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U.S. DEPARTMENT OF COMMERCE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
Environmental Research Laboratories

Climatology of Stagnating Anticyclones East of the Rocky Mountains, 1936 - 1970

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Air Resources
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SILVER SPRING,
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October 1971

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Since stagnating anticyclones are often associated with incidents of heavy air pollution in urban areas, a 35-year climatology is presented to delineate occurrences of stagnating anticyclones in the eastern United States. Occurrences of stagnation are determined on the basis of pressure-gradient values considered with other meteorological factors. Affected areas are depicted on maps by use of a system of grid points. Data showing cases of stagnation (i.e., episodes) are shown on both an annual and seasonal basis. These data indicate stagnation is most likely in autumn. The total number of stagnation days for the 35-year period is also shown.

1. INTRODUCTION

This study combines the results of three separate investigations. The first study covers a period of 21 years, from 1936 to 1956 (Korshover, 1960); the second, a period of nine more years, from 1957 to 1965 (Korshover, 1967); and the third, a period of five more years (1966-1970). The second period was revised before including it here because in the original study areas of stagnation were excluded when precipitation (including traces) had occurred, while in the nine-year (1957-1965) survey areas with traces were included. To be consistent, the 35-year study eliminated all areas of precipitation. The revision resulted in the exclusion of numerous stagnation cases. The combined results of these studies are consolidated in the present 35-year synoptic climatology of stagnating high-pressure systems in the eastern part of the United States.

Our chief interest in these stagnating anticyclones is their association with incidents of heavy air pollution in urban areas. Such anticyclones usually linger over an area for a protracted period (four days or more). During this period, surface wind speeds may be very low and vertical mixing is often restricted. Thus, the circulation is often insufficient to diffuse the accumulated pollutants of the local atmosphere. The resulting accumulations cause distressful and possibly hazardous conditions for inhabitants of the area.

In recent years, because of a rapid increase in urban living, the air pollution problem has become more and more aggravating and has commanded considerable attention. Our population is growing, and heavy industries are concentrated in relatively congested areas. Thus the possibilities that polluted air can affect human life adversely are also increasing. Since the major air pollution episodes in or near urban areas (see Lynn, et al., 1964; Fensterstock and Fankhauser, 1968) are usually associated with stagnating anticyclones, the synoptic climatology presented in this report may be useful in efforts now underway to prevent harmful effects of air pollution upon human life in the future.

When this study was conceived in 1956, there were little or no sampling data to compare with the more numerous meteorological observations; therefore, the simplest and most obvious criteria were considered. Starting with the year 1960, High Air Pollution Potential forecasts were inaugurated. Gross (1970) discusses a refined, realistic and conservative procedure used by the National Meteorological Center. Some of the criteria considered to contribute to large scale pollution episodes are: mixing height, average wind through the mixing height, morning stability, etc. Since this study considers fewer criteria, it results in about double the number of stagnation cases when compared to the more inclusive computer approach.

2. PRESSURE GRADIENT TECHNIQUE

There have been few studies of air pollution climatology published. After considerable preliminary experimentation, it was decided to employ a technique based on pressure gradient for determining the occurrence of cases of stagnation. This procedure is desirable because the pressure gradient gives a more representative picture of the general flow near the surface of the earth than do individual surface wind measurements. Willett (1949) evaluated the significant surface wind during the extreme smog development at Donora, Pennsylvania, in October 1948. At no time during a 4-day period was the maximum surface wind greater than 8 mph. In the present study, therefore, the limiting wind speed taken at anemometer level is assumed to be 7.5 knots. The authors of Dynamic Meteorology and Weather Forecasting show (in their Table 12.35.1) the ratio between surface wind and geostrophic wind speed (Godske, et al. 1957). At 30°N latitude over land, this ratio is 0.31, and at 40°N latitude the value is 0.38. Elsewhere, Willett (1944) maintains that the surface winds are observed to average about 2/5 of the gradient wind speed. Brunt (1941) states that the value for surface wind speed should be about 0.7 times the geostrophic value for light winds. In this study, the value of 0.5 has been adopted as the ratio between surface wind speed and geostrophic wind speed. Usually the difference between the geostrophic and the gradient wind speeds is small, and for this reason these two terms are used interchangeably by many authorities. As added confirmation for the 15-knot geostrophic value, J. J. George (1939) found that the average maximum gradient (geostrophic) wind speed allowing the formation of fog is close to 15.0 mph.

3. METHOD AND PROCEDURE

All the apparent stagnant anticyclones that have occurred between 1936 and 1970 east of the Rocky Mountains were selected for this study. The following procedures were used in determining cases of stagnation with the pressure gradient method:

Step 1. The United States Weather Bureau Daily Map (1936-1970) containing synoptic sea-level analysis was used exclusively to determine the pressure gradient. The period of this survey extends for 35 years, 1936 to 1970. Before 1936 available upper-air information was sparse and inconclusive. All anticyclones that showed a possibility of stagnation for four days or more were recorded. These cases were carefully checked to determine whether portions of areas of stagnation overlapped for periods of four days or more; see Step 2. In figure 1, the technique for determining stagnant areas is shown. For simplicity in this figure, the effect of latitude on the geostrophic wind is not considered, and therefore the geostrophic wind is constant for a given pressure

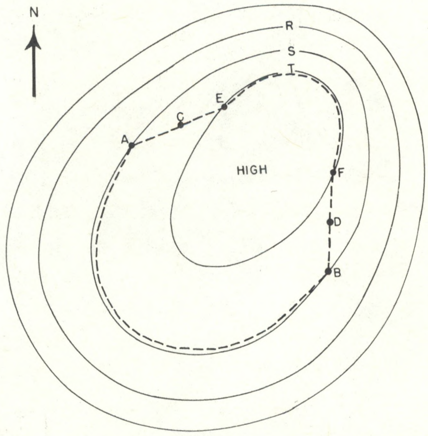


Figure 1. Schematic illustration of technique for determining stagnation area.

gradient. In the numerical evaluations, latitude was considered, and the pressure gradient corresponding to a 15-knot geostrophic wind was determined at each 5° of latitude from 27.5 to 47.5. In the isobaric channel ST (see fig. 1), the geostrophic wind changes from more than 15 knots to less than 15 knots at points C and D, with the stronger winds to the northeast. In the isobaric channel RS, the geostrophic wind speed is everywhere more than 15 knots; therefore, the dashed curve delineating area of stagnation is drawn coincident with the isobar approximately up to the points C and D. Within the isobar T the geostrophic wind is everywhere less than 15 knots; consequently the dashed curve delineates the area of stagnation as drawn coincident with the isobar T approximately up to the points C and D. The dashed line is "faired-in" across the isobaric channel at points C and D. The region enclosed by the dashed line represents the area of stagnation.

Step 2. A map of the United States from the Rocky Mountains to the east coast was divided into a set of grid points at every 2° of latitude and of longitude (fig. 2). An overlay pattern was applied to facilitate the locating of the grid points that lay within stagnant areas. The grid points of the "squares" thus located were then numbered. The daily records of areas of stagnation were recorded by means of these points on a worksheet. It was then possible to read off areas of stagnation for four, five, six, and seven or more consecutive days.

Step 3. Wherever frontal areas overlapped areas of apparent stagnation, the latter were excluded because of changing air masses, cloudiness, wind speed, and other elements.

Step 4. Areas of precipitation (including traces) were excluded because of the cleansing properties of precipitation.

Step 5. Each case was checked for either a trough or a ridge in the area of interest at 700 mb (approximately 10,000 ft) in the earlier studies and 500 mb (approximately 20,000 ft) now.

It was discovered that generally warm highs meet the criteria for stagnation conditions, since cold highs do not persist long enough. Warm anticyclones are usually deep, stagnant systems; the high pressure prevails far into the troposphere and may extend into the stratosphere.

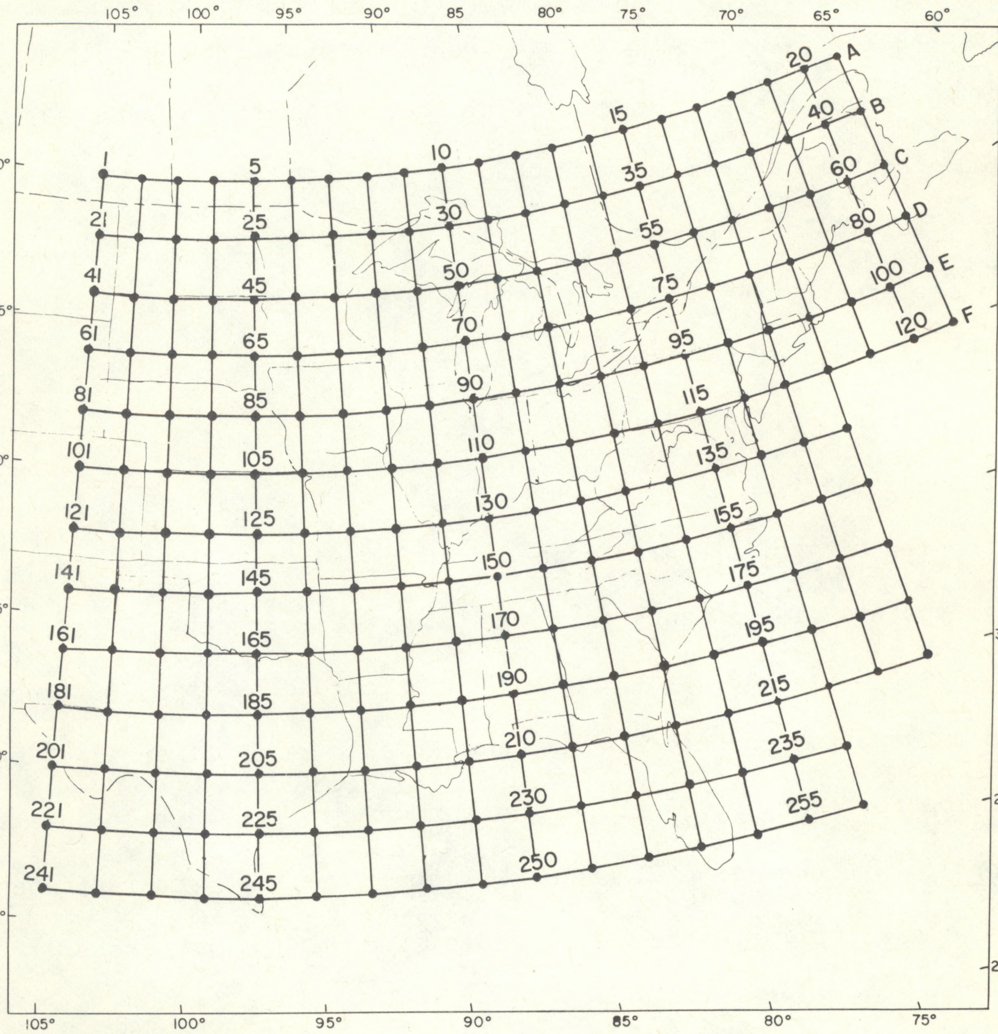


Figure 2. Geographical data reduction grid.

4. SUMMARY OF RESULTS

The 35-year study yields results similar to those of earlier surveys and conclusions are largely the same also.

Table 1 is a chronological presentation of all cases of stagnation.

In figure 3, the upper values (above each grid point) are the total number of stagnation cases (four or more days) and the lower values are the total number of days of stagnation. Dashed isopleths show the distribution of the number of stagnation cases; solid isopleths, the distribution of the number of days of stagnation. They are distributed similarly. This chart suggests a strong influence of the Bermuda High on the east coast. A maximum frequency in both the number of cases and the number of days stagnation occurs in an area that covers parts of Georgia and South Carolina. This region is frequently dominated by the western extension of the semipermanent high-pressure area.

Figure 4 shows the geographical distribution of annual occurrence of cases of stagnation for seven or more days. The values given are the total for the entire 35-year period, 1936-1970. These can be compared with figure 3, the total annual number of stagnation cases for four or more days (dashed isopleths).

A monthly distribution of the number of cases of stagnation for four, five, six, or seven or more days and of the total number of days of stagnation is given in table 2.

Figure 5 depicts the distribution by months of the number of cases of stagnation for four, five, six, and seven days and illustrates table 2 graphically. The primary peak for four or more days occurred in October;

Table 1. Stagnation Cases in the United States East of the Rocky Mountains, 1936-1970

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1936		23-26			6-11 23-27							21-27	4
1937				17-20				14-17	21-25 S27-O1		23-26		5
1938				12-17	17-21			9-12 13-17 19-24		8-13 15-20 25-28			8
1939					4-7	24-28			23-26	4-10	13-18		5
1940				1-5	5-9	2-6			3-7 17-21	10-13 23-28	18-21		8
1941				8-12 14-20 A23-M1	19-22	18-22			19-22 S28-O1	12-16			8
1942	11-14			14-17 23-26	A29-M3	M30-J3	18-21		8-11 12-15	7-10			9
1943		17-21		25-29		M30-J5 9-16		3-7 19-26 A29-S2	26-29	3-11 18-21	18-21		11
1944		23-28			A30-M5 12-18	M30-J3	4-7			16-19		4-7	7
1945			16-20 M28-A1			10-13		A27-S1		O27-N3			5
1946						22-27	27-30		3-7 13-20 26-29	2-7 14-18 20-25	11-14	3-11	10
1947						20-25		11-18		1-8		1-5	4
1948						1-4	2-6 9-12	21-30	1-8	24-31			6
1949					13-16		23-20			9-12 19-22	6-9		5
1950						6-9 13-20		7-12 22-27	S26-O3	16-19 O29-N3	6-9		8
1951	27-30		2-5		14-18						20-25 N28-D3		5
1952	D31-J5* 12-18			18-24		23-28		23-28	9-14 S27-O1	22-27 O30-N2			9
1953	13-16						10-14	A17-S2			O30-N3 13-20		5

*Dec 31 - Jan 5

Table 1. (continued)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1954							J26-A1		1-7	1-6 20-27			4
1955			F28-M3 12-19			M31-J6 15-18	1-5	1-6 27-30		9-13	12-17		9
1956				3-6	10-15	13-19 23-27			11-14 26-29	11-16			7
1957	J27-F1			22-29	7-10 M29-J1		16-22	6-11		11-16		15-18	8
1958					14-17		J29-J4		13-16 23-26	12-17	11-14		6
1959	12-15			5-10 24-28	1-5 27-30	8-12 25-30		11-16 20-23	5-10 20-26	3-7	8-11		13
1960	10-14			12-17 23-26	15-21	10-13		17-20	22-25	10-14	13-16	3-7	10
1961		13-17		22-27		2-7			9-13 21-25	6-13			6
1962					16-20			23-26 A29-S2		11-14	N27-D4		5
1963				M30-A4 17-22	8-11			3-6	7-11 16-21	1-4 6-9 14-22 23-26	16-19		11
1964				17-23	7-11 16-20				1-4	25-28			5
1965					1-8 15-20				19-23	25-28		D30-J2**	5
1966			10-13			2-7 21-29	22-27	A27-S4	8-11		15-19 21-24		8
1967	21-26		2-5	2-5	M25-J1	2-16		12-18	1-8 11-22	1-8 13-16			10
1968	17-22 27-30						21-25	21-24 26-31	11-25		O30-N3		7
1969					1-8 28-31	23-26	15-20	21-26 A27-S1	12-16				7
1970					8-16 18-24		J29-J3	25-30	13-17 20-26	7-10			7
Total	11	4	7	21	29	26	15	30	38	42	20	7	250

**Dec 30 - Jan 2

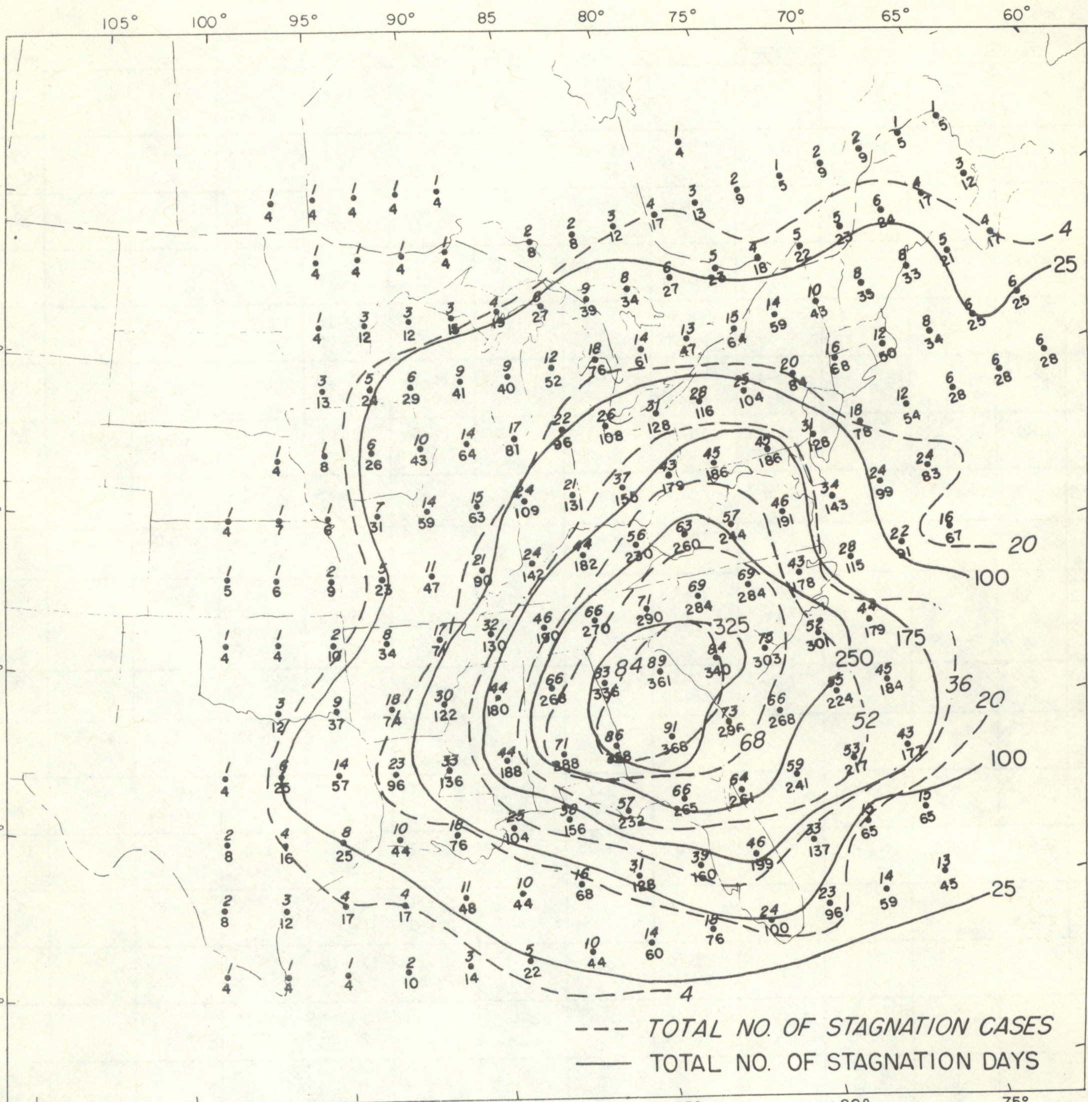


Figure 3. Distribution of stagnation cases and stagnation days, 1936-1970

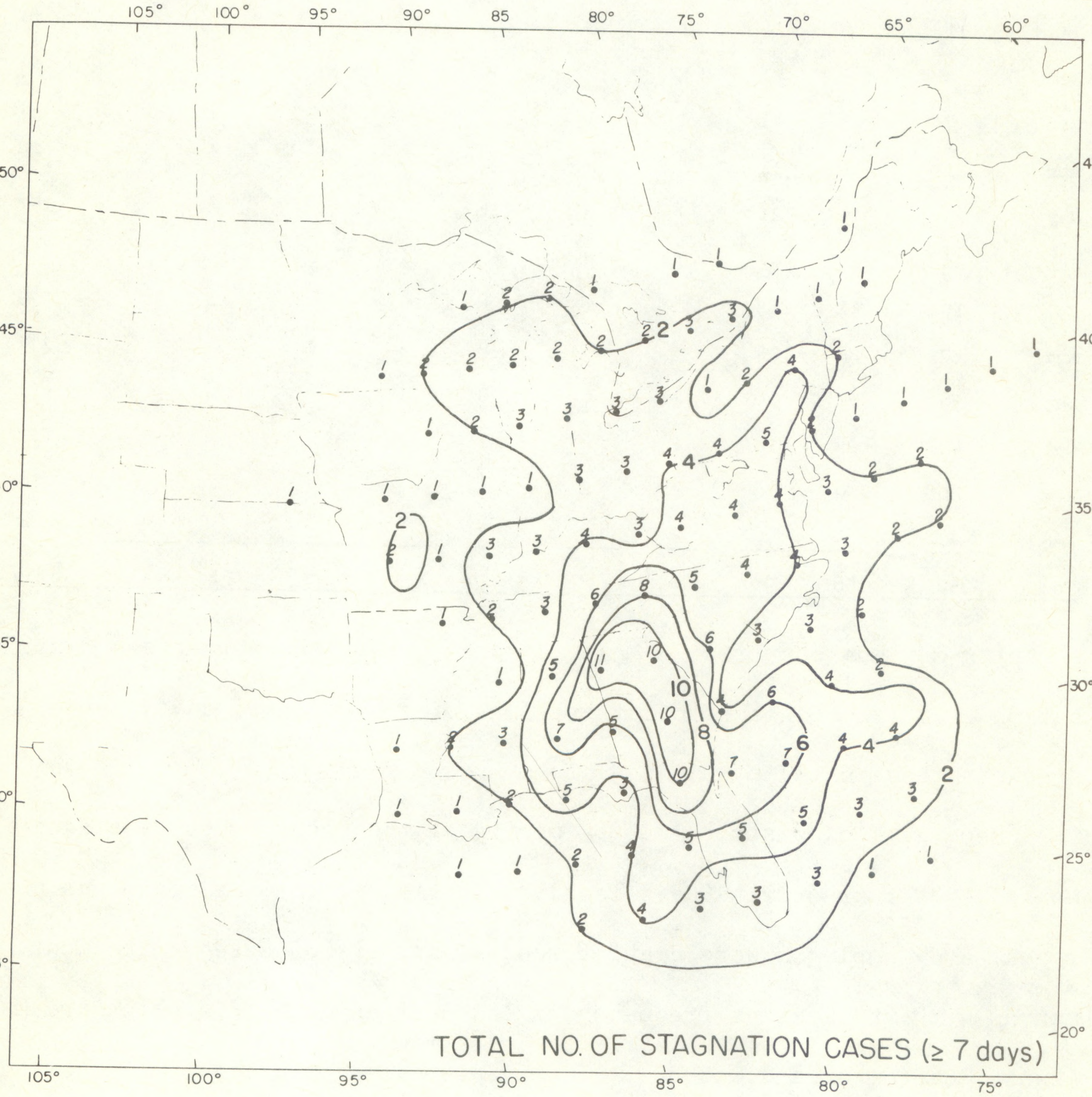


Figure 4. Total number of stagnation cases (seven or more days), 1936-1970

Table 2. Number of Stagnation Cases for Indicated Period and the Total Number of Days by Month in the United States, East of the Rocky Mountains, 1936-1970.

	Days										Total Days
Month	4	5	6	7	8	9	10	11	12	17	
Jan	11	6	4	1							55
Feb	4	3	1								20
Mar	7	3	1	1	1						34
Apr	21	14	11	5	2						116
May	29	19	11	7	3	1					157
Jun	26	20	13	7	4	2	1				151
Jul	15	11	5	2	1						79
Aug	30	22	14	5	5	2	2	1	1	1	177
Sep	38	21	10	9	6	2	1				201
Oct	42	24	18	9	8	1					228
Nov	20	9	6	2	2						99
Dec	7	4	2	2	1	1					38
Total	250	156	96	50	33	9	4	1	1	1	1355

a spring maximum occurred in May. Figure 5 shows the percentage distribution by months of cases of stagnation for four or more days; table 3 presents these data in numerical form.

Geographical distribution by months of the occurrences of stagnation episodes of four or more days is given in figure 6. Each month was analyzed, and isopleths were drawn for equal numbers of cases. The four months with the maximum frequency of cases at any one grid point are May, August, September, and October. In May, 15 cases of stagnation occurred over South Carolina and Alabama. By August, 16 stagnation cases are located near Roanoke, Virginia; the secondary maximum, 10, is located over southwestern Georgia. In September, the maximum number of cases, 15, occurred near Harrisburg, Pennsylvania; the secondary maximum, 13, was

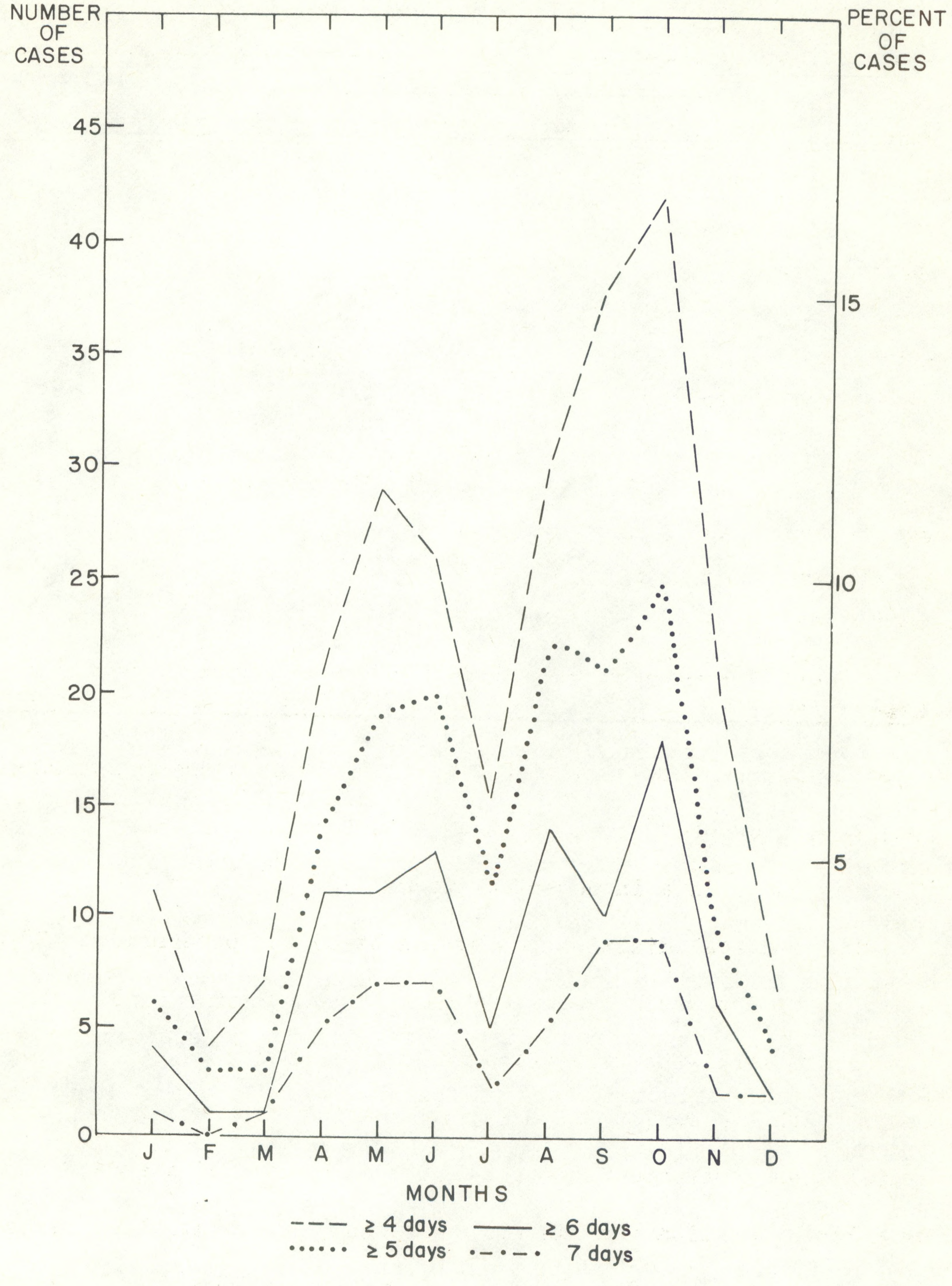


Figure 5. Number and percentage of stagnation cases for four, five, six, and seven days by month in the United States east of the Rocky Mountains, 1936-1970.

Table 3. Percentage Distribution of Cases of Stagnation for Four or More Days by Month in the United States, East of the Rocky Mountains, 1936-1970.

Month	Day 4	Percent
Jan	11	4.4
Feb	4	1.6
Mar	7	2.8
Apr	21	8.4
May	29	11.6
Jun	26	10.4
Jul	15	6.0
Aug	30	12.0
Sep	38	15.2
Oct	42	16.8
Nov	20	8.0
Dec	7	2.8
Total	250	100.0

found over north central Alabama. In October, 22 cases of stagnation occurred over northern Georgia. From November through April, the monthly maximum of stagnation cases is found in South Carolina, Georgia, and Florida. Wexler (1949) also finds October the month most favorable for the occurrence of deep anticyclones and hazardous smog episodes. Klein (1951) depicts the number of different highs for 5^o squares for each month during 20 selected years of the original Historical Map Series, 1904-1914 and 1924-1937. In Klein's paper, charts 20, 21, and 22 for August, September, and October are similar to those for the same months shown in figure 6 but with centers of maximum frequency displaced somewhat northward. He also gives the number of days with highs (both migratory and stationary) during the 40 years from 1899-1939. September and October apparently are the crucial months when stagnation is most likely to occur.

For the present study, figure 7 presents a seasonal distribution of stagnation cases that have a duration of four or more days. The maximum number of cases for each season of the year are distributed as follows:

winter --- south central Georgia

spring --- near Jacksonville, Florida

summer --- central West Virginia

autumn --- northern Georgia

It is interesting to note that the seasonal location of stagnation centers is similar to the movement of the Bermuda High, that is, south in winter, north in summer; however, frequently a continental polar high coming from northwest Canada stagnates over eastern states and then amalgamates with the Bermuda High.

Data for additional years have not affected the previously reported location and distribution of stagnation anticyclones in the eastern United States; thus, the present report appears to furnish a reliable climatology of such events.

5. ACKNOWLEDGEMENTS

Dr. Lester Machta initiated the project, established the criteria for classifying the stagnation wind speeds, and suggested the procedures to be followed in analyzing the weather charts. The author is also grateful to Donald H. Pack, Dr. James K. Angell, and Fred D. White for their many suggestions and constructive criticism. The diagrams were drafted by Marguerite M. Hodges.

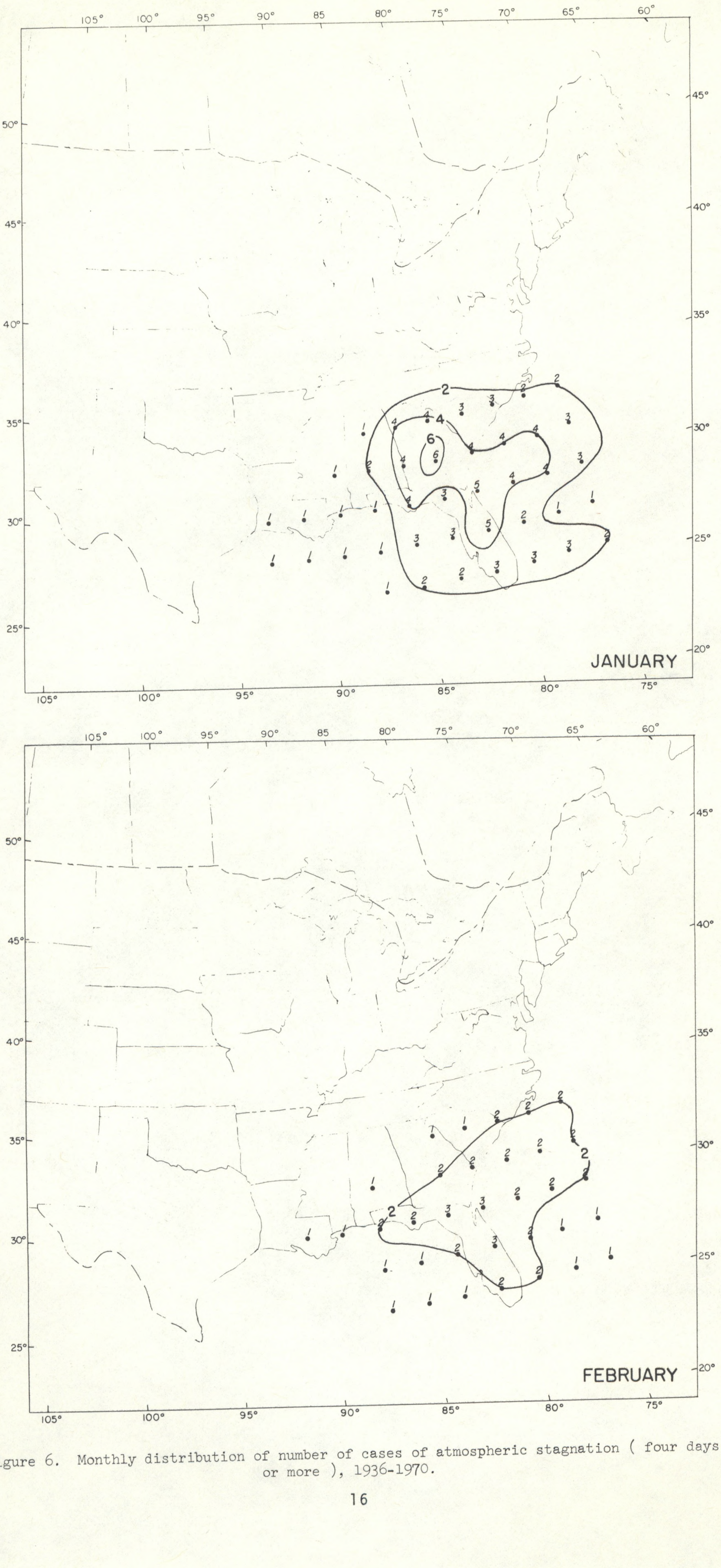
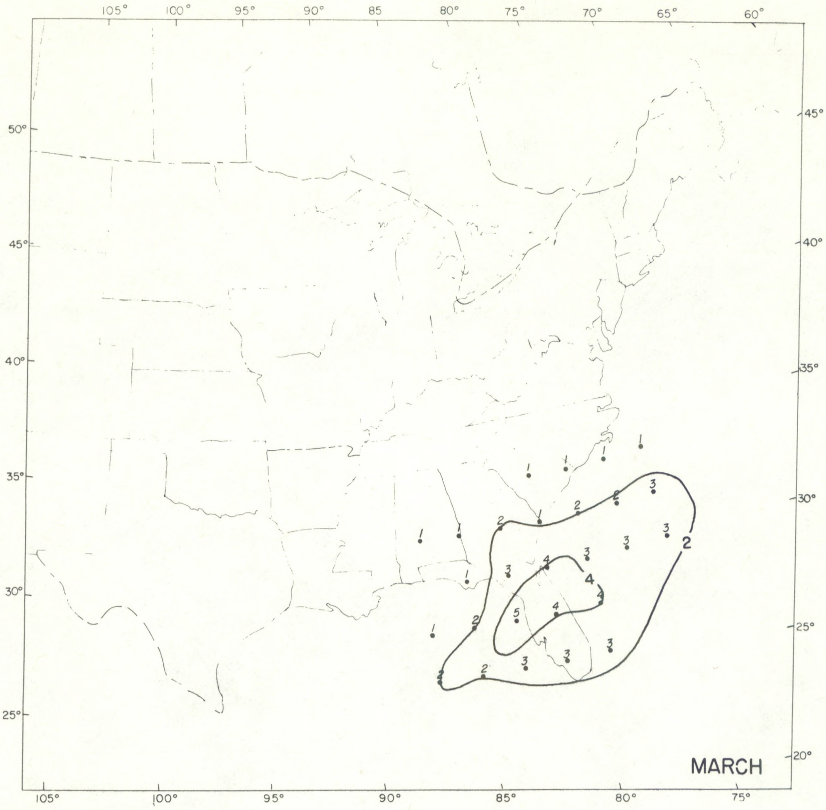
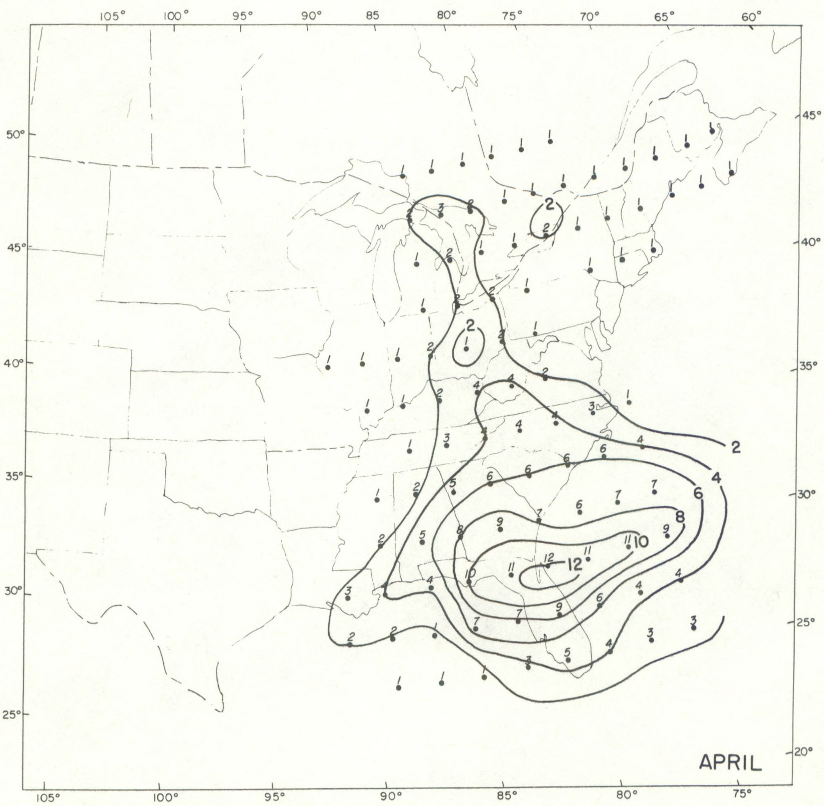


Figure 6. Monthly distribution of number of cases of atmospheric stagnation (four days or more), 1936-1970.





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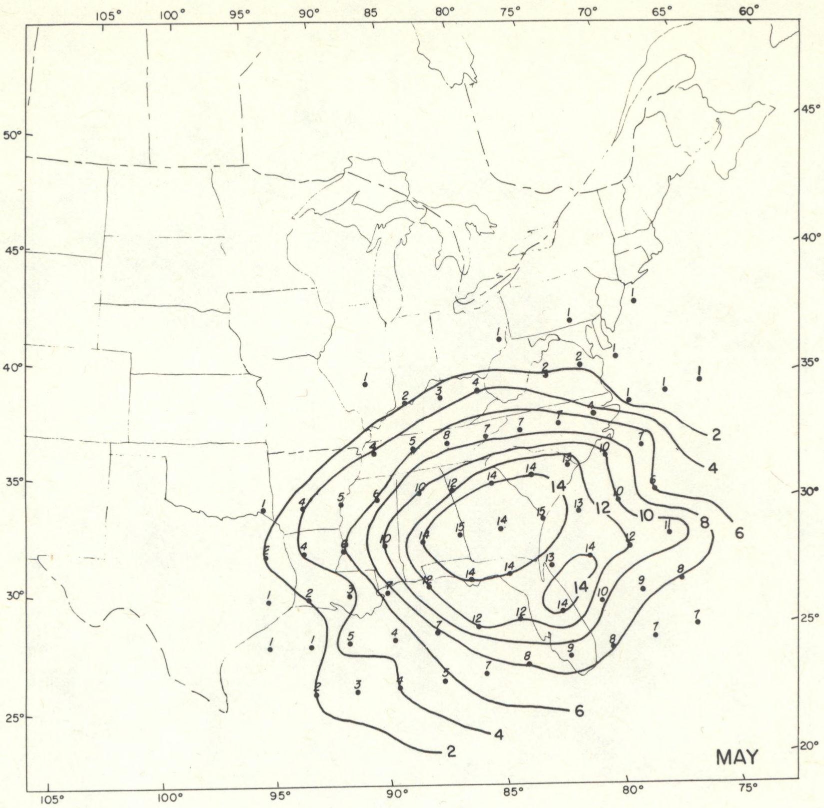

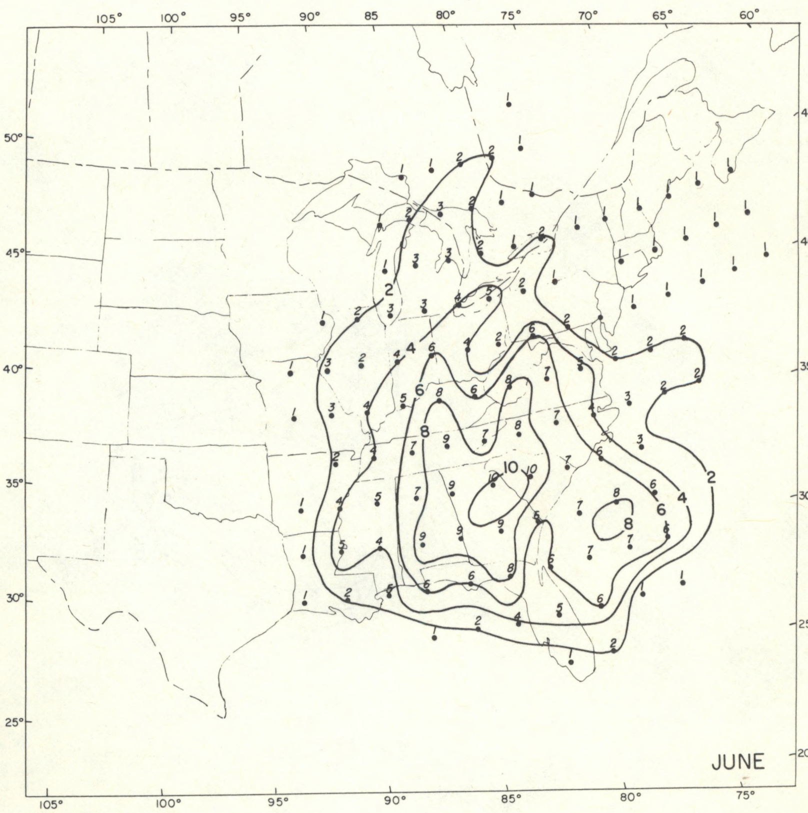

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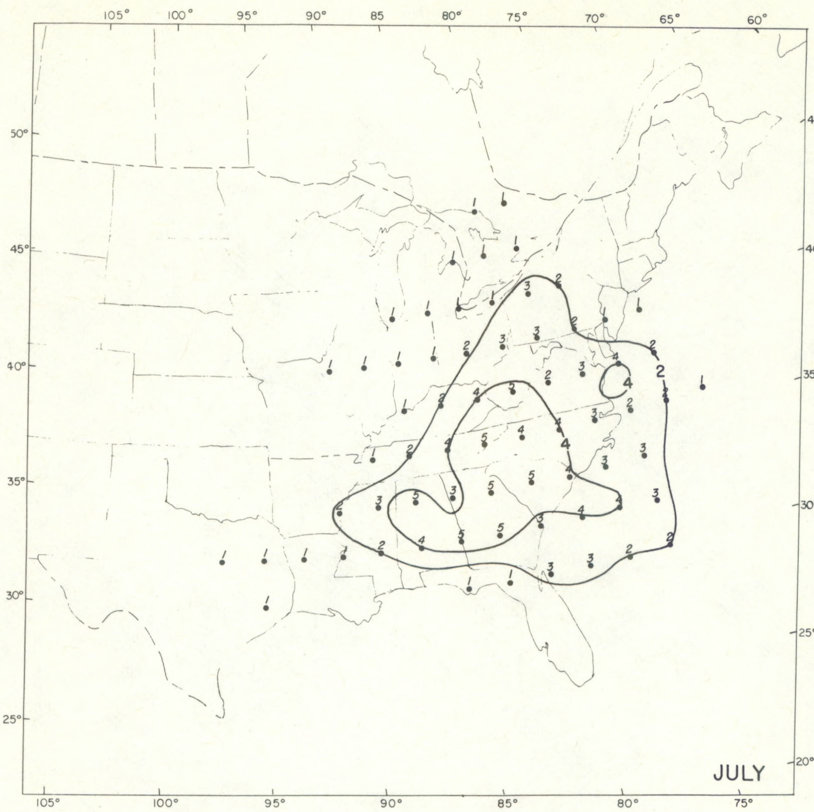

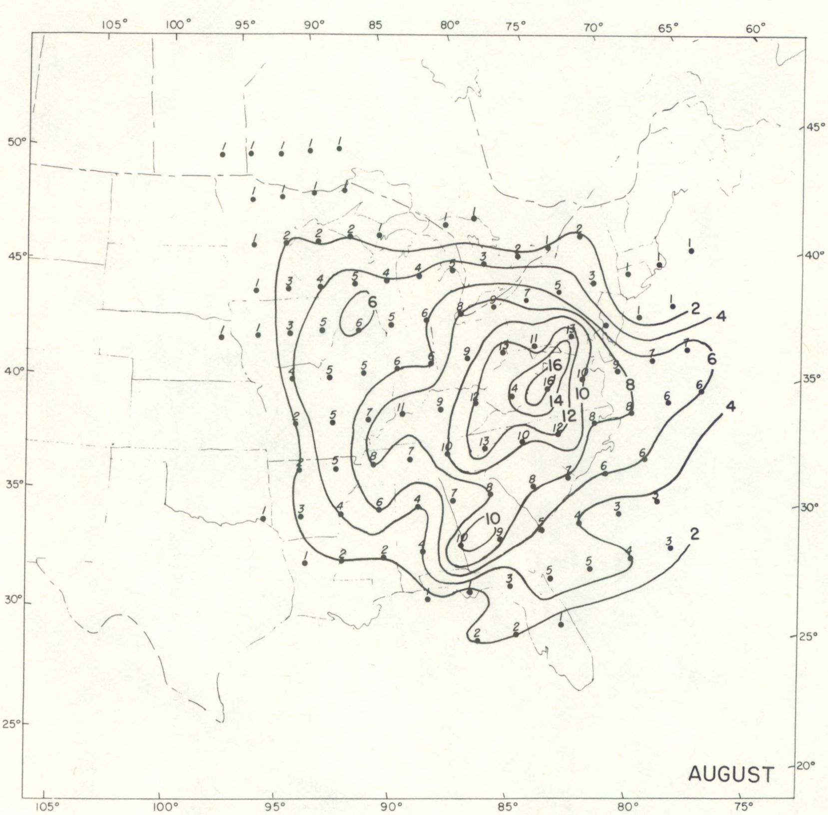

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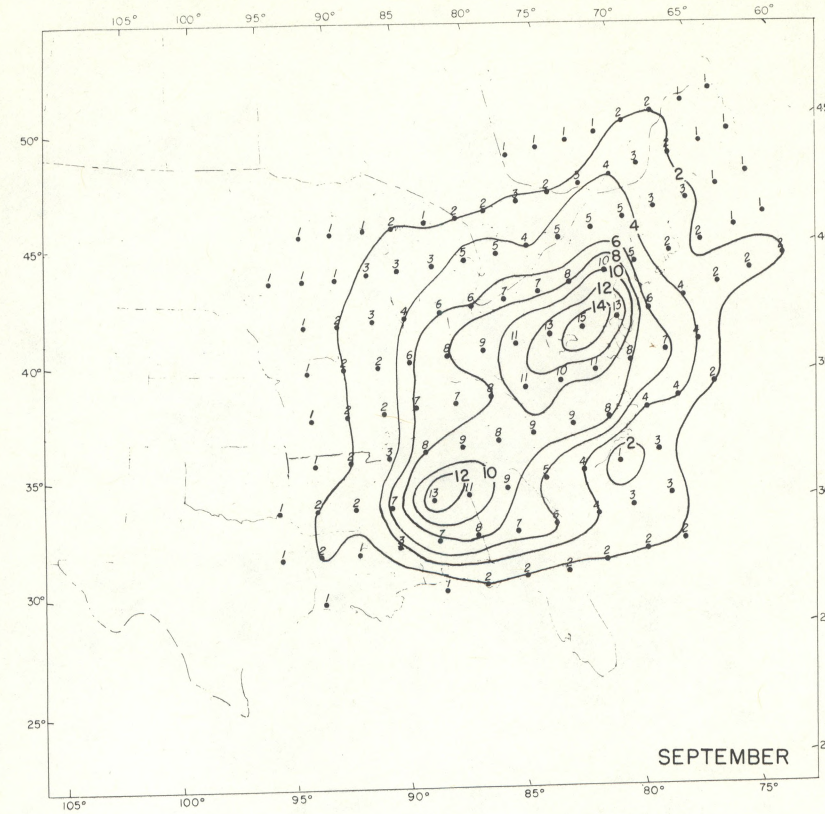

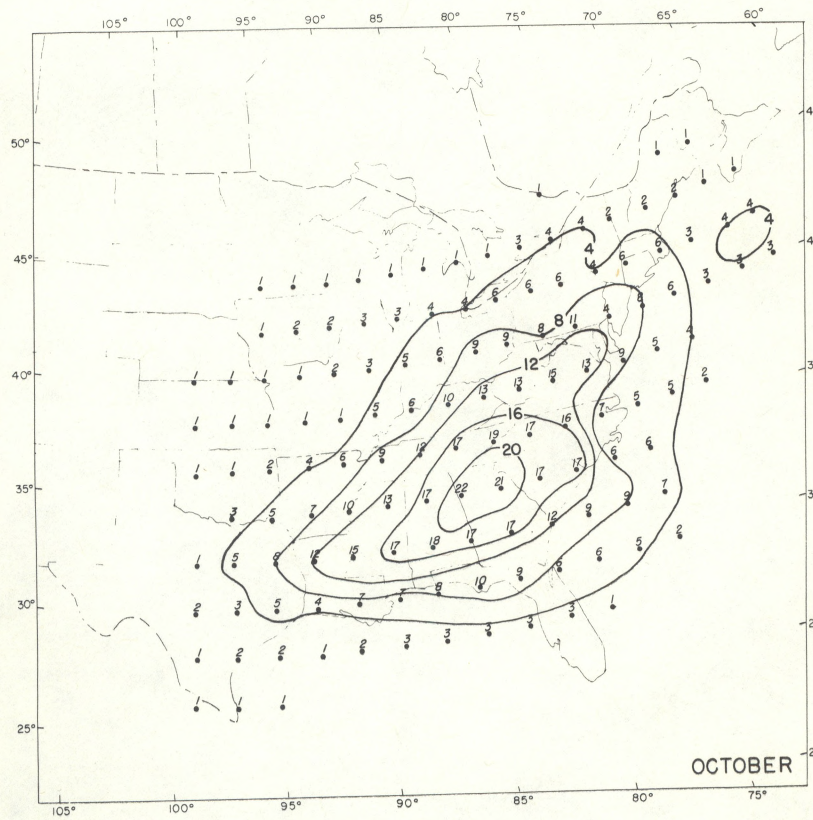

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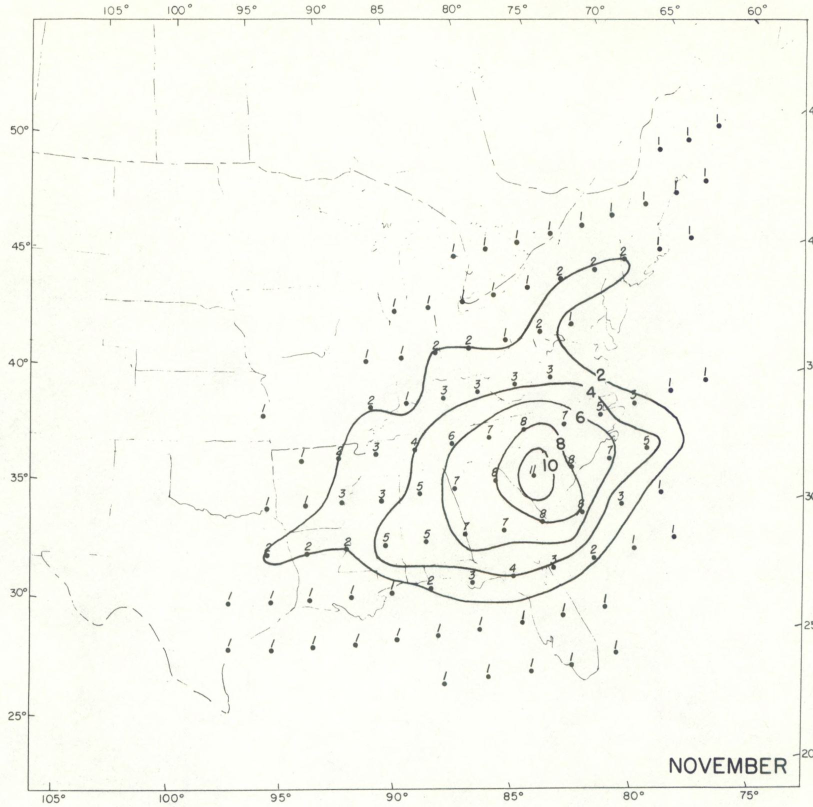

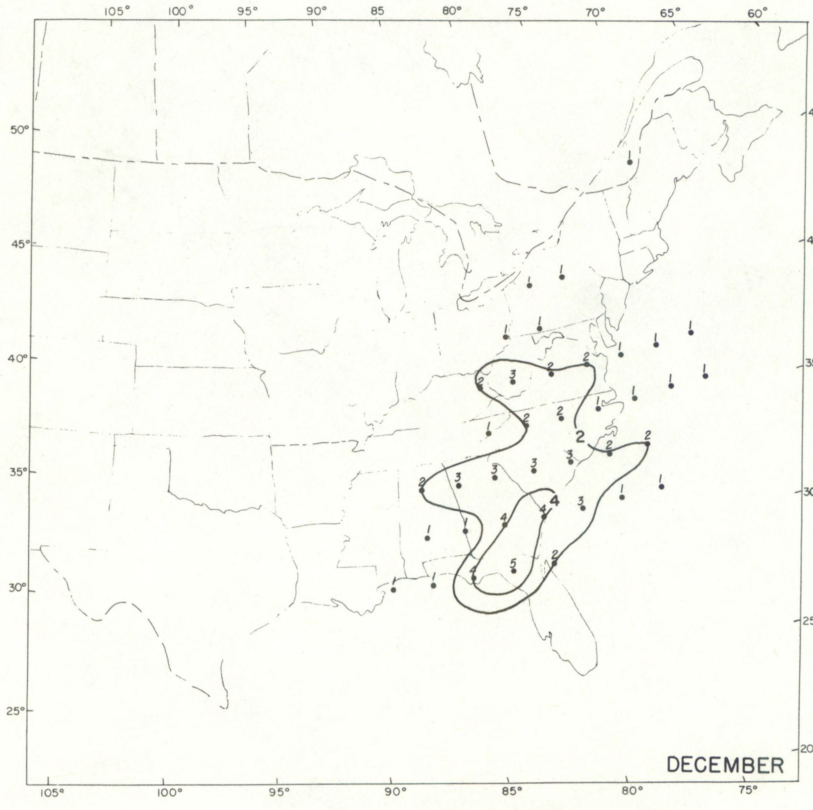

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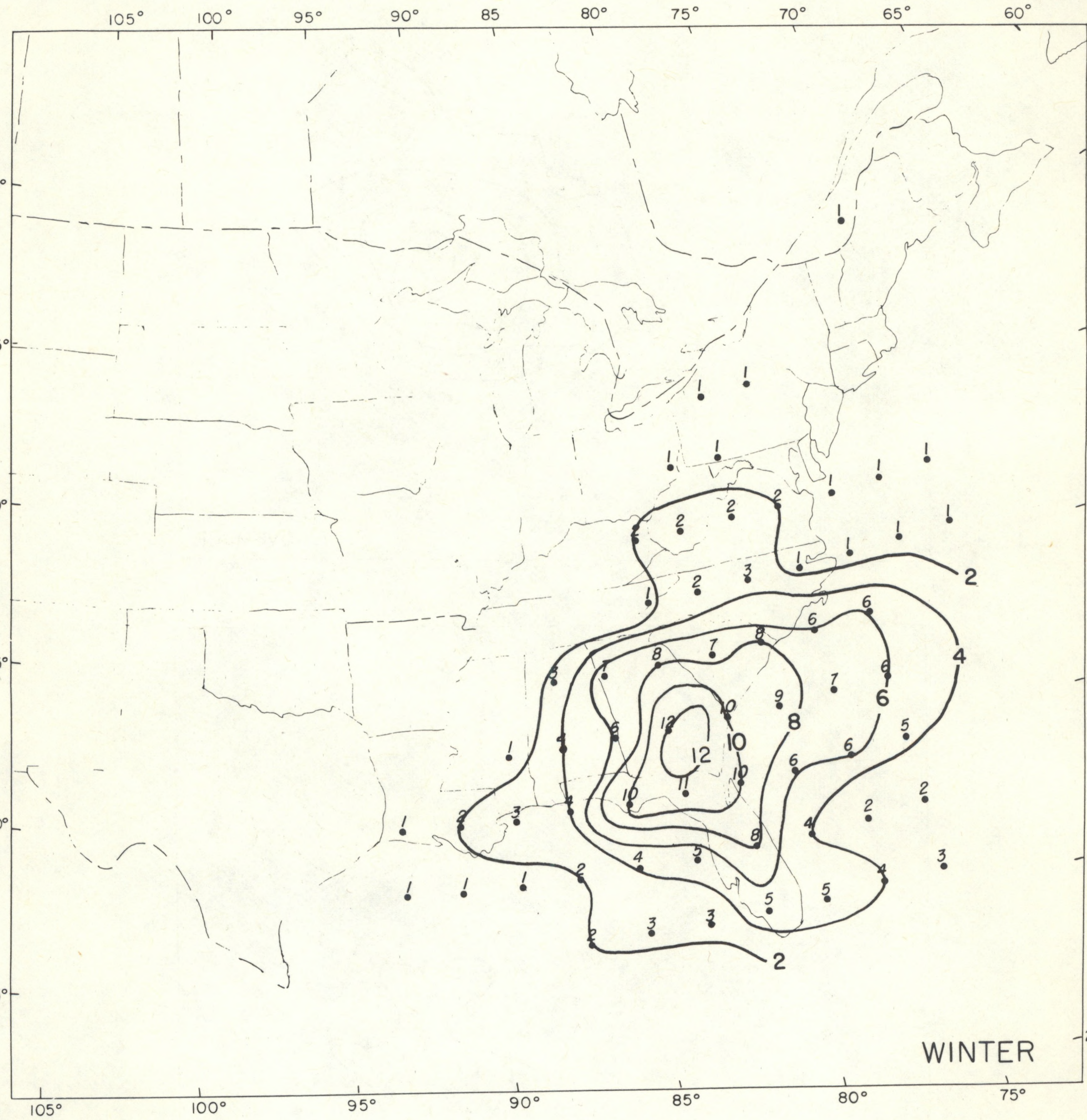
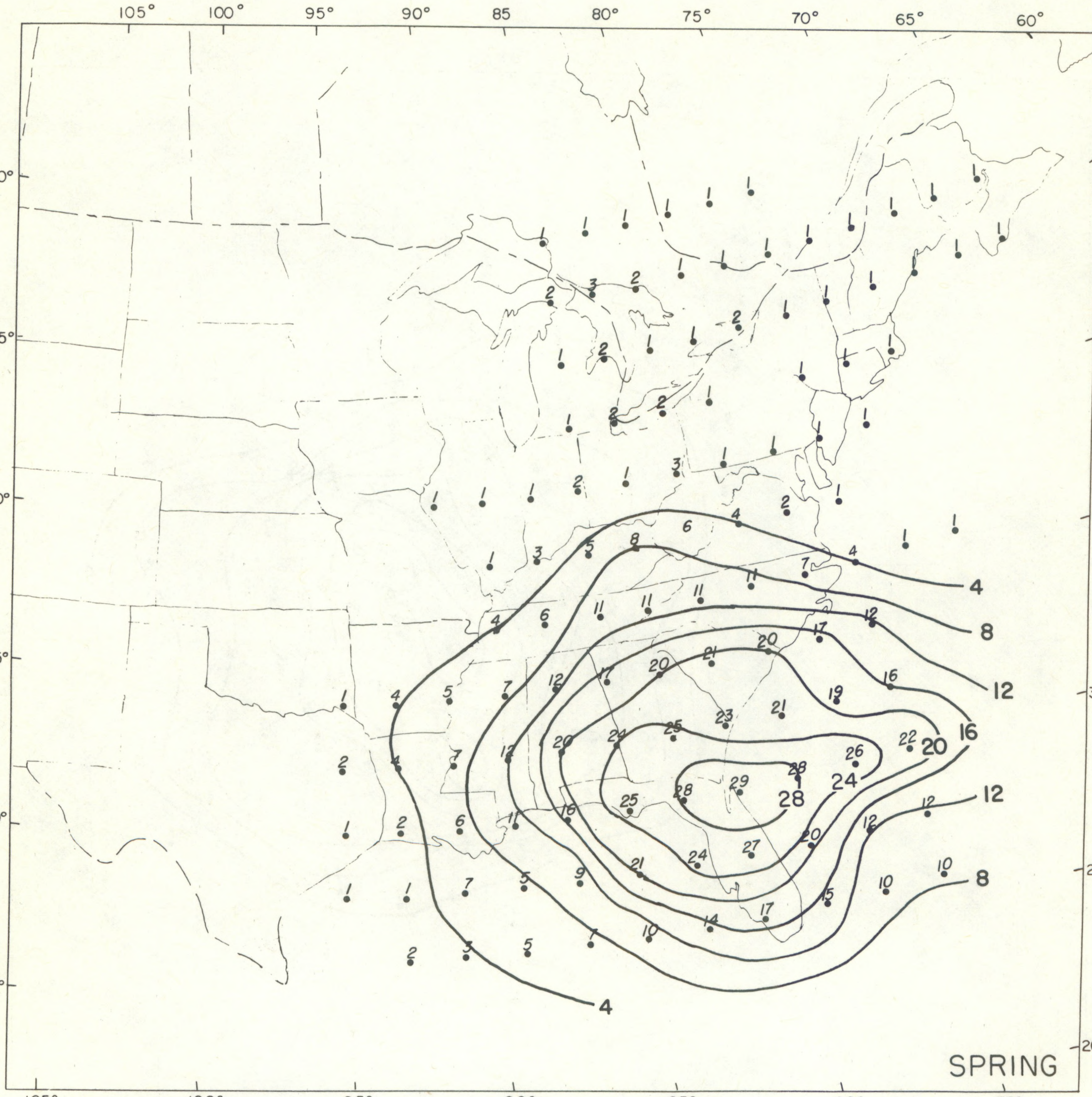


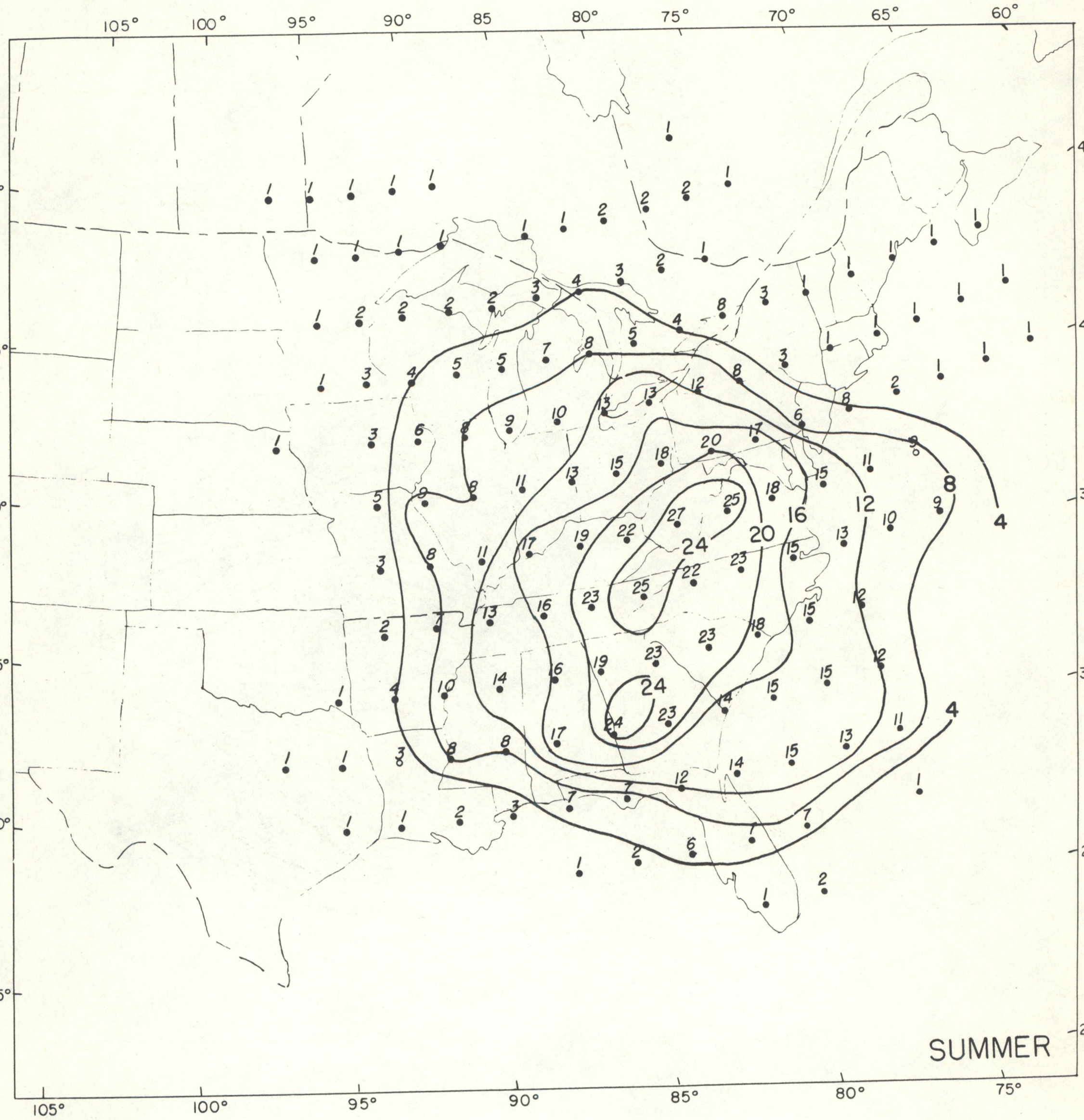
Winter (December, January, February)

Figure 7. Seasonal distribution of number of cases of atmospheric stagnation (four days or more), 1936-1970.



Spring (March, April, May)

Figure 7. (continued)



Summer (June, July, August)

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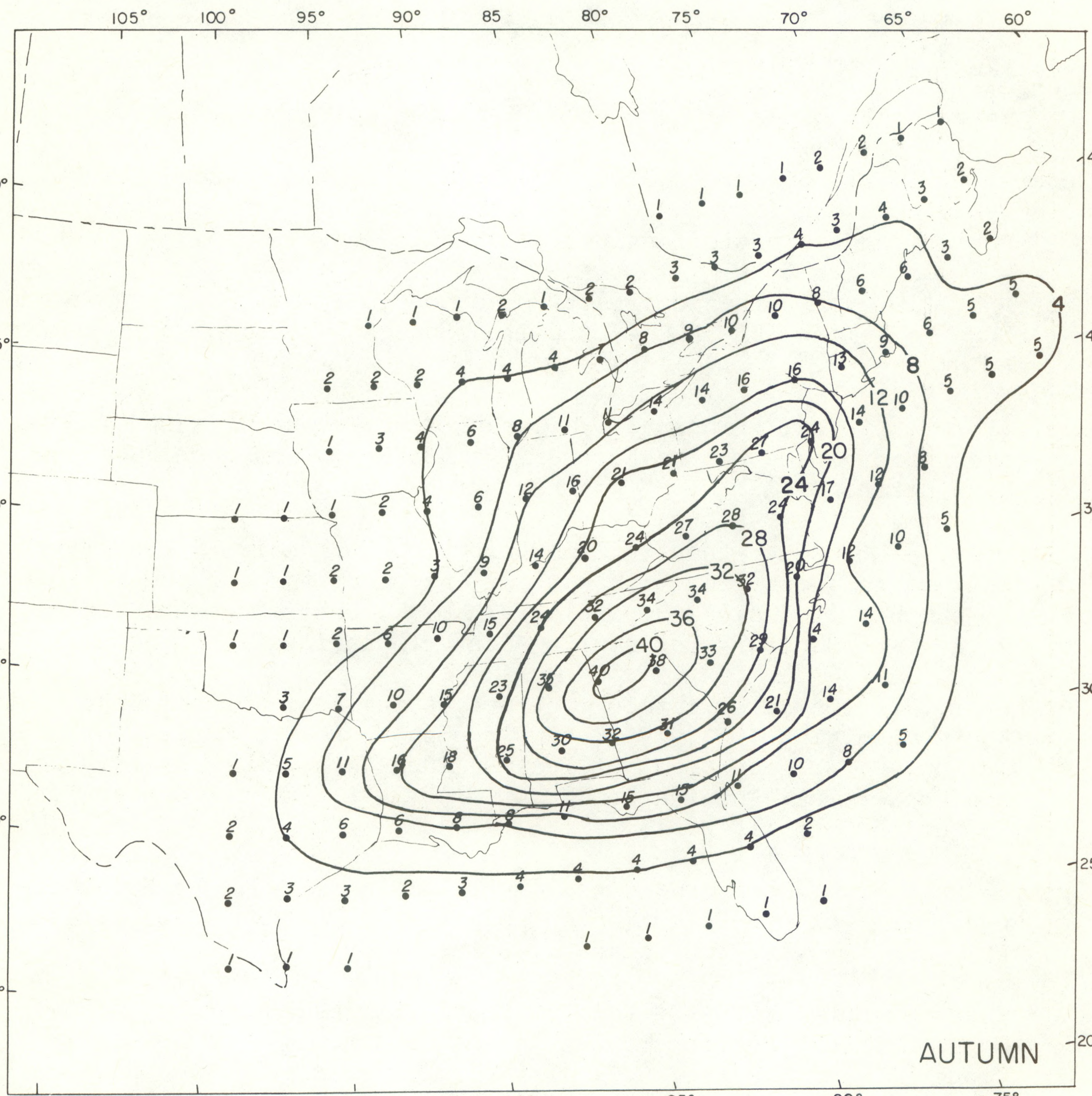

Autumn (September, October, November)

Figure 7. (continued)

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