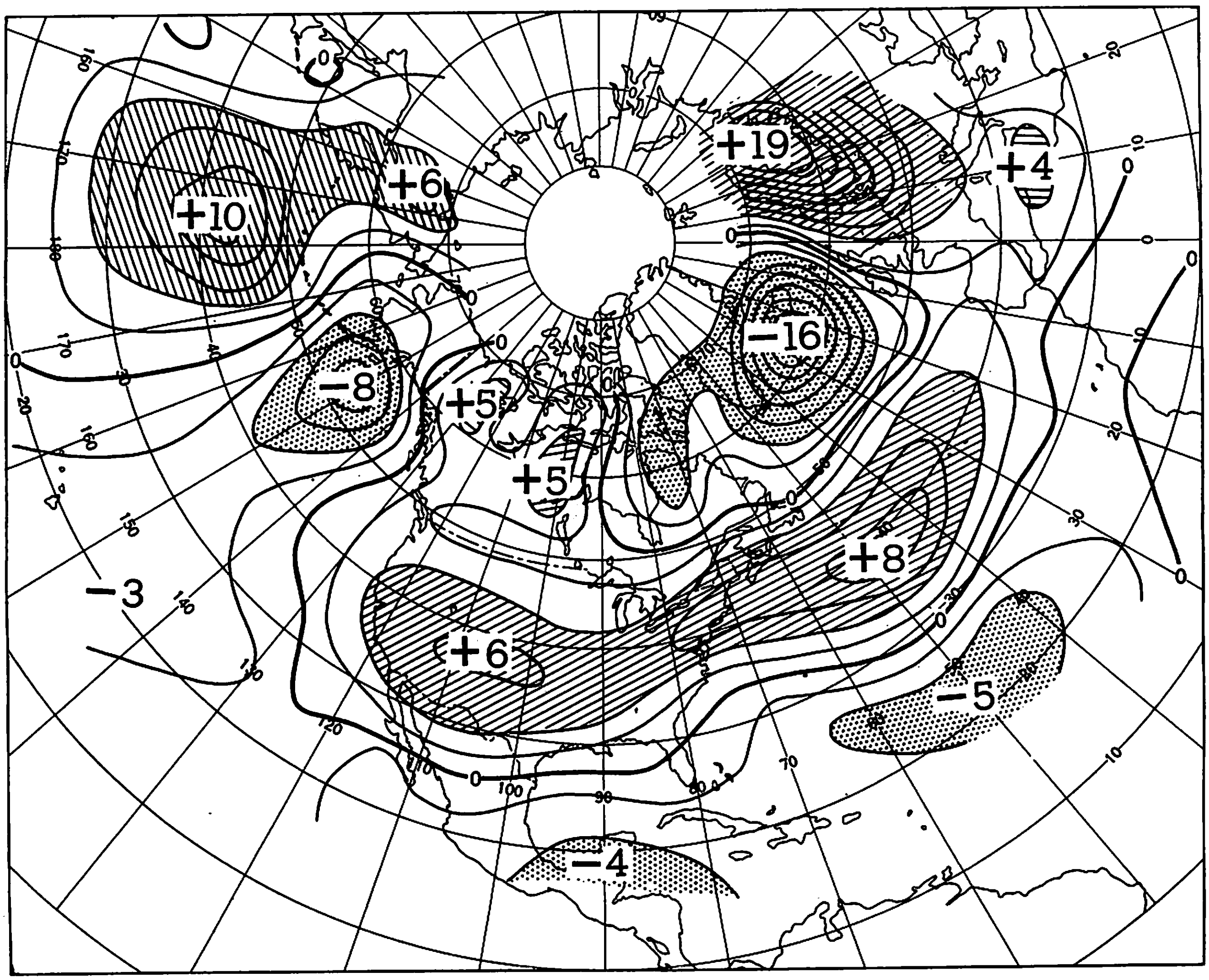

Figure 6. - Composite chart of the average departure from normal (in tens of feet) of 700-mb. height for the eight months (1933-1956) during which at least two tropical storms developed in the eastern Atlantic (Atlantic Zone II).

tropical cyclogenesis in the eastern Atlantic (fig. 6) are a manifestation of frequent northward and eastward thrusts of the Azores High.

Formation in the Gulf of Mexico - This pattern (fig. 7A) is quite analogous to that favorable for storm formation in the eastern Atlantic (fig. 6). Both charts display a broad zone of easterly flow relative to normal across the Atlantic and southern United States. However, positive anomalies are much stronger in the Atlantic in the case of Cape Verde storms (fig. 6) while they are stronger over the Ohio Valley and Middle Atlantic States in the case of Gulf storms (fig. 7A). Riehl and Shafer [13] pointed out that all cases of tropical storm formation in the Gulf were associated with a broad current of deep easterlies with cyclonic deformation along the Gulf coast. Normally, the winds are westerly along the north Gulf coast during all months of the year; but, the mean 700-mb. flow during the seven months when at least two tropical

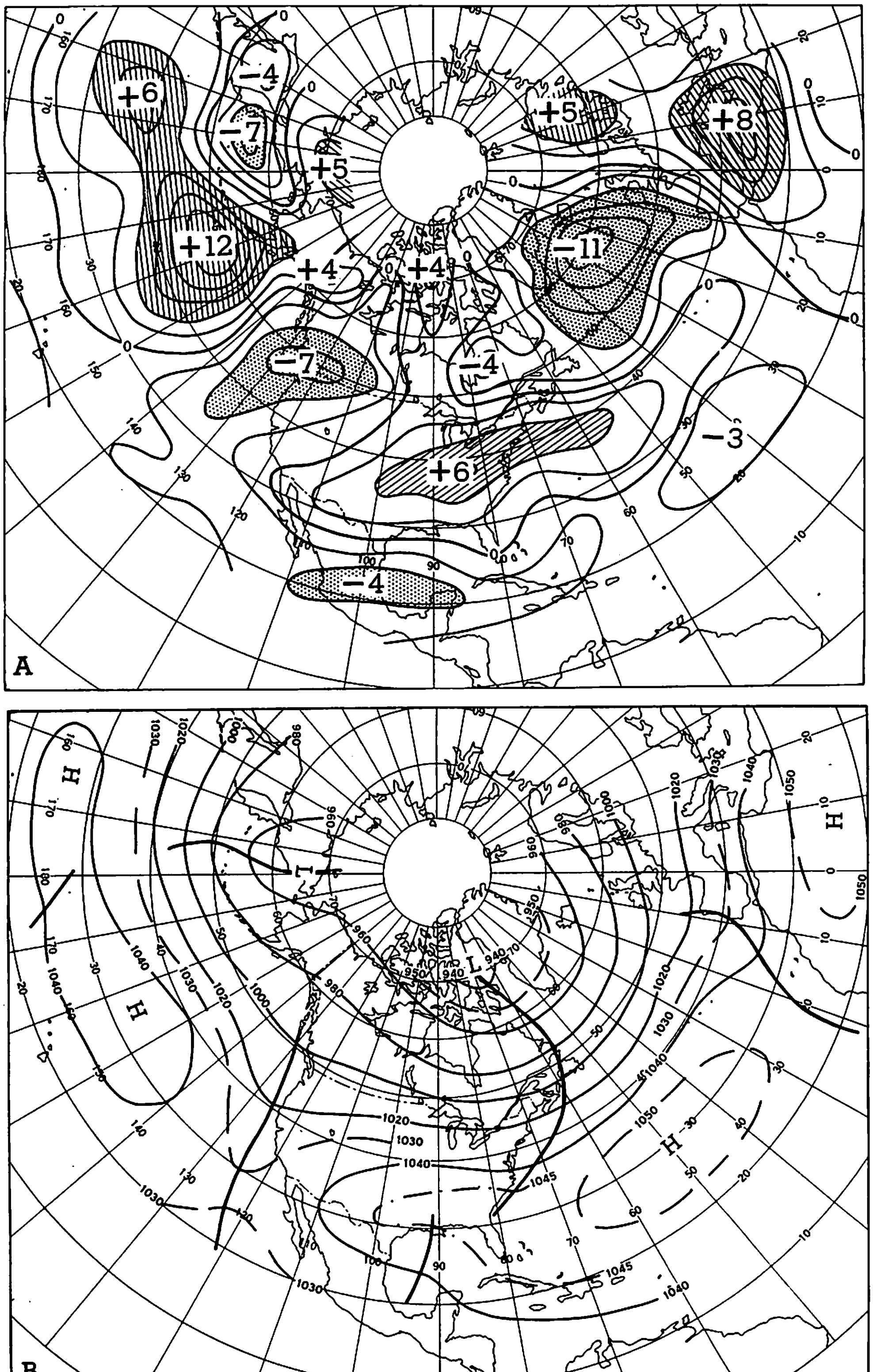

Figure 7. - (A) Composite chart of the average departure from normal (in tens of feet) of 700-mb. height for the eight months (1933-1956) during which at least two tropical storms developed in the Gulf of Mexico. (B) Composite chart of the average 700-mb. height contours (in tens of feet) for the same seven months as (A). Observe the easterly wave in the Gulf

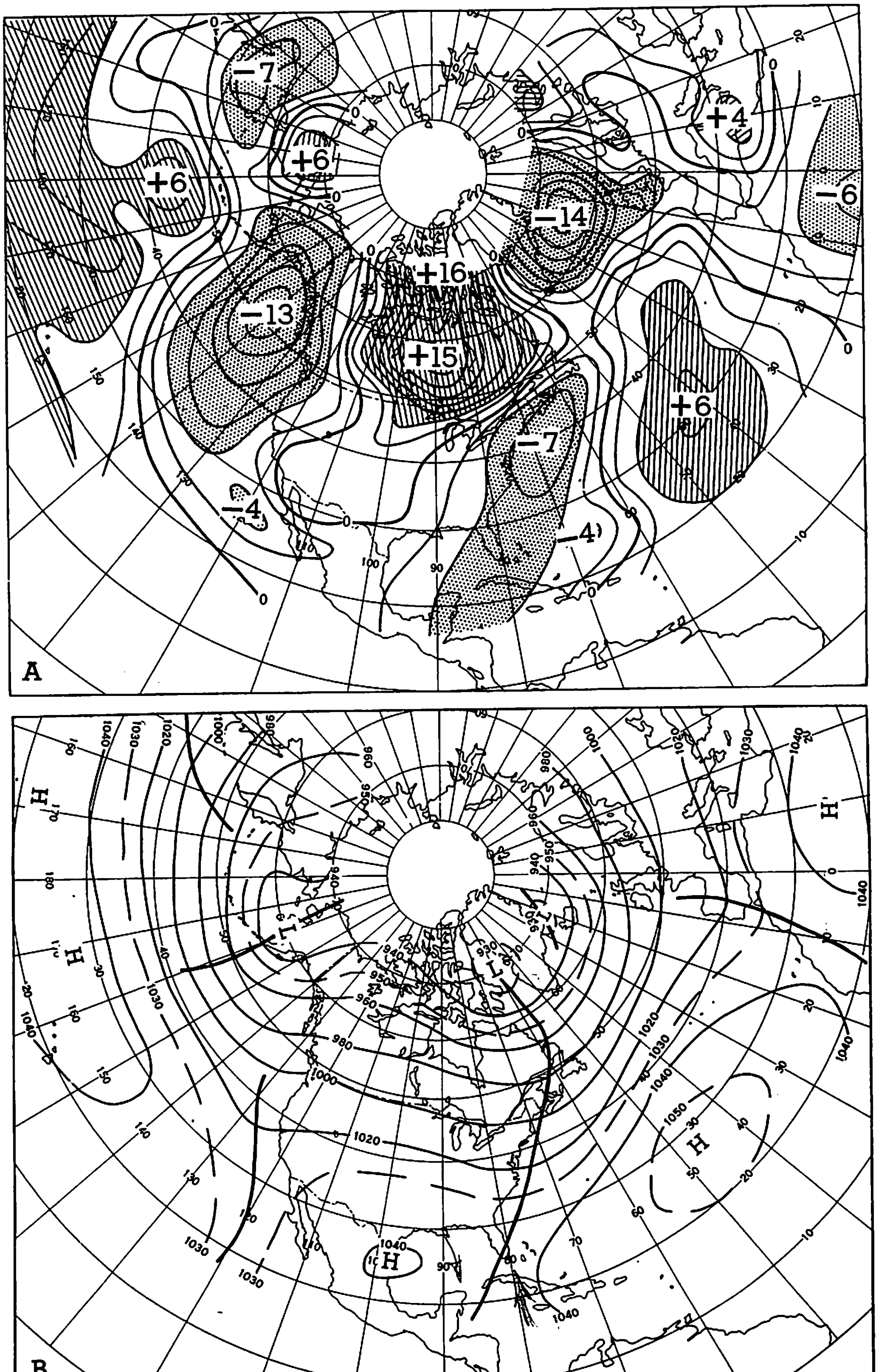

Figure 8. - (A) Composite chart of the average departure from normal (in tens of feet) of 700-mb. height for the eight months when at least two tropical storms developed in the Caribbean. (B) Composite chart of the average 700-mb. height contours (in tens of feet) for the same eight months as (A). Observe the extended trough in the area of formation.

storms developed in the Gulf of Mexico (fig. 7B) showed easterly flow with cyclonic curvature throughout the Gulf and along its northern coast.

A brief survey of 5-day mean 700-mb. charts just prior to the formation of tropical storms in this area showed, in general, the circulation characteristics of the composite (fig. 7A). They all showed below normal heights in the Gulf of Mexico. The few charts which did not exhibit pronounced easterly flow, showed an extended trough in the area of formation prior to the appearance of the vortex. Low pressure centers in the latter case did not develop to great intensity unless the easterlies deepened.

Formation in the Central and Western Caribbean Sea - Conditions favorable for tropical storm formation in the central and western Caribbean are very different from those attending formation in the Gulf or in the eastern Atlantic (cf. figs. 6, 7A, and 8a). Formation in those latter areas was associated with easterly anomalous flow in the area and stronger than normal anticyclonic wind shear to the north of the hurricane breeding grounds, whereas formation in the Caribbean (fig. 8A) is not associated with this extensive easterly anomalous flow. Formation in the Caribbean is attended by negative anomalies in the area of generation extending northeastward to Newfoundland. Another unique feature of this composite is the extensive area of positive anomaly extending from central Canada to the Maritime Provinces. This positive anomaly area is probably significant in storm formation because of its association with a depression of the westerlies in eastern North America so that the trough is quite deep at middle and low latitudes (fig. 8B). This pattern suggests that most tropical storm formation in the area tends to occur in the lower latitude portions of mean polar troughs reaching southward from middle latitudes.

According to evidence presented by Dunn [7], 80 percent of 40 Atlantic hurricanes in the years 1901-1955 developed in perturbations moving away from the intertropical convergence zone (ITC) in the Panama region. Although almost all the major developments occurred a considerable distance away from the ITC, few developed in connection with a trailing polar front. That being the case, what is the role of the extended trough? In the mean, the ITC lies just south of Panama with occasional northward thrusts into the Caribbean. This shear line is at its farthest north in June and mid-September to mid-October (Alpert[1]) which roughly corresponds to the times of peak frequency of tropical storms in the Caribbean.

Variations in the position of the ITC may be related to changes in the flow pattern over the North American region. For example, the strong southerly flow on the east side of the extended trough (fig. 8B) or the anomaly trough (fig. 8A) can advect the shear zone northward into the Caribbean. It is also possible that the position and the strength of the principal subtropical anticyclone in the South Pacific may account for the location of the ITC (Riehl [10]), but this has not been investigated thoroughly. In general, this center of action lies due south of Mexico with its outflow directed toward Central America. This current will be large or small depending on the position and intensity of the anticyclone. When the flow is strong the ITC, the boundary between the outflowing current and the northern trades, may be displaced into the Caribbean.

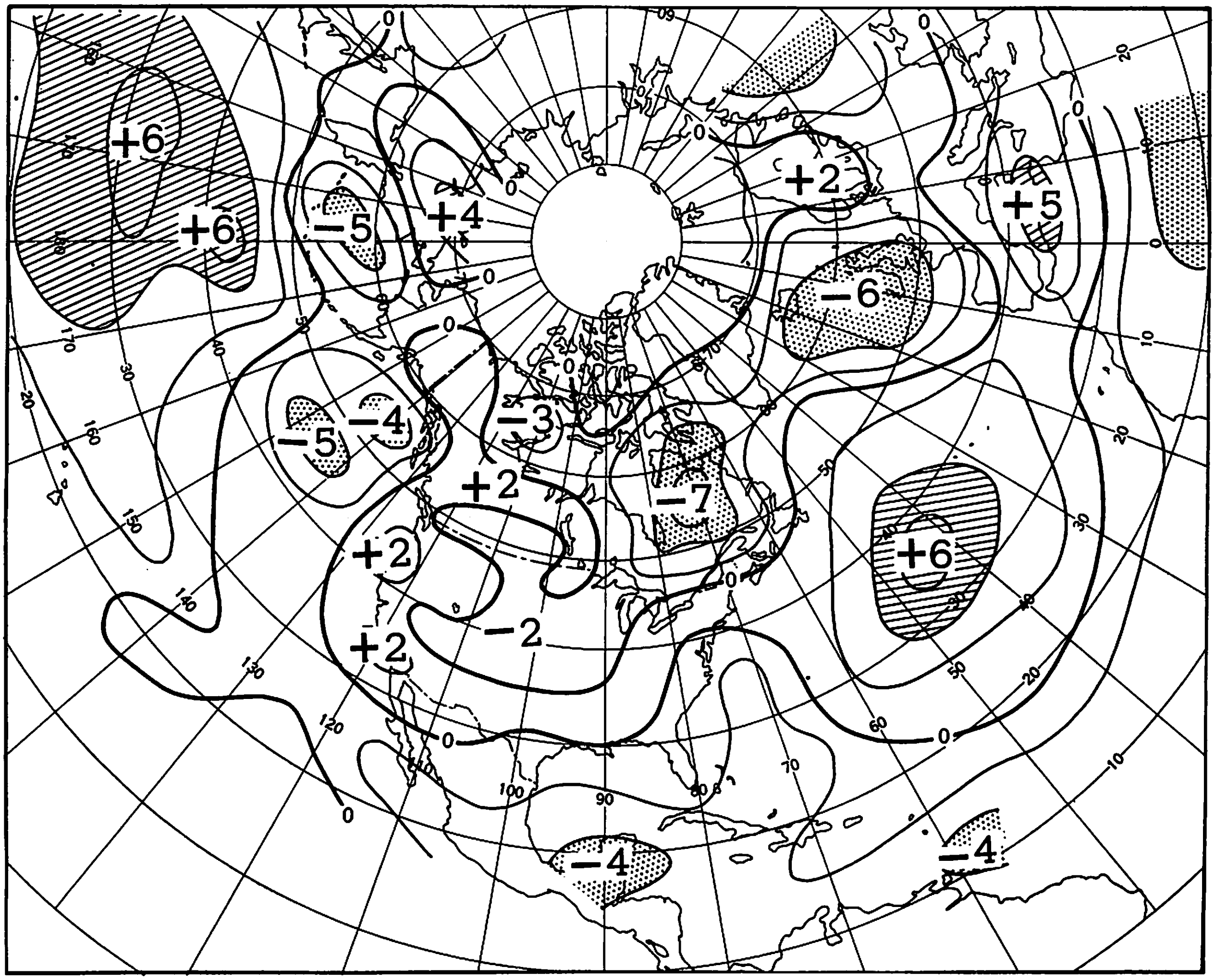

Figure 9. - Composite chart of the average departure from normal (in tens of feet) of 700-mb. height for the 14 months when at least two tropical storms developed in the vicinity of the Lesser Antilles.

When the shear zone is north of normal, the wind shear is generally sharper than normal inducing the formation of a large number of vortices. Intense shear lines may persist for long periods of time with numerous small vortices forming. Riehl [11] believes that an extended trough must intersect an equatorial shear line if a hurricane is to form there, as the presence of the polar trough provides a concentration of cyclonic vorticity. With a northward surge of the ITC the Caribbean can become subject to hurricane formation if a deep trough passes athwart the shear zone. Such extensive breakthroughs of troughs into the subtropics are infrequent in August and September, but their frequency increases by October as the colder season approaches. It is well established, of course, that formation in the Caribbean is most frequent in the first half of October (5 of the 8 months making up fig. 8 are Octobers). Furthermore, the composite anomaly pattern shows that a good southerly steering current generally accompanies storm development in

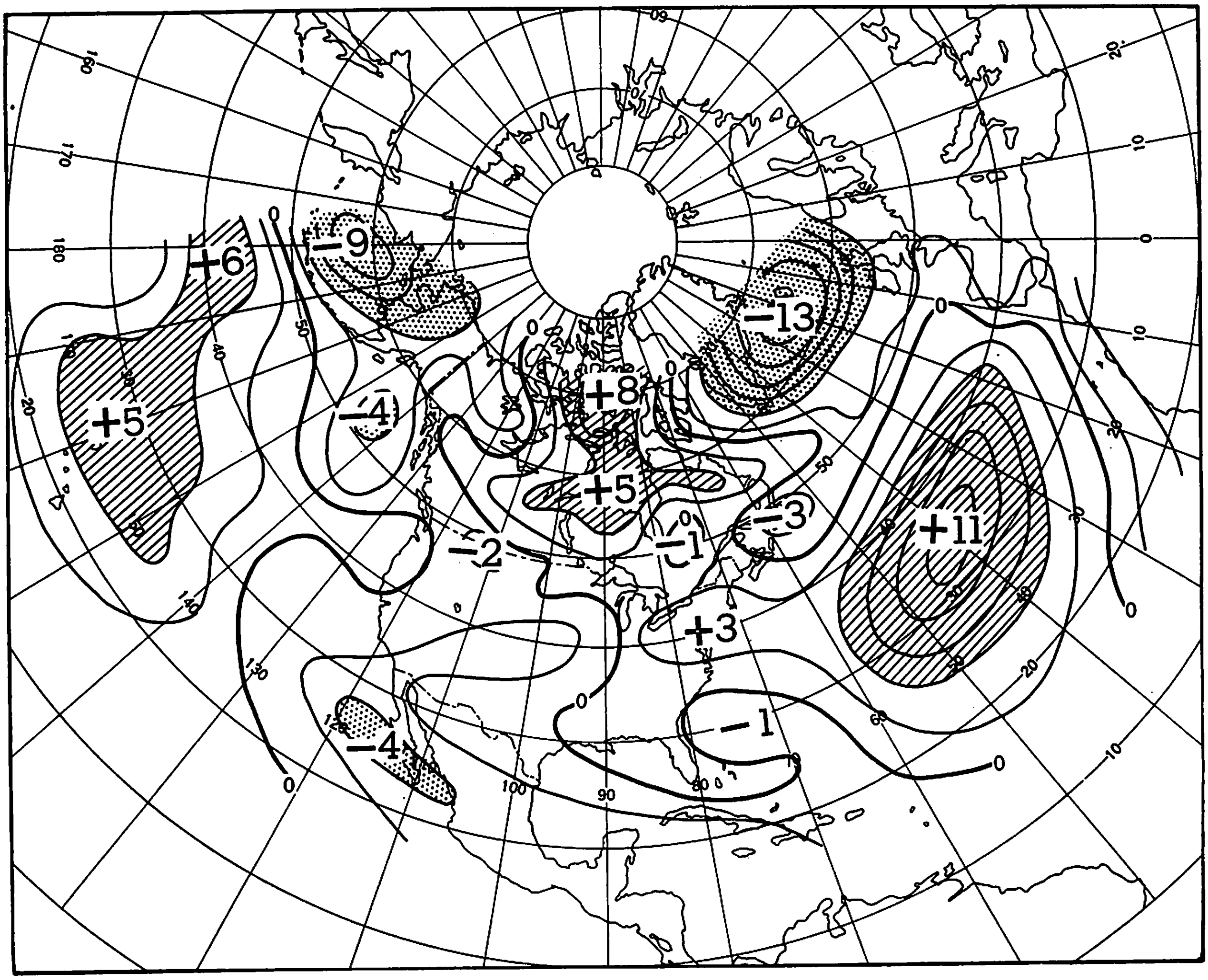

Figure 10. - Composite chart of the average departure from normal (in tens of feet) of 700-mb. height for the 10 months when at least two tropical storms developed in the vicinity of the Bahamas (Atlantic Zone I).

the Caribbean, and these cyclones often move in a direction between north and northeast.

Formation in the vicinity of the Lesser Antilles - This area is the most prolific spawner of tropical storms in the entire Atlantic. The chief feature of the composite situation favorable for tropical storm formation in the Antilles region (fig. 9) is the large circular area of positive anomaly in the central Atlantic with a negative anomaly area cresting across the north with centers over eastern Canada and Great Britain. Associated with this anomaly pattern is strong easterly flow at low latitudes. To the northeast of the Antilles the mean wind is 8 m.p.s. from the east; to the northwest 5 m.p.s. from the east. Such a convergent picture may be associated with the deepening of easterly waves in that vicinity. Again as in the studies for the Gulf of Mexico and for the eastern Atlantic, strong anticyclonic shear is present north of the area of generation. In this case the shear was 18 m.p.s. between 40°N. and 20°N. along the 55th meridian. Most formation in this area is associated with easterly waves; formation of vortices in easterly waves is often associated with polar trough intrusions and there is some suggestion of troughiness in the western Atlantic. Furthermore, storms from this area generally take one of two tracks, westward toward Yucatan or northwestward to recurve off the east coast of North America. Both of these climatological features are suggested by the anomalous flow.

Formation in the vicinity of the Bahamas (Atlantic Zone I) - Figure 10 shows no clear-cut indications of conditions favorable for cyclogenesis in this area. Formation in this area often occurs in trailing portions of polar troughs and frequently in easterly waves. This composite suggests trough shear to be most likely in the central Atlantic between about 40°W. and 60°W. But heights in subtropical latitudes (and, perhaps, in tropical latitudes) appear to be above normal between these longitudes, a feature tending to inhibit cyclogenesis in that area. To the west of about 65°W. the negative 700-mb. height anomaly would be more favorable for deepening easterly waves passing into this area. There is also some sign of an anomaly trough extending southeastward from Newfoundland to just north of the Bahamas[1]. This anomalous flow is conducive for steering storms toward the Middle Atlantic Coast and greater than one-half of all storms forming in the vicinity of the Bahamas in the past 70 years have approached the Middle Atlantic States.

4. SUMMARY

It is believed that the anomalous features of the general circulation shown in the accompanying composite charts are associated with basic recurrence of similar large-scale features on daily and 5-day mean maps, and that these features tend to influence the generation of tropical cyclones as well as to control their paths. On the basis of the data examined it appears that overall tropical storm frequency is a function of the horizontal wind shear in middle latitudes, as well as that in lower latitudes, plus the strength of the westerlies in lower middle-latitudes and the subtropics.

Figures 6-10 have several common characteristics which resemble somewhat the composite chart for maximum hurricane frequency in the entire Atlantic (fig. 1). Notable are the negative height anomalies near Iceland and in subtropical portions of the Atlantic, Caribbean, and Gulf, and the positive anomalies near 35°-40°N. in the Atlantic.

However, the composites for the various areas have several distinctive characteristics of their own. For the most part, the strongest negative height anomalies in the subtropics are located over the areas of formation, reflecting in a general manner the tendency for tropical storms to form in regions where the 700-mb. flow is more cyclonic than normal. Both the charts for formation in the eastern Atlantic (fig. 6) and in the Gulf of Mexico (fig. 7A) display a broad zone of easterly flow relative to normal in the Atlantic

[1]Much better indicated in a seasonal study (not reproduced).

and across the southern United states with differences in the local intensity of the anomaly centers. It is interesting to note that storms forming in the Lesser Antilles (fig. 9), the Atlantic north of the Antilles (fig. 10), and the Caribbean (fig. 8A) are not accompanied by extensive easterly anomalous flow to the north of the areas of generation. The Caribbean composite (fig. 8A) shows a marked northward extension of negative anomalies along the east coast of the United States associated with a trough extending into lower latitudes where it may intersect an E-W shear line and result in tropical cyclogenesis. It also suggests a southerly steering current for these storms which is in agreement with climatology. The composites for the other two areas were less well defined. The one for the Lesser Antilles (fig. 9) also exhibited an extension of negative anomalies toward the east coast of the United States, but also showed a suggestion of easterly anomalous flow to the north and east of the islands. Strong easterly flow and anticyclonic shear are present to the north of the islands. Most of the tropical developments in the Lesser Antilles are associated with easterly waves, but a trough in the westerlies could help to trigger the cyclogenesis. Furthermore, many of the storms from this area move northward in a mean trough near the east coast of the United States or westward toward Yucatan. Conditions favorable for formation in the Bahamas are not well indicated in this composite study (fig. 10), although it is suggested that weak easterly waves may tend to intensify and occasional polar trough developments may acquire tropical characteristics in this zone. Steering toward the mid-Atlantic coast is suggested by the anomaly field.

Composite charts indicating formation of tropical storms, as illustrated in this article, serve as a convenient guide to the likelihood of tropical storm generation in general and in specific areas, provided, of course, that a reasonably good circulation prognosis is available. In other reports, the interaction between storm motion and the large-scale flow has been presented. Although some were developed from seasonal data, these composite charts have been found to be equally valid for circulation patterns and tropical cyclone frequencies for monthly periods, and indeed, are used in the routine preparation of experimental 30-day hurricane outlooks. It is also believed that many of these relationships are adaptable to shorter-period mean circulations and should thus be part of the short- and medium-range forecasters' stock in trade.

REFERENCES

1. L. Alpert, "The Inter-Tropical Convergence Zone of the Eastern Pacific Ocean, Pt. 1," Bulletin of the American Meteorological Society, vol. 26, No. 10, Dec. 1945, pp. 426-432.
2. E. M. Ballenzweig, "Fluctuations in Frequency of Tropical Storms," Weatherwise, vol. 10, No. 4, August 1957, pp. 121-125.
3. E. M. Ballenzweig, "Seasonal Variations in the Frequency of North Atlantic Tropical Cyclones Related to the General Circulation," Proceedings of the Tropical Cyclone Symposium, Brisbane, December 1956, pp. 57-70.
4. E. M. Ballenzweig, "Seasonal Variations in the Frequency of North Atlantic Tropical Cyclones Related to the General Circulation," National Hurricane Research Project Report No. 9, Preprinted, U. S. Weather Bureau, 1957, 32 pp.

5. E. M. Ballenzweig, "The Weather and Circulation of September 1957 - Including a Discussion of Tropical Storm Activity," Monthly Weather Review, vol. 85, No. 9, Sept. 1957, pp. 315-325.
6. A. T. Bath, S. H. Lloyd, and P. Ryan, "Practical Techniques Used in the Australian Region for Tropical Cyclone Forecasting," Proceedings of the Tropical Cyclone Symposium, Brisbane, December 1956, pp.121-133.
7. G. E. Dunn, "Areas of Hurricane Development," Monthly Weather Review, vol. 84, No. 2, Feb. 1956, pp. 47-51.
8. J. Namias, "Tropical Cyclones Related to the Atmosphere's General Circulation," Transactions, New York Academy of Sciences, Ser. 2, vol. 17, No. 4, Feb. 1955, pp. 346-349.
9. J. Namias, "The Weather and Circulation of August 1955 - Including the Climatological Background for Hurricanes Connie and Diane," Monthly Weather Review, vol. 83, No. 8, Aug. 1955, pp. 163-170.
10. H. Riehl, "How Hurricanes Form," The Petroleum Engineer, 1957, pp.B29-B34.
11. H. Riehl, "On the Formation of West Atlantic Hurricanes," Part I of "Studies of Upper Air Conditions in Low Latitudes," Department of Meteorology, University of Chicago, Miscellaneous Reports No. 24, 1948, pp. 1-67.
12. H. Riehl, and N. M. Burgner, "Further Studies of the Movement and Formation of Hurricanes and Their Forecasting," Bulletin of the American Meteorological Society, vol. 31, No. 7, Sept. 1950, pp. 244-253.
13. H. Riehl, and R. J. Shafer, "The Recurvature of Tropical Storms," Journal of Meteorology, vol. 1, Nos. 1-2, Sept. 1944, pp. 42-54.