The Climatology of Cyclones and Anticyclones in the Upper Mississippi and Ohio River Valleys and Great Lakes Region, 1950-74

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Introduction

It is well known that migrating synoptic-scale cyclones and anticyclones are crucial in determining the weather over North America. Such events have been subjected to numerous individual case studies designed to diagnose their kinematic, dynamic, and thermodynamic properties and associated weather. However, in order to establish typical behavior and to understand the extent to which individual cases represent significant departures from the norm, a complete diagnosis of cyclones and anticyclones must also include analyses of their climatologies. Previous climatological studies of synoptic-scale systems have been reported by Hurley (5), Hosler and Gamage (4), Petterssen (8), Klein (6), Halzworth (3), Korshover (7), Reitan (9), and Colucci (2). Clearly, the amount of attention given to this subject has been very small. Further, aside from the work of Holzworth (3) and Colucci (2), little has been done to relate these climitologies to fluctuations in accompanying weather parameters.

The objectives of the work described in this paper are:

(1) to establish a climatology of cyclone and anticyclone events over the upper Mississippi and Ohio Valleys and Great Lakes region, and

(2) to conduct a preliminary study of the relationship of this climatology to temperature and precipitation climatologies at a station in the interior of the region.

The results provide more detailed depictions of the spatial distributions and temporal variations of cyclones and anticyclones over the study region than in any previous studies.

Data Analysis Procedures

The data utilized for this study span the 25 year period from 1950-74 for the region bounded by 32° N and 52° N latitude and 77° W and 97° W longitude (Fig. 1). This region was selected to capture cyclones and anticyclones most likely to influence the upper Mississippi and Ohio River valleys and the Great Lakes area. The primary source of data was the NOAA/EDS monthly publication of *Climatological Data—National Summary*. Contained in each monthly volume are charts depicting positions and central pressures of cyclones and anticyclones that occurred during that particular month and could be identified for at least 24 hours. Positions are indicated in six hour increments, while pressures are given every 24 hours.

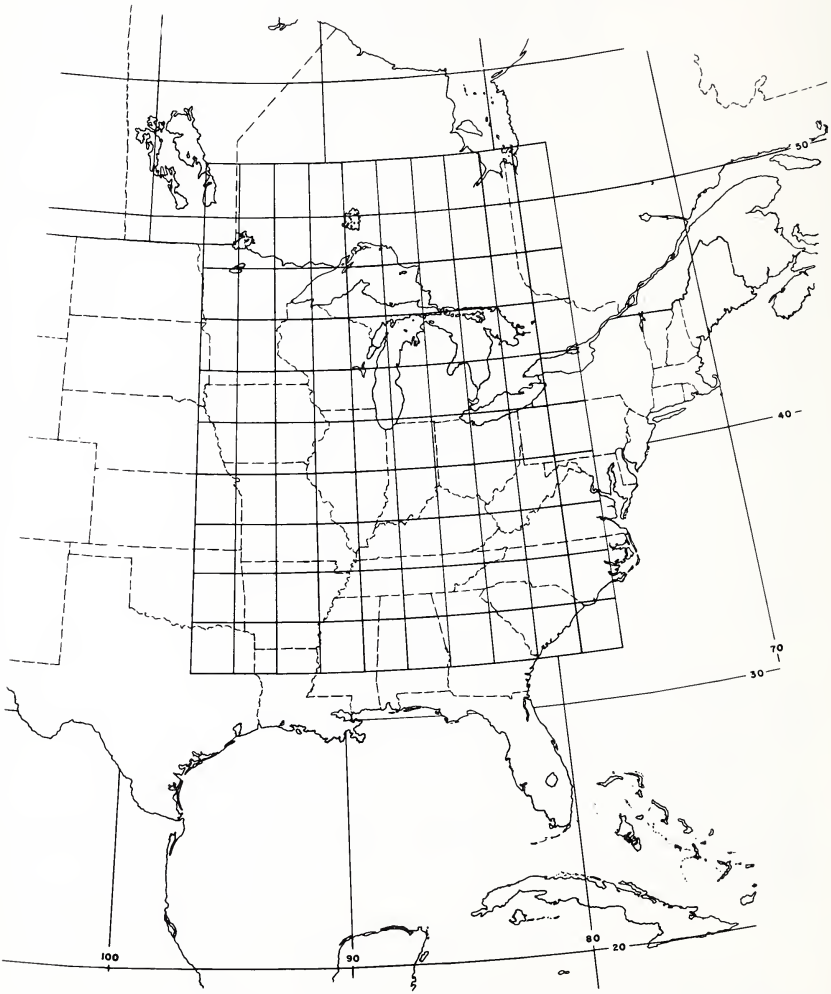

FIGURE 1. *Study region and 2° x 2° latitude/longitude analysis grid.*

Cyclone and anticyclone frequencies for the latitude/longitude bounds previously noted were obtained by overlaying a 2° x 2° latitude/longitude grid (Fig. 1) on the monthly data charts. The number of cyclones and anticyclones passing through each of the 100 2° x 2° quadrangles was recorded for each month in the period. Repeated entries into the same quadrangle by the same cyclone (anticyclone) were not included in the tabulation. In order to obtain quadrangle values representative of equivalent areas each value was normalized through multiplication by the factor A_o/A_n, where A_o is the area of the quadrangles bounded by 40° N and 42° N and A_n is the quadrangle area bounded by any 2° longitude limits. Seasonal frequencies for the 25-year period were obtained for each quadrangle by adding the frequencies in that quadrangle for each month in the season. Seasons are defined as: winter (December-February); spring (March-May); summer (June-August); fall (September-November).

At the initial entry and final exit of a cyclone (anticyclone) from the study region the central pressure was recorded to the nearest millibar. The central pressure was determined by linear interpolation between the 24 hour interval pressure values given in the original data charts. Individual pressure values were combined to determine average incoming and outgoing central pressures for each month and season in the period and in some cases were subjected to 5 year running mean smoothing. This latter procedure was chosen in order to isolate the more persistent trends while smoothing shorter term fluctuations. Also recorded was the total number of cyclones (anticyclones) that travelled through the study region during each month. If a cyclone or anticyclone left the region and re-entered at another point, it was counted as only one occurrence.

Finally, monthly precipitation and average temperature data for Whitestown, Indiana were derived from Indiana climatological records[1] for comparison with the cyclone and anticyclone statistics. This station was selected because it is located near the center of the study region, its data represent a particularly reliable climatological series over the period of study, and the data were readily available.

Results

Cyclone/anticyclone distributions

Figs. 2 and 3 show, respectively, 25 year total cyclone and anticyclone frequency distributions for each season. The analyses reveal that distinct areas of maximum and minimum frequency occur and, in addition, that axes of maximum and minimum frequencies can also be seen. The resulting axes of maximum frequency suggest preferred cyclone or anticyclone tracks. The term "preferred" is employed in the sense that cyclones and anticyclones generally tend to travel along or very near these axes, although individual cyclones and anticyclones may deviate from or converge upon these axes at many different locations. In fact, the analyses occasionally show that some tracks terminate inside the study region because the movement of individual cyclones and anticyclones is so highly variable downstream from the termination point.

[1]Provided by Mr. Lawrence A. Schaal, Dept. of Agronomy, P.U.

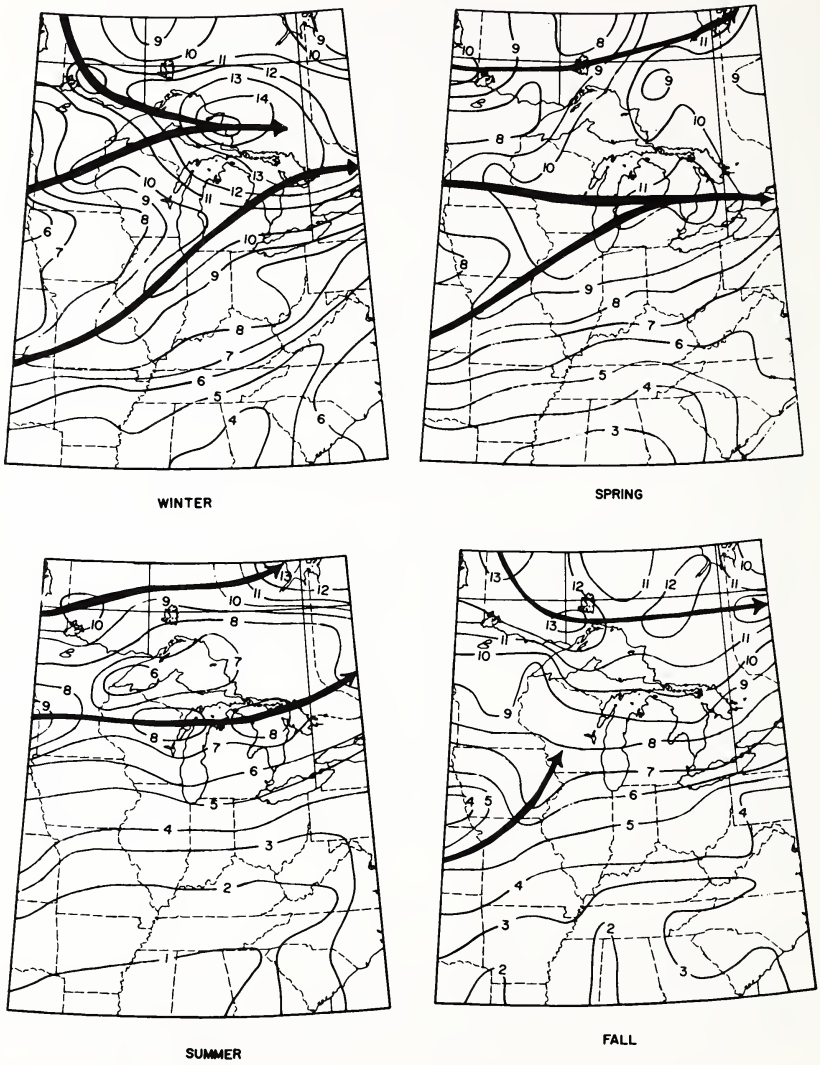

FIGURE 2. *Spatial distributions of cyclones for each season. Arrows represent preferred tracks. Isopleths correspond to 25 year totals in tens of units.*

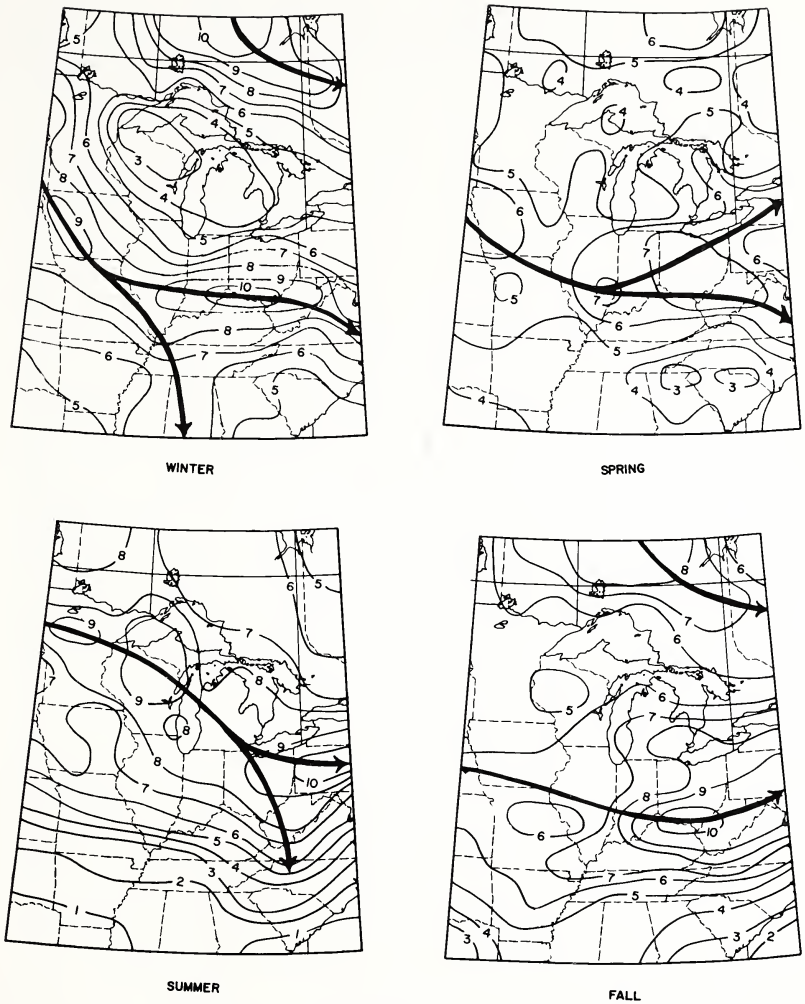

FIGURE 3. *Same as Fig. 2 for anticyclones.*

Prominent in the cyclone statistics are the frequency maxima that occur in the Great Lakes region and minima in the southern states. The maximum cyclone axes suggest the existence of three major cyclone tracks, with the overall cyclone occurrences exhibiting a northward migration from winter to summer. The first track, which is present in all seasons except summer, enters the region from the southwest and is likely associated with cyclones that originate or intensify in the area from the Texas panhandle to Colorado. Such cyclones are especially prominent in winter and spring, as verified by the present results. The second, which appears in all seasons except fall, lies along the northern tier of states and represents and extension of cyclones originating from Colorado north and west to Alberta. The third, which is prominent in all seasons, reflects cyclones propagating out of western and northwestern Canada across southern Ontario and Quebec. It is of interest to note that the cyclone tracks are similar to those documented by Reitan (9). However, the factor of three higher resolution used in the present study (2° vs. 740 km quadrangles by Reitan) results in less smoothing and reveals multiple track features not present in Reitan's results.

The most prominent area of maximum anticyclone frequency occurs in the Ohio River Valley with a shift to the Allegheny region during the summer. Another maximum occurs west of James Bay during the fall and winter. Minimum anticyclone frequency occurs in the western Great Lakes region in the winter, spring, and fall. Two major anticyclone tracks, which again reflect seasonal migrations, traverse the region. The first, which is within the northeastern boundaries of the region only in fall and winter, reflects polar outbreaks penetrating central Canada. The second represents high pressure penetration into the midwest from the western states and Canada.

Area average frequencies and central pressures

Fig. 4 depicts five year running means of annual cyclone and anticyclone frequencies. Definite trends appear in both frequencies during the period, although they are less pronounced for anticyclones. Fluctuations in the cyclone frequencies are in phase with those in the anticyclone frequencies with the number of cyclones exceeding the anticyclones by a factor of 1.25. This corresponds closely to Klein's (6) factor of 1.3 for the Northern Hemisphere. Fig. 4 also suggests a cyclic pattern to the frequencies, although the amplitude of the pattern varies. Frequency minima occurred around 1956 and, more prominently, in the late 1960's. A frequency maximum occurred around 1960 and possibly another around 1954, although the lack of data before 1950 prevents complete definition of this maximum. The seasonal contributions depicted in Fig. 4 show that in general greatest cyclone frequencies can be expected in winter, followed in order by spring, fall, and summer. The greatest anticyclone frequencies are also seen in winter, but are followed in order by fall, summer, and spring.

Fig. 5 contains five year running means of average annual entering and exiting central pressures for cyclones and anticyclones. Lower (higher) average central pressures are assumed to represent in general more intense cyclones (anticyclones). The average central pressure of cyclones increased during the first half of the period to a maximum around 1960, decreased to a minimum in the mid-1960's, and then began rising again during the last quarter of the period.

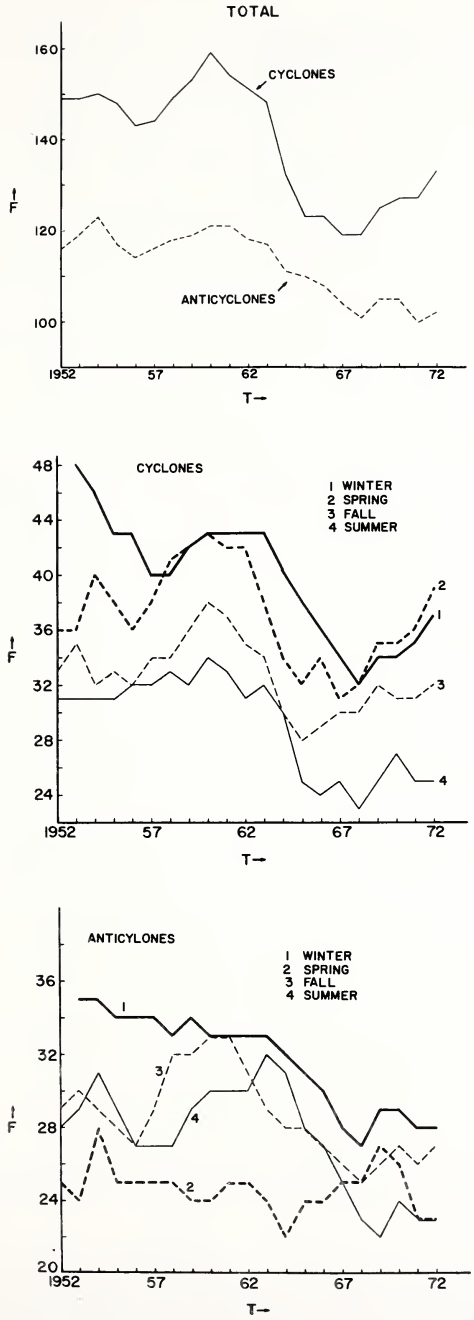

FIGURE 4. *Five year running means of cyclone and anticyclone annual (top) and seasonal (center and bottom) frequencies for the study period.*

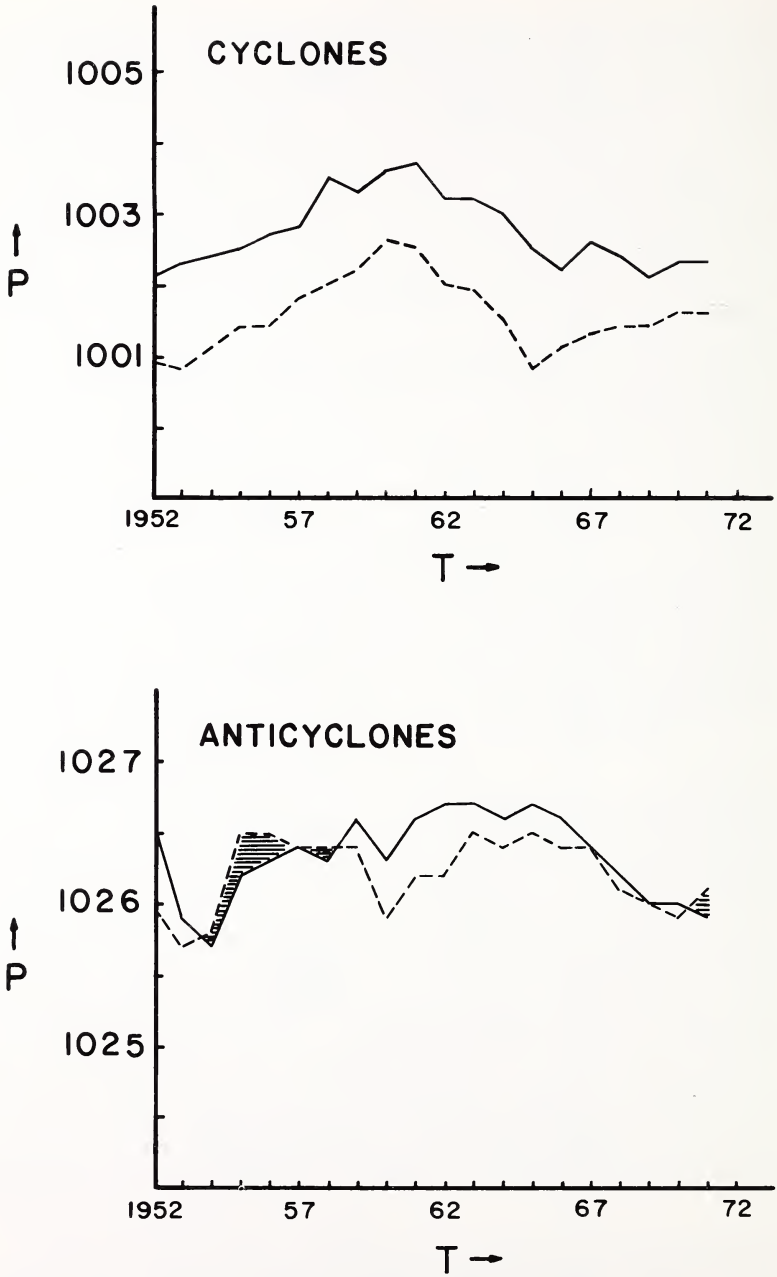

FIGURE 5. *Five year running means of average annual central pressure in mb for cyclones and anticyclones. Solid line represents the average incoming central pressure and dashed line the average outgoing central pressure. Shaded areas indicate periods during which outgoing exceeds incoming pressure.*

The average central pressure of anticyclones reached a minimum around 1954, rose to a maximum during the first half of the 1960's, then fell to a minimum again in the early 1970's. Throughout the period cyclones intensified after entering the study region with the magnitude of the intensification remaining fairly constant (usually 1-1.5 mb). Anticyclones, on the other hand, tended to weaken after entering the region, although intensification did occur in each case when the central pressure was increasing from a minimum. The magnitude of anticyclone weakening (maximum value of 0.6 mb) is much less than cyclone intensification and tends to vary more throughout the period.

Similar analyses of average central pressures for each season (not shown) reveal that cyclones generally intensified while propagating through the region in all seasons. Only during the spring did any significant periods of weakening occur, and then only during years of relatively low central pressure. In contrast to cyclones, fall and winter anticyclones weakened in the region throughout the period, while spring and summer anticyclones generally intensified.

Fig. 6 depicts the 25 year monthly means of frequency and central pressure for cyclones and anticyclones occuring in the study region. January is the month of maximum cyclone activity, with a secondary minimum occurring in March. These results are in contrast to those of Hurley (5), who studied cyclones in the midwest for the period 1920-1929 and found a single cyclone maximum in April. July contains the fewest number of cyclones, in agreement with Hurley, and is the only month in which anticyclones outnumber cyclones. December and January are the favored months for anticyclones activity, while minimum anticyclone activity occurs in April. The central pressure of cyclones exhibit a roughly inverse relationship to their frequencies, with the lowest central pressure occurring in April and the highest in July. Further, while cyclone intensification occurs throughout most of the year, the previously noted tendency for spring cyclones to weaken in some years is seen in April and May. The central pressures of anticyclones are strongly seasonally dependent with the greatest pressures occurring during the colder winter months and lowest pressures in the warmer summer months. Again as noted earlier, anticyclones tend to weaken in the fall (especially November) and the winter (especially January) and tend to intensify during the spring and summer. The greatest intensification of anticyclones occurs in July.

Comparisons with temperature/precipitation statistics

Finally, a preliminary attempt was made to relate cyclone/anticyclone statistics to temperature and precipitation variabilities at a single station located near the center of the study region (Whitestown, Indiana). It is of course recognized that comparisons between regional cyclone/anticyclone statistics and single station temperature/precipitation data are necessarily uncertain. Nevertheless, some relationships do emerge.

Fig. 7 illustrates the annual mean temperature and total precipitation (five-year running means) for Whitestown. Also presented to exemplify the comparisons for one season are analgous statistics for the summer. The shape of the cyclone and anticyclone frequency pattern of Fig. 4 closely resembles that of the Whitestown temperature pattern except that the two profiles are out of

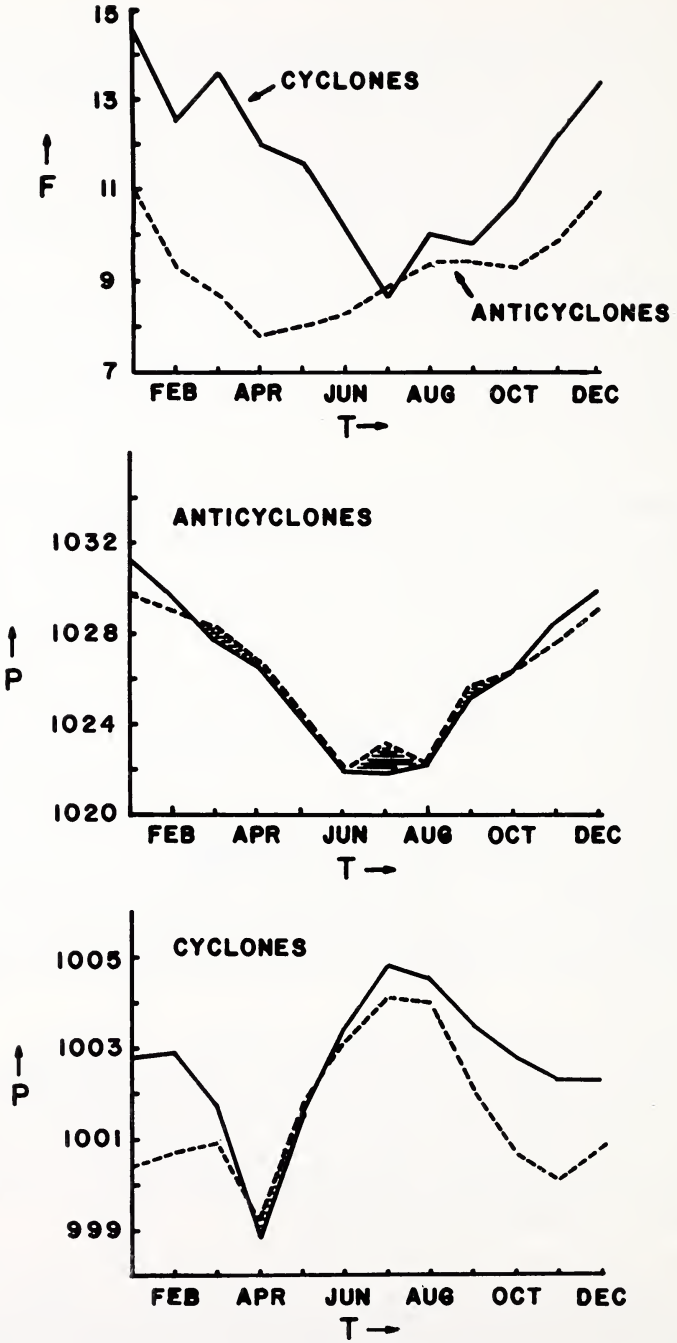

FIGURE 6. *Top: Mean monthly frequencies of cyclones and anticyclones. Center and bottom: Mean monthly incoming (solid) and outgoing (dashed) central pressures for anticyclones and cyclones.*

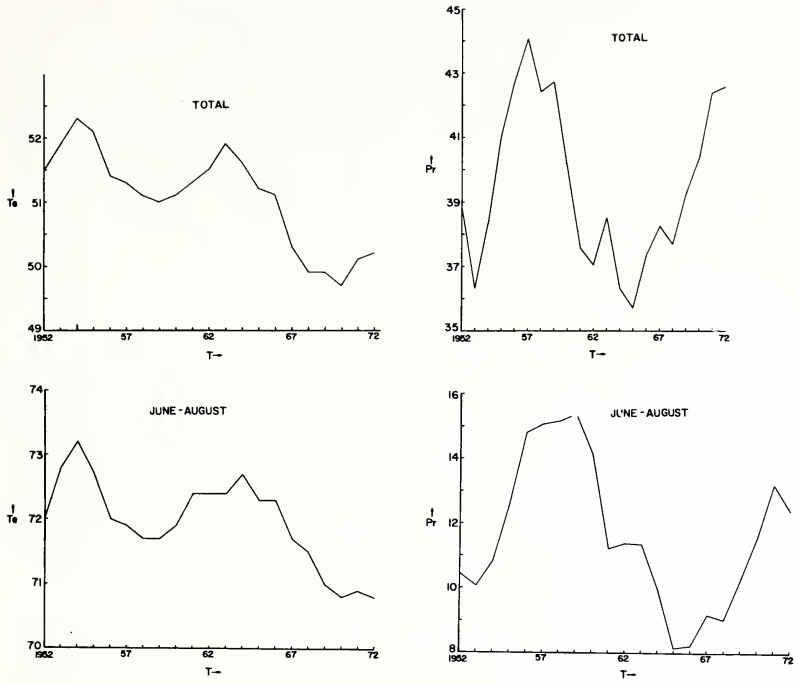

FIGURE 7. *Top: Five year running means of Whitestown average annual temperatures in ° F (left) and total annual precipitation in inches (right) for the period. Bottom: Same as top for summer season.*

phase by approximately three years. Thus, warmer annual mean temperatures tend to occur during periods of more frequent cyclone and anticyclone occurrences. Comparison of average summer frequencies with average summer temperatures shows the same general result, with a particularly good comparison to be noted for the anticyclone frequencies. Relationships between annual precipitation amounts and cyclone/anticyclone frequencies are less pronounced, a somewhat surprising result which probably reflects the limitations inherent in using a single station to represent the precipitation statistics. However, it is of interest to note that the relatively greater precipitation amounts prior to 1960 and the lesser amounts during the 1960's occur, respectively, during periods of relatively greater and lesser cyclone and anticyclone frequencies.

Summary

This study reveals that spatial and temporal patterns exist in the movement and intensities of cyclones and anticyclones and that these patterns bear some relationship to the average temperature and precipitation at a representative station. The study further suggests that extensions of the 2° x 2° grid analyses to all of North America, analyses of other regions, and more comprehensive summaries of the temperature/precipitation characteristics of each region might be fruitful. Having established a full array of such statistics, it would then be of interest to study the causal mechanisms responsible for such statistics.

Acknowledgements

This research was partially supported by the Atmospheric Research Section of the National Science Foundation under Grant Nos. ATM 75-02898 A01 and ATM 77-00932.

Literature Cited

1. Climatological Data-National Summary. 1950-1976. NOAA/EDS, U.S. Dept. of Commerce.
2. COLCUCCI, S.J. 1976. Winter cyclone frequencies over the eastern United States and adjacent western Atlantic. Bull. Amer. Meteor. Soc. **57**:548-553.
3. HOLZWORTH, G.C. 1962. A study of air pollution potential for the western United States. J. Appl. Meteor. **1**:366-382.
4. HOSLER, C.L., and L.A. GAMAGE 1956. Cyclone frequencies in the United States for the period 1905-1954. Mon. Wea. Rev. **84**:388-390.
5. HURLEY, J.C. 1954. Statistics on the movement and deepening of cyclones in the Middle West. Mon. Wea. Rev. **82**:116-122.
6. KLEIN, W.H. 1956. The frequency of cyclones and anticyclones in relation to the mean circulation. J. Meteor. **15**:98-102.
7. KORSHOVER, J. 1967. Climatology of stagnating anticyclones east of the Rocky Mountains, 1936-1965. Public Health Service Publication No. 999-AP-34, U.S. Dept. of Health, Education, and Welfare.
8. PETERSSEN, S. 1956. Weather Analysis and Forecasting, Vol. I. McGraw-Hill Book Co., Inc. 422 p.
9. REITAN, C.H. 1974. Frequencies of cyclones and cyclogenesis for North America, 1951-1970. Mon. Wea. Rev. **102**:861-868.