Reconstruction of the Climatic Fluctuations over the Ohio Area

美國俄亥俄州的氣候變遷

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摘　　要

近年來，北半球的溫度有不斷下降的趨勢。自 1961 年至 1970 年，北美洲年平均溫度即逐漸的降低，其中最顯著的區域是俄亥俄流域（Ohio Valley）以及北美洲東南部，在該地區，1961～1970 年平均溫較 1931～1960 年平均溫降低了攝氏一度。

本文之目的在於探討俄亥俄州的氣候變遷情形，取 1820 年（自是年起，俄卅開始有完整系列的氣候觀測紀錄）至 1970 年的紀錄與 1931 年至 1960 年的準平均相比較。研討重點爲季節性溫度降水差的變化趨勢。

在本文中，採取下列方法計算其統計上的顯着性：溫度、降水相關係數，1820 年至 1970 年三十年移動平均，以及用 student t-test 方法探測辛辛那提城不同期間的冬季溫度變化。

所有的結果均指出：以季節性溫度而言，在十九世紀年間和 1955 年後，該州有一明顯的較濕冷氣候。季節性溫度在 1951～1970 年與 1891～1920 年間有很類似的變化情形。其次，從 1961 年後，低的年加權平均降水值差與冷的年平均溫度差並存於此區，和以前的低年平均溫度值、高降水量紀錄迥異。

造成此一現象的因素是，由於持續的低指數緯流及增強的阻塞高壓長期存在於東太平洋北美洲沿岸，於是強的寒潮爆發，不停的從極區向南移動，其結果使北美洲中西部的溫度、降水自 1961 年起較前三十年的數值爲低。除此以外，氣候越來越冷的自然因素部份可歸處於火山爆發增加所帶來的塵埃，及人爲空氣污染所導致的污濁大氣使得大氣輻射減少其到達地表的正常量。

ABSTARCT

Seasonal and annual mean temperature and precipitation values from the 1820's to 1970 are compared with the 1931-1960 normals in Ohio. Correlation coefficients are obtained for temperature and precipitation departures across all of Ohio. Thirty-year moving averages from the beginning of record through 1970 are determind.

All these results show that a remarkably cooler and wetter climate existed in the 19th century and again after 1955.

The seasonal temperature variation between the periods 1951-1970 are found to be compatible with the periods of 1891-1920.

Low annual precipitation amounts accompanied by cold annual temperatures were noted in recent years, in contrast to the earlier records.

1. Introduction

A number of papers have been written about the climatic changes which have been noted during the last 100 to 150 years.

Mitchell (1963) has shown (Fig. 1) from computations of surface temperature changes from latitudes 0 to 60 degrees over the northern hemisphere that the annual average temperature rose by about 0.8°F from1880 to 1940,s and has fallen by 0.2 to 0.3°F since then. The winter curve is somewhat different showing a warming trend of nearly 1 degree from 1880 to 1940, with a tendency for cooling afterward. Reitan (1974) has confirmed Mitchell's result and indicates the mean temperature over the northern hemisphere increased about 1.1°F from 1890 to 1945, and decreased by 0.5°F from 1945 to the late 1960's.

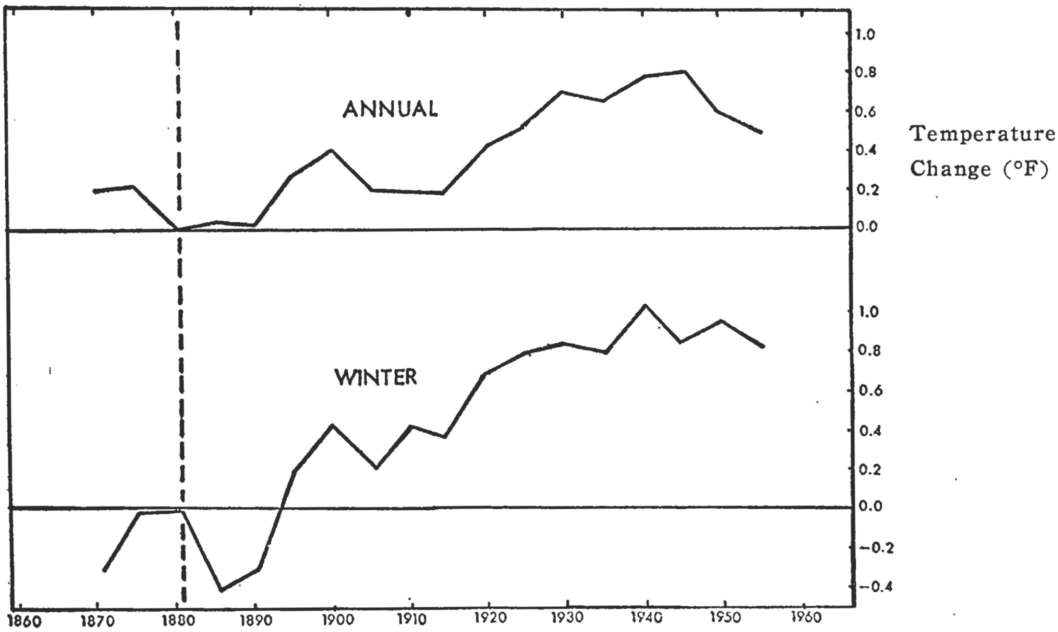

Fig. 1. Trends of mean temperature in 0°-60°N, shown for successive pentads relative to the 1880-1884 pentad (after Mitchell).

Analyzing the long-term climatic trends, Lamb (1966) points out that the large-scale atmosphere circulation during the 1960's may be more relevant to the climatic behavior before 1895, and "the decline of the temperate-zone westerlies and increased frequency of blocking in high latitudes since 1960 have been associates of temprature and rainfall regime that are having effects in many parts of the world."

Wahl (1968) compared average seasonal temprature and precipitation amounts (in percent) for the 1830's and 1840's with the 1931-1960 climatic normals over the eastern United States. He fonnd that the largest temperature changes occurred in early fall with maximum departures (Fig. 2) in the region of Indiana, Ohio and Michigan where temperatures were 3 to4°F cooler than that during the 1931-1960 period. The core area of higher rainfall amounts coincide with approximately the area of maximum temperature in early fall (Fig. 3). According to Wahl, average cyclone tracks of the 1830's and 1840's extended farther south than those of 1931-1960, thus falls were cooler, and more intense shower activity was found in the midwestern U.S.

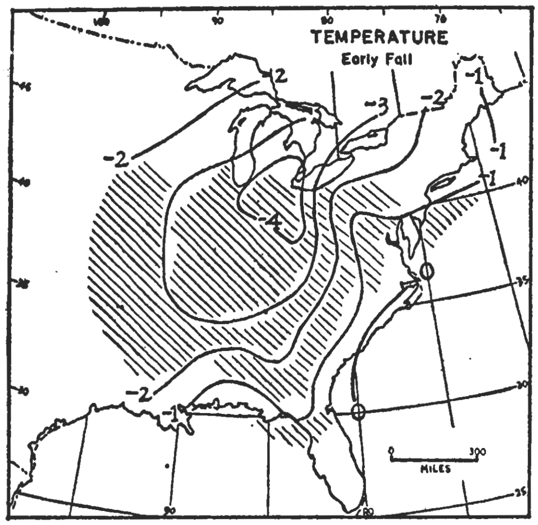

Fig. 2. Temperature deviations (°F) of the data in the 1830's from climatic normals 1931–1960. Early fall (after Wahl).

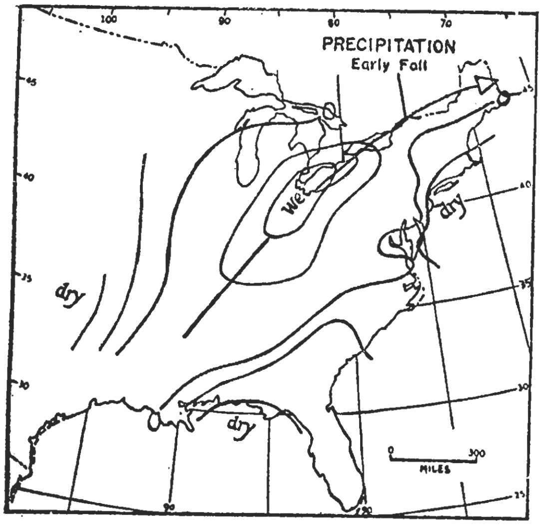

Fig. 3. Precipitation departures of the data in the 1830's and 1840's from climatic normals 1931–1960 (in percent of normal amount)

Temperature variations from 1957 to 1966 in the United States had been studied be Quade (1968). He found significantly cooler temperatures related to a noticeable increase in the frequency of low zonal index values during this period over the eastern midwest.

Recently Kalnicky (1974) has compared the temprature change from 1961–1970 with the 1931–1960 normals in the Untted States. His results indicate that the area of maximum cooling occurred in the Ohio Valley and southeastern U. S. with the 1961–1970 annual temperature departures being at least 1.0 degree Centigrade below the 1931–1960 normals.

With the goal of examining the impact of the climatic changes upon a specific area, namely Ohio, seasonal and precipitation data are used at some selected recording sites in this area. With this material, seasonal departures from 1931–1960 normals for every selected station can be reconstructed and then used to investigate the climatic fluctuation since the first complete observations began in the 1820's (Cincinnati, Portsmouth, Marietta). For every five-year interval, temperture and precipitation departures from the 1931–1960 normals have been established separately and then compared to each other. The geographical distribution of the largest temperature and precipitation deviations and their statistical significance will also be discssed.

2. Procedure and organization of temperature and precipitation data

The first permanent settlement, according to the climatological history of Ohio, published in 1924, was eatablished at Marietta (in southeastern Ohio) in the spring of 1788. During the fall of the same year three settlements were started in the southwestern corner of Ohio, in the vicinity of the modern city of Cincinnati. A record of temperature from 1814 to 1814 was taken at

College Hill, which is now a suburb of the city of Cincinnati; this is believed to be the first segment of climatic record in Ohio. However, the first long and continued series of temperature and precipitation observations at one single site were carried out from 1818 to the present at Marietta. Unfortunately, there are some missing periods in 1824, 1825, 1871-1882 (temperature only), 1943, 1948, and 1950.

For the past hundred years, especially since the establishment of the Weather Bureau in 1870, there are ample meteorological measurements covering the whole state which can be used. Prior to that, especially in the 1820's and 1830's the odservational data are scarce and they are of doubtful accuracy, homogeneity and reliability. For example, temperature records used in this study numbered 3 to 7 in the whole area of Ohio from 1821-1825 to 1836-1840; the precipitation records were even fewer, only 1 to 4 records are available in this period.

It is often assumed that during the early years of the last century the instrument calibrations are doubtful, exposure are generally unknown, and the thermometers are of probable inferior quality. Wahl (1968) compared the temperature and prevailing wind data during the 1830's in the eastern U.S. with a regression technique. His results indicate that the temperature observations appear to be reasonably reliable and not distorted by systematic errors.

Landsberg (1962) compared the urban with rural environment to compute the average chanes in temprature caused by urbanization and showed the annual mean temperature rose by 0.5 to 1.0 degree Centigrade and the winter average rose by 1 to 2 degrees. The precipitation change amounts to 5-10% increase in urban rather than the rural environments.

In this study, rural station were cooperative stations. Thus, the various problems associated with drastic site shifts or urban effects are of minor importance.

All data were expressed as departures from the 1931-1960 climatic normals, published in the "Decennial Census of United States Climate" by the United Sates Weather Bureau in 1962. For most stations these normals are the actual averages of the published data for these thirty Years; however, there exist some discrepancies for several first order stations such as Toledo Ap, Cleveland AP, Youngstown AP, Akron AP, Columbus AP, Dayton AP and Urbana where the normals are not equal to the average over thirty years of the published values. The normals in the "Decennial Census of United State Climate" for these stations are the currently best "adjusted normals" for the latest location of the station usually the airport. For the evaluation of the records prior to the move to this latest location, "substitute" normals were obtained as averages of the records as printed in the published data. These newly derived values were then used in this study for such stations.

Some stations do not have normals for the thirty-year period 1931-1960. This is frequently due to missing observations in these years. In order to establish a reasonable estimate of the normal for such stations, a method of adjustment is suggested by usinng the "factor of discrepancy." This discrepancy is obtained by averaging the differences between the temperature or precipitation data of the surrounding stations and the station of interest for the years in which the records are complete. Then this discrepancy is added to the surrounding stations' normal to obtain the estimate of the station with the missing observations.

The estimate of the normal for temperture is calculated from

$$T(\text{Normal}) = \frac{1}{m}\sum_{j=1}^{m}\left(\frac{\sum_{i=1}^{n}\Delta T}{n} + T_m(\text{Normal})\right)$$

where m is the number of neighboring sites, n is the number of years for wich records are available at the station of interest and at one of the neighboring sites, ΔT is the difference of seasonal temperature departures at the station of interest and at the neighboring sites, T_m (Normal) is the normal for the neighboring station. Similarly, the estimate of the normal for precipitation also can be obtained by this method.

Lack of station records during certain time periods also have been remedied by using neighboring station data. In this way, a long and reasonably homogeneous time series of observations can be obtained for this study. For example, temperature and precipitation records at Urbana between 1881-1895 (missing period) are reconstructed from North Lewisburg data (10 km away). Through the use of simultaneous observations during the periods 1853-180 and 1896-1908 (where records of N. Lewisburg stopped), the Urbana period was computed. According to the Climatological History of Ohio, there is confusion as to the early part of the records (probably before 1852) at N. Lewisburg and Urbana; the data for N. Lewisburg apparently have been used, to supplement the record at Urbana.

Station with several data sources in close proximity to each other also have been reorganized in this study. For example, Cincinnati has five different major sources of data to contribute to the long-time series of climatic information as shown in Table 1. The latest airport records were not used since Abbe Observatory is available through 1970. Abbe Observatory and Federal Building overlap 15 years and there is no difference between the average of the two temperature records. Combing the two, the temperature record of Abbe Observatory may be extended back to 1871. A difference in the precipitation record was found between these two sites, therefore the Federal Building was corrected to Abbe Observatory from 1871 to 1915. For years when both Woodward High School and College Hill recorded temperature and precipitation, the climatic series was constructed from the average of both values and corected to Abbe Observatory. During the years when Woodward High School, Federal Building and College Hill have precipitation reecords (1872-1890), the final record also was taken as an average of these three values after being corrected to Abbe Observatory. Where only the Federral Building (1903-1915 for

Table 1. Cincinnati

Location	Elevation	Period of records used in this study	Period of service
Abbe Observatory	761 feet	1916-1970	1916-now
Airport	484 feet	1949-1970	1949-now
Federal Building	553 feet	1871-1915 (temp) 1872-1915 (precip)	1871-1930
Wordward High School	628 feet	1835-1870 (temp) 1836-1902 (precip)	1835-1873 (temp) 1835-1902 (precip)
College Hill	800 feet	1814-1848 (temp) 1861-1870 (temp) 1864-1890 (precip)	1814-1848 (temp) 1861-1890 (temp) 1861-1890 (precip)

precipitation only) or Woodward High School (1849–1960 for temperature only) record was available, it was corrected to Abbe Observatory. The final record of temperature was then computed as deviations from the 1931–1960 normal, the precipitation record was obtained as percentages of the 1931–1960 normals for Abbe Observatory. In this way, a long sequential record for Cincinnati was constructed.

Since the temperature and precipitation data for some stations are inhomogenous, incomplete and lack normals, individual climatic record may be biased and could indicate random fluctuations which do not fit withthe over all change pattern. For example, spring rainfall departures from normal at Kenton during 1871–1875 were about 62% above normal amounts while neighboring stations a few miles apart were about 11–27% below their normal amounts. Thus, initial results were plotted on maps to ascertain a real continuity. If a distinct bias at any station was found, such biased site would be eliminated if the area under cosideration had sufficient other recording sites.

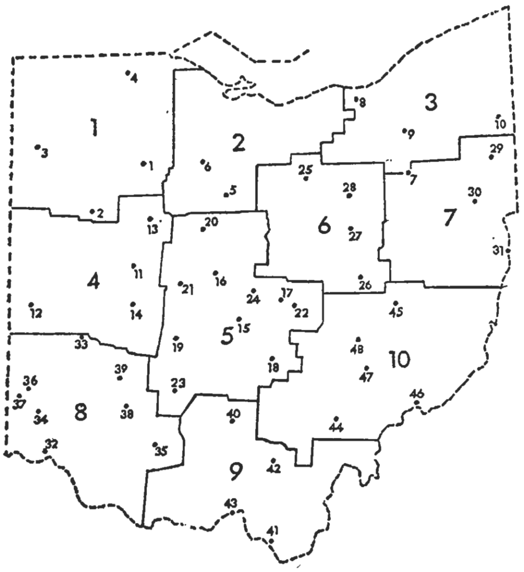

Fig. 4. Network and divisions for analysis in this paper,
Stations are identifiedby number according to the Appendix Table 11.

Winter is defind as December–February, spring as March–May, summer as June–August and fall as September–November. The seasonal and annual average temperature departures from the 1931–1960 normals were calculated for each five-year interval from 1821-1825 to 1966–1970; the average precipitation departures (in percent) were similarly calculated from 1831–1835 to 1966–1970 throughout the Ohio. These divisions were defined by the United States Weather Bureau for the climatological study in Ohio. The network and divisions are shown in Fig. 4.

3. Climatic fluctuations over the Ohio area

(1) Kalnicky (1974) recently pointed out that the northern hemispheric circulation flow changed from more zonal to more meridional after about 1950. Temperature changes from warming to cooling are also associated with the adjustment of upper air circulation, In order to study the climatic trends, the data are divided into 20 or 30 year periods. This length was chosen since climatic normals usually include thirty years data and this removes the year to year variability. Thus, it results in more stable mean. In this study, five periods with an interval of 20 30 year long periods were chosen (1951–970, 1921–1950, 1891–1920, 1861–1890, 1831–1860). The temperature departure pattern for the period 1951–1970 is the most interesting to note because of the magnitude of the changes and the completeness of the data. The winter pattern in Fig. 5 shows a band of

temperatures 2°F below normal across the central portion with a core area in the south-central Ohio. The 1951-1970 annual pattern is also pronounced, negative departures being spread over all the area (Fig. 6). The change of mean temperature from the 1921-1950 period is relatively small due to the 20 year overlap with the 1931-1960 normals. The annual change of mean temperature from 1891-1920 is also considerable, being

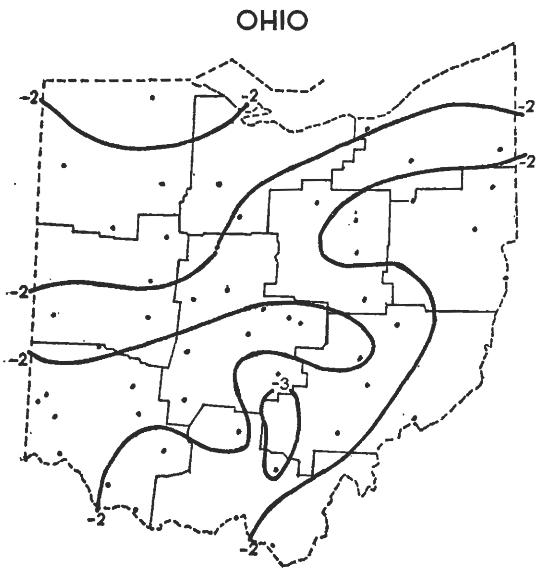

Fig 5. Twenty-year tmperature change, winter. (°F) (1931-1960 mean minus 1951-1970 mean)

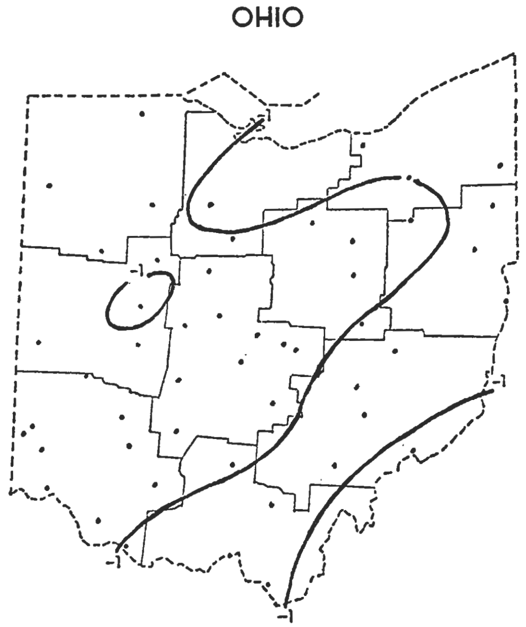

Fig. 7. Thirty-year temperature change, annual. (°F) (1931-1960 mean minus 1891-1920 mean)

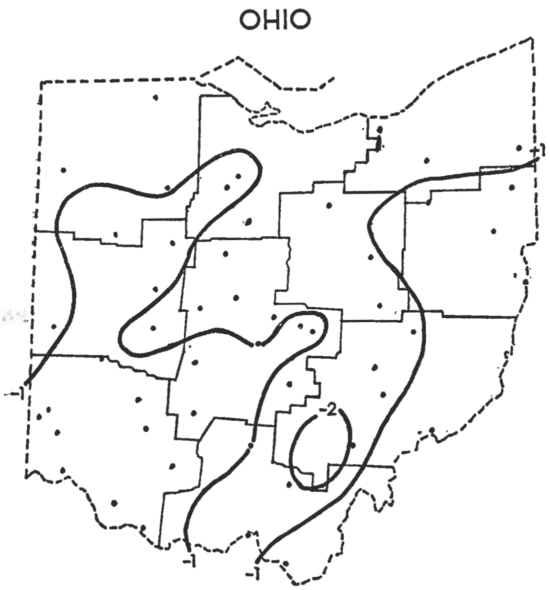

Fig. 6. Twenty-year temperature change, annual. (°F) (1931-1960 mean minus 1951-1970 mean)

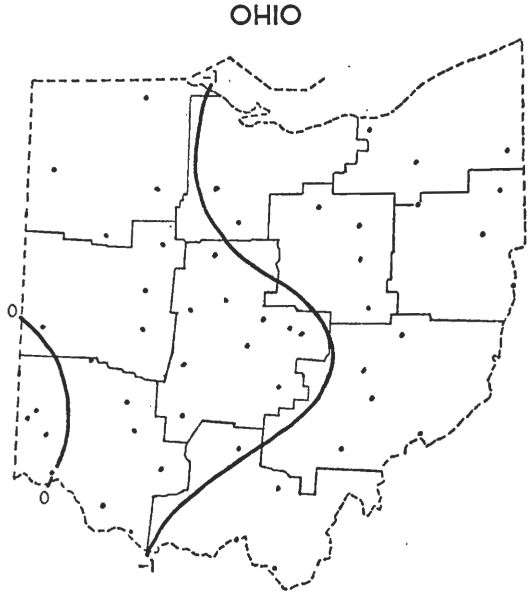

Fig. 8. Thirty-year temperature change, annual. (°F) (1931-1960 mean minus 1861-1890 mean)

nearly 2°F below normal along the northern lakeshore (Fig. 7). The 1861-1890 annual pattern closely resemble the 1991-1920 pattern, with the eastern half of the area being 1°F below normal (Fig. 8). But one should keep in mind that there are only six station records available during this time. Few data exist from 1831-1860, but there is an indication of a negative temperature change with the southern part of the region being 1-2°F below the normals. Thirty-year average departures of seasonal and mean annual temperature of Ohio are listed in Table 2. Callendar (1961) has pointed out that there was an increase of the 30-year annual mean temperature of 0.7°F between 25°-60°N from the 1891-1920 period to 1921-1950. In Ohio, a 0.9°F increase is found. Annual temperature has decreased 1°F from 1921-1950 to 1951-1970. Comparing the seasonal temperature variation during 1891-1920 and 1951-1970, one finds similar values for these two periods. The annual temperature change between 1831-1860 and 1931-1960 is the most striking. Fall has a negative departure of 2.5°F and snmmer was 1.7°F below the normals. The average annual temperature of the earlier period is 1.3°F below the recent normals.

Table 2. Thirty-year mean temperature departures from the 1931-1960 Normals. Ohio.

	Winter	Spring	Summer	Fall	Annual
1951-1970	−1.9	−0.3	−1.0	−0.6	−1.0
1621-1950	0.0	0.1	−0.3	0.1	0.0
1891-1920	−2.1	−0.1	−0.9	−0.4	−0.9
1861-1890	−0.8	−0.5	−0.8	−1.5	−0.9
1831-1860	−1.1	0.1	−1.7	−2.5	−1.3

(2) In order to establish whether the changes observed between these periods have statistical significance, the inter-period changes, for winter temperature at one station, namely, Cincinnati are tested by use of the Student t-test. The t-value is calculated from

$$t=\frac{M_1-M_2}{\sigma\sqrt{\frac{n_1+n_2}{n_1n_2}}}$$

where M_1 and M_2 are the mean values of each period, n_1, n_2 are the numbers of observations in the samples, σ is an estimate of the standard deviation of the population from which the samples are believed to have been drawn. The standard deviation (σ) is detemined from

$$\sigma=\sqrt{\frac{x_1^2+x_2^2}{n_1+n_2-2}}$$

where x_1, x_2 are the deviations from the sample mean. It is assumed that temperature deviations are normally distributed about their mean. The winter change at Cincinnati between 1951-1970 and 1921-1950 was not significant (less than 90% level of significance) using 48 degrees of freedom. Between 1921-1950 and 1891-1920, the t-value is significant at the 95% level with 58 degrees of freedom; whereas the t-value of the change between 1861-1890 and 1891-1920 is significant at the 99% level. The fact that the change in average temperature at Cincinnati between 1921-1950 and 1951-1970 is not significant statistically is due to the application of the t-test to a single station record and does not invalidate the results of Mitchell (1961) which indicates a large-scale cooling of the northern hemisphere. It obviously is due to the rather large variablity of the single station record. Indeed, one would not expect all sites to exhibit similar changes in or direction in a large sample, magnitude since some regions are climatically more sensitive and responsive than others.

(3) In order to establish a homogeneity of station records and to examine the climatic variability over the whole area of

Ohio, correlation coefficients were used. Using the normal period 1931–1960 for which ample data existed, correlation coefficients for temperature were calculated between Cincinnati and Xenia, Delaware, Ashland and Cleveland (Fig. 9) during 1921–1970. Table 3 gives the coefficients between the variables. All the coefficients are positive and the most pronounced correlation exists in winter (all the values are higher than 93%). As expected, the summer temperature correlation is lower. Spring and fall correlations are less pronounced but all values exceed 83%. These correlations indicate that even a single station will give some information about the temperature

Fig. 9. Location of Stations used for Correlation Coefficients Study.

Table 3. Correlation coefficients of temperature values at Cincinnati and specified stations during 1921–1970. Based on the 1931–1960 normal period.

Stations and Distances from Cincinnati	Winter	Spring	Summer	Fall
Xenia (~75km)	0.954	0.937	0.814	0.917
Delaware (~176km)	0.990	0.836	0.869	0.862
Ashland (~240km)	0.936	0.847	0.782	0.873
Cleveland (~320km)	0.936	0.930	0.783	0.841

behavior (departures) in all of Ohio. The precipitation correlations are considerably lower (of the order of +.08 in summer) and will not be discussed here.

(4) In order to present the data in perhaps a clearer format, smoothing was necessary. Thirty-year moving averages spaced for every 5-year interval, which filter higher frequencies, were determineid for temperature and precipitation time series in the whole area and applied in this study. As shown in Fig. 10, winter, summer and fall show marked negative temperature departures from the average of 1821–1850 through the average of 1921–1950, and a warm episode occurred during the period of 1921–1950 average to 1931–1960 average, then a pronounced decline of temperature thereafter for winter and summer. A major upward trend of summer and fall tempera-

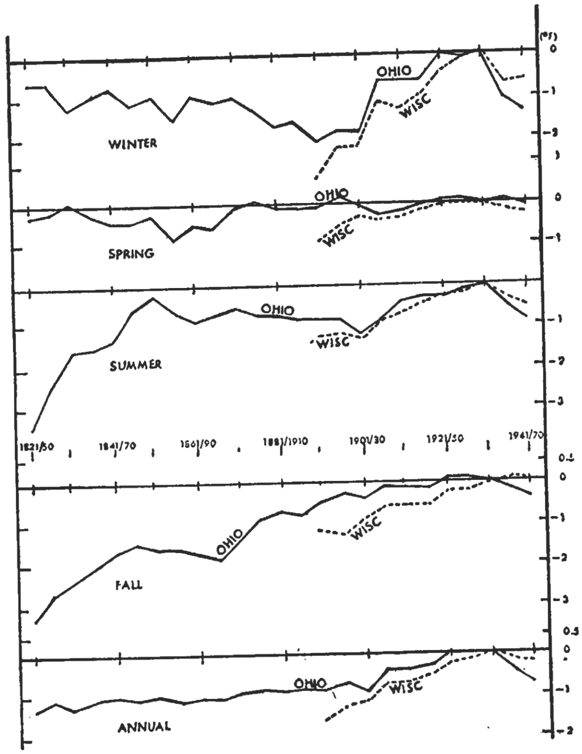

Fig 10. Thirty-year moving averages of season and mean annual temperatues from 1931–1960 normals.

ture was found especially in the early years of record. The average of the 1830's to 1860's was about 2-3°F below recent normals whch is consistent with Wahl's (1968) stiudy. The spring moving averages are less pronounced. Wahl (1974) has done the similar study in Wisconsin. The running means of six areas in Wisconsin are indicated by the dashed curve. Compared to the curve in Ohio the temprature trends for Wisconsin closely coincide. For the annual curve, a negative trend in Ohio is accompanied by a negative trend in Wisconsin.

Before examining the precipitation moving averages, it should be recognized that the seasonal records between stations only a few kilometers apart may vary by a considerable degree. The rainfall regime in Ohio is similar to the continental interior type described by Trewartha (1961); 40-45 inches of rainfall are well distributed throughout the year with higher amounts chiefly in the summer. Alexander (1924) has suggested dividing the area of Ohio into three sections of rainfall due to the variability of topographic featues. However, in this study of precipitaion departures, it was unnecessary to followh is idea. The whole area was assumed to be rather uniform because precipitation departures showed no systematic anomalies.

The moving average for rainfall departures are shown in Fig. 11. Above recent normal amounts are noted approximately from the beginning to the 1931-1960 averages in winter and fall. Annual weighted averages show a similar downward trend from the very beginning through the last thirty year averages. Compared to Wahl's curve for Wisconsin (also shown in Fig. 11), the surprising thing is the consistency of the precipitation trends found in fall in both areas. It is also interesting to note that

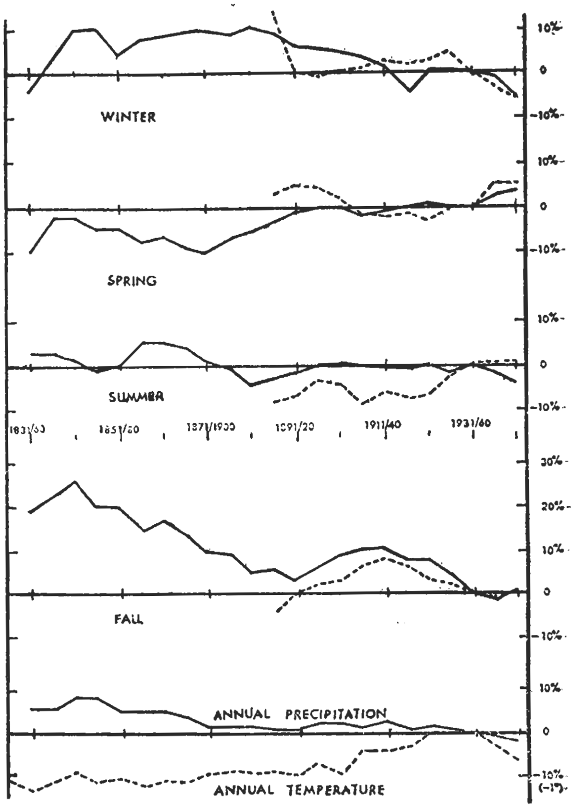

Fig. 11. Thirty-year moving averages of seasonal and annual weighted average precipitation departures from 1931-1960 normals (in percent of normal amount).

the winter trend is downward and the spring trend is upward in both areas since the 1931-1960 averages. One might speculate that the cyclonic activity was lingering around the Midwest more frequently in spring since 1950's. The positive rainfall anomaly in spring can be attributed to a longer lasting southerly displacement of the storms tracks associated with the polar front. Similarly, the downward winter trend can be a result of the drier polar air staying longer in Midwestern U.S. than the early years of this century and the last century.

A comparison of the annual curve of temperature and precipitation in Ohio shows a warming trend associated with the downward trend of precipitation from 1831-1860 till 1931-1960. Since the 1931-1960 averages, the behavior of these curves is not quite the same as during the last hundred years. In Ohio, before 1931-1960, cold temperature and dryness had never occurred together.

(5) The temperature and precipitation departures from the 1931-1960 normals for each consecutive five-year average at three long record stations were plotted on Fig. 12 and 13. Temperature trends in Ohio Valley all exhibit a pronounced cooling

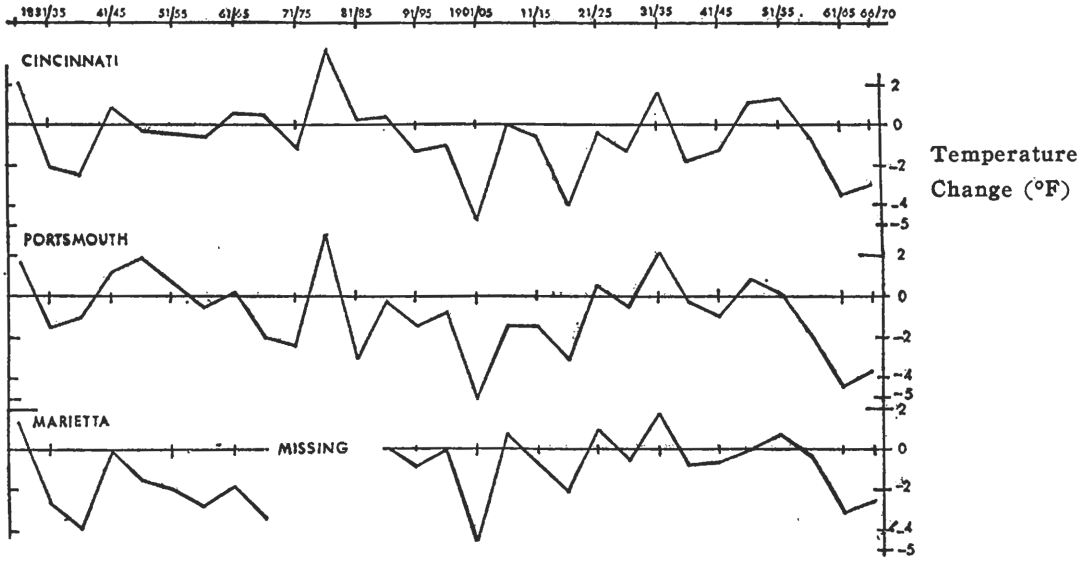

Fig. 12. Trends of winter mean temperature deviations from 1931-1960 normals of every 5-year interval at three long record stations in Ohio.

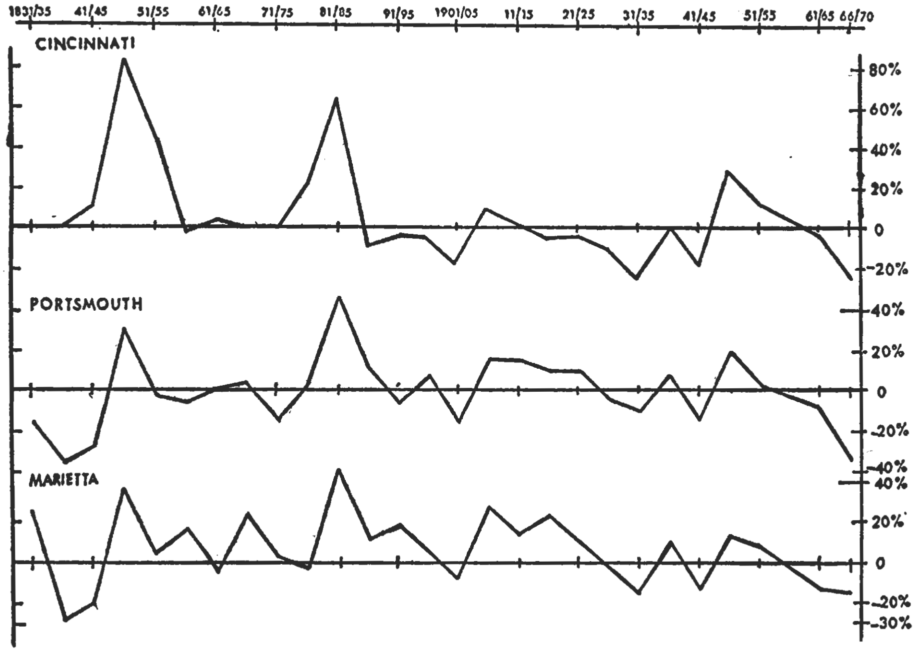

Fig. 13. Trends of winter mean precipitation deviations (in percent of normal amounts) from 1931-1960 climatic normals of every 5-year interval in Ohio.

after 1951-1955. Years with the largest temperature departures are found in the period of 1901-1905. The temperature behavior in the period of 1961-1965 and 1901-1905 will be discussed in more detail. The trends of winter mean precipitation departures also show a downward tendency toward dryness since the 1946-1950 averages; the negative departures occurred after the 1956-1960 averages in Marietta with 15% and Portsmouth with 30% below normal amounts. The highest rainfall amounts were observed in 1881-1885 period which also will be discussed in the next section. During the period of 1841 to 1855, the winter rainfall departures at Cincinnati tends to be high compared to Marietta and Portsmouth.

(6) The five-year period with the largest winter temperature departures from the 1931-1960 normals were the years 1901-1905 and 1961-1905 and 1961-1965. The geographical distribution of these departures are given in Figs. 14 and 15 for winter and Figs. 16 and 17 for the year as a whole. Temperatures are distinctly colder than normal. The coldest region is near the west-central area with the 1961-1965 average temperatures being 6 degrees below the normals; a rather large area from south-central to northern Ohio with the 1901-1905 average temperatures being 5-6 degress

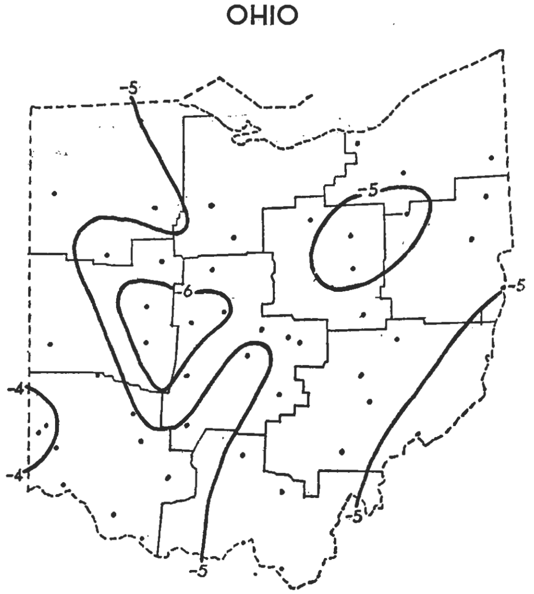

Fig. 15. 1901-1905 temperature deviations (°F) from 1931-1960 normals; winter

Fig. 14. 1961-1965 temperature deviations (°F) from 1931-1960 normals winter

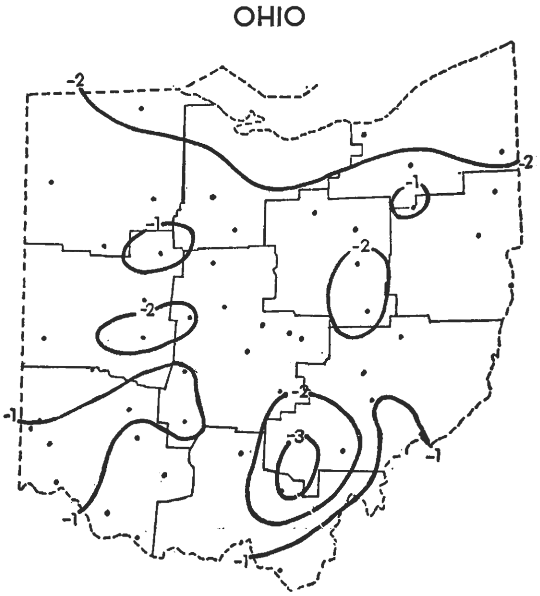

Fig. 16. 1961-1965 temperature deviations (°F) from 1931-1960 normals; annual

OHIO

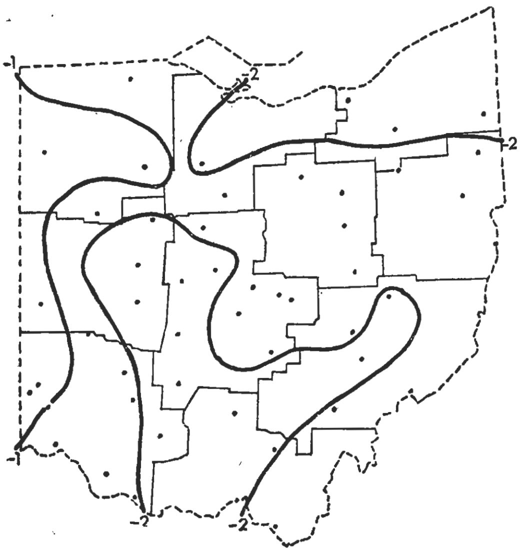

Fig. 17. 1901-1905 temperature deviations (°F) from 1931-1960 normals; annual

below the normals. These colder areas are also well defined although less pronounced, during the summer season. The spring and fall patterns during these two periods are less well organized. Negative temperature departures dominate over the whole area for the whole area for the annual pattern. For the most part, the annual distributions agree with the winter pattern but with a lesser magnitude. This is particularly true in the midwestern and south-central portions of the area.

The maximum deviation of winter and corresponding annual rainfall from the 1931-1960 normals occurred in 1881-1885, and are shown in Figs. 18 aud 19. The "Great Flood", beginning in August, 1879 and ending in May, 1884 as described by the Climatological History of Ohio, was a period of nearly five years of great rains. The extreme high water in February, 1884 was due to the combined effects of great rains, melting snow and high temperatures. Areas with departures from winter normals of more than 50% were located in the southwest and northwest portions of the area. The departure from the yearly-weighted normals exhibit a similar pattern with magnitudes of approximately less than half of winter departures.

OHIO

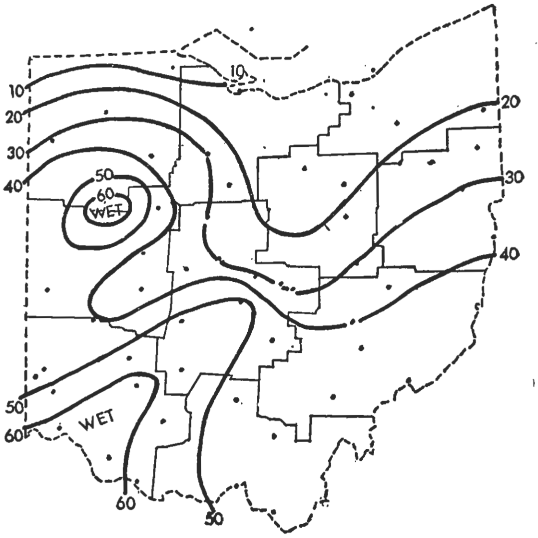

Fig. 18. Departure of 1881-1885 Winter precipitation from 1531-1960 normals (in percent of normal amounts).

OHIO

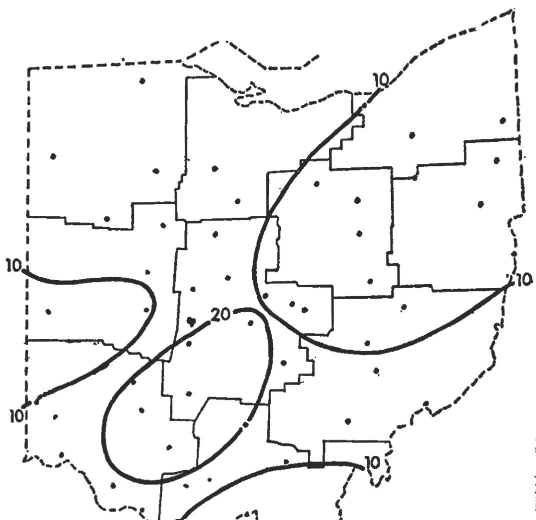

Fig. 19. Departure of 1881-1885 annual weighted-average precipitation from 1931-1960 normals (in percent of normal amounts).

4. Discussion of results

In general it can be said that the annual temperature trends over Ohio have been upward from 1821-1850 averages to at least 1921-1950 averages (see Fig. 11) with an indication that the rising trend has reversed over the last 15-20 years. The march of seasonal temperature departures are in phase in Ohio and Wisconsin; the magnitude of these negative departures are slightly smaller in Ohio than in Wisconsin before the 1931-1960 averages for winter and summer. The winters of 1961-1965 and 1901-1905 are the most striking cold periods; temperature departures being 4.2°F below the normals averaged over the whole area in Ohio for the 1961-1965 winter seasons, while for the period 1901-1905 the averaged temperature departures was 5.3°F below the normals. In both periods, the central-west, southcentral and northern lakeshore area. For the central area, it can be explained by the Appalacian Mountains which stopped the northerly air going further southeastward, thus the cool air accumulated in central Ohio. When the influx of polar air is persistent into Ohio, the open northern lakeshore area will also experience a drastic cooling situation.

A positive annual rainfall departure dominates through an interval of about 100 years to the middle of this century. Since the 1931-1960 averages, the precipitation changes are not significant, but a tendency toward lower totals is indicated over the whole area in Ohio. This phenomena is attributed to a strengthening of the blocking high over western North America and strong northerly flow in the Midwest.

A 2°F below normal area across central Ohio from south to north in the 1951-1970 winter temperatnre departures approximately coincides with the 1891-1920 winter

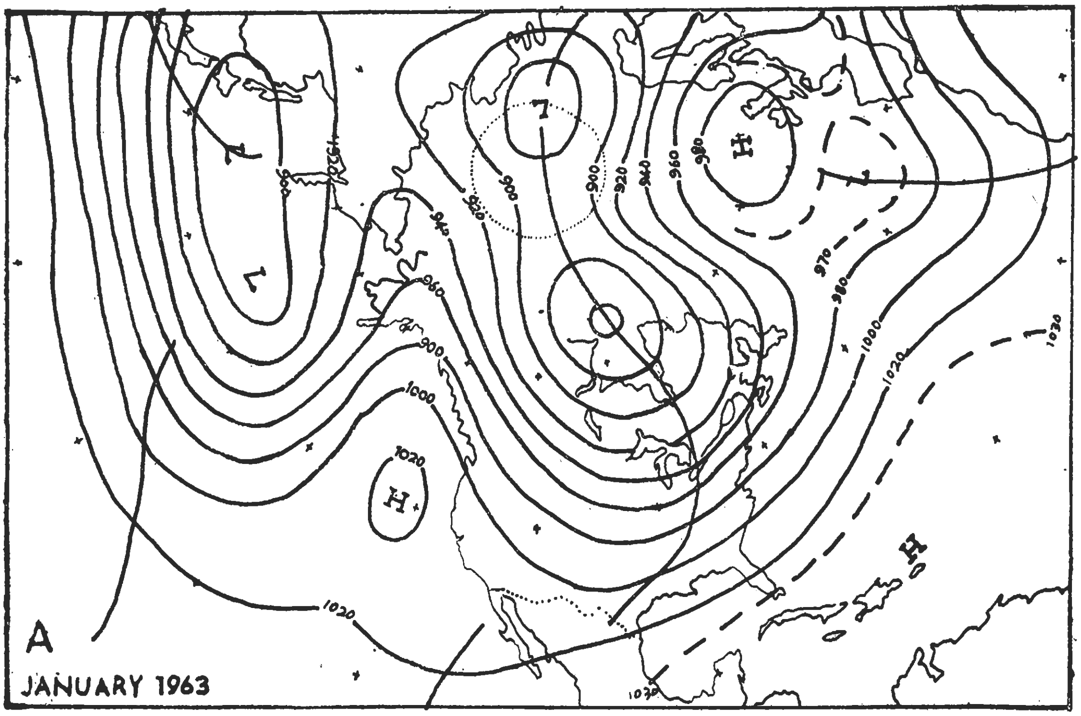

Fig. 20. Mean 700 mb chart and its height departure from normal for January 1963 (after Andrew).

pattern. Similar areas are also found for the summer and fall during the period of 1951-1970 and 1891-1920. Over all, the seasonal temperature behavior during the 1951-1970 is comparable to that of the 1891-1920 period.

Climatic variations respond to the shifts in preferred position and strength of the upper air troughs and ridges. For example, the January 1963 pattern, as shown by 700mb chart in Fig. 20 (Andrewt. 1964) was the most typical case. Outbreaks of Arctic air spread southward and southeastward which kept temperatures distinctly below the normals. Persistence of the extreme cold air in the Midwest is related to a persistent low zonal flow and strong blocking blocking characteristics.

The average winter circulation for the same year at sea level also indicated low zonal index characteristics, as shown in Fig. 21. (Andrew, 1964). Northerly flow, which inhibited the penetration of moist air from

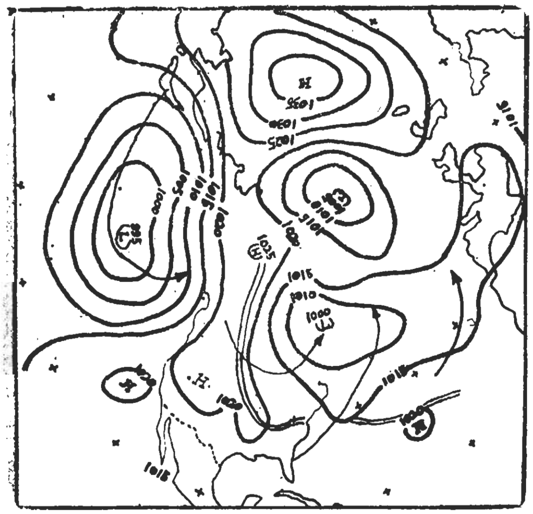

Fig. 21. Mean sea level map for the winter season (Dec. 1962, Jan. 1963, and Fcb. 1963). Thin solid lines are isobars giving prfssure in millibers. The prevailing tracks of daily pressure centers are shown by heavy solid arrows for Lows and open arrows for Highs (after Andrew).

the Gulf of Mexico, is found in the Midwest. Therefore, for the cold stormy weather in the U. S. one would usually find a strong ridge over western North America which effectively blocked the passage of moist Pacific air mass into the west and a deeper than normal trough in the central continent which would bring cold air and dryness into the midwest.

The statistical significance of climatic change in North America had been studied in detail by many authors (Blasing, 1968; Quade, 1968; Wahl, 1968; Kalnicky, 1974). To avoid repetition, the significance of the Student t-test was only applied to a single station. It shows that a significant winter temperature change does exist between 1861-1890, 1891-1920 and 1921-1950 period.

All the coefficients in Table 3 show a high correlation of seasonal temperature values over Ohio. With these values, one can estima the seasonal temperature variability across the whole area of Ohio within a reasonable range once the temperature records at Cincinnati Abbe Observatory are obtained.

Since the recording sites in the early half of the 19th century do not cover the entire state of Ohio, only a few stations along the Ohio Valley are available. Therefore, the figures and curves which have been shown here are not true averages over all of Ohio. However, these curves are the most representative for the climatic variation over Ohio Valley in earlv times.

5. Summary and concluding remarks

The warming trend in Ohio existed at least since the late 1820's and evidently culminated in the early 1950's. The temperatures have been markedly colder than normal since 1955. A marked similarity of seasonal temperature change is found in the periods of 1951–1970 and 1891–1920. The largest seasonal temperature departures from normal are found in winter. The march of 30 year moving averages of annual temperature and precipitation departures are opposite to each other from the beginning of computations through the 1931–1960 averages; then cold temperatures accompanied by low rainfall amounts occurred in Ohio.

It has been suggested by many authors (Lamb, 1966; Wahl, 1968) that we have been passing through the "Optimum" period and now return to conditions that prevailed before the warming trend at the end of the "Little Ice Age." The 1931–1960 normal period used by the U. S. W. B. was possibly the most abnormal for warmth and drought in the eastern U. S. within the last few hundred years.

The physical reason for recent cooling has been explained partially by the increase in atmospheric turbidity by volcanic dust and man-made pollution which would depress the noɹmal incidence of solar radiation.

The area of this study is concentrated on Ohio; in a sense it can be regardcd as a pilot study which can be a model for similar investigation in other regions. For example, there exist stations with long records also in other areas of eastern Midwest, e. g., northwest West Virginia and Northeast Kentucky. Further studies of this kind of survey can be extended to these areas. Thus, we can have a better understanding of the climatic changes in the eastern Midwest rather than restricted to a limited area. The results are only for a part of the Midwest and do not contradict the results of other studies.

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