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LONG-TERM FLUCTUATION OF TORNADO ACTIVITIES

by

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ABSTRACT

In an attempt to assess the tornado risk over the United States, paths of individual storms during the past 25 years were mapped. Since the tornado frequency prior to 1950 is less reliable than tornado death counts, the death patterns for the 64-year period, 1911-74, were analyzed in detail. It was found that the path and death patterns show reasonable relationship, making it possible to estimate tornado activities in early years based on deaths. A series of the fatality maps, thus produced, signify a wide fluctuation of the activity center averaged over 7 to 8 year periods. This research suggests that the statistical period for tornado-risk assessment should be at least 45 years. The area of high fatality anomaly fluctuated widely around the overall activity center which has been located near the Missouri-Arkansas border.

1. INTRODUCTION

The mean tornado frequency for the United States was only about 90 per year shortly after 1916 when the Weather Bureau started compiling tornado statistics. The total count during the first ten-year collection period, 1916-25, was only 1007.

It took about 30 years for the annual frequency to increase 100%, from 100 per year to 200. Then, the 199 per year frequency in 1950 increased by more than a factor of two to 437 in only 3 years.

Since 1954 the annual tornado frequency has exceeded 500 and the quality of the published data on tornadoes was improved. This is attributable to a change in emphasis and the uniform use of newspaper clipping services in 1953.

With better input data, various researchers produced tornado frequency maps. For the collection of tornado maps, refer to Court (1970). The U. S. Weather Bureau systematized the data and Wolford (1960) revised the earlier work and included a frequency map for the 1953-58 period. Her results showed the highest frequency in Oklahoma. An expanded study by the USWB (1962) for the 1916-1961 period produced a frequency pattern similar to Wolford's.

A conclusion that might ensue from the works cited was that the expansion of the statistical period from 6 years (1953-58) did not show any significant difference to that of the 46 year period (1916-61). But when we examine the breakdown for the two periods,

5429 tornadoes in 9 years (1953-61)
5627 tornadoes in 38 years (1916-52)

it can be seen that the 9-year collection is weighted about 4 times that of the 38 year collection.

Earlier work by Brown (1933) and Brown and Roberts (1935) did not emphasize an Oklahoma-Kansas maxima. Instead, the high risk areas, as revealed by maps showing paths, suggested that Arkansas, Mississippi and Alabama were tornado prone, with Kansas and Iowa indicating a higher tornado risk than Oklahoma. This leads to a natural speculation --- what is the true distribution of tornadoes over the midwest? Are the variations random (Kansas has been below the median tornado frequency 7 of the last 8 years,. Oklahoma 6 of the last 8 years) or are the movements systematic?

2. TORNADO FREQUENCIES, INTENSITIES, AREA AND PATH MAPS

Tornado frequencies per unit area are comparable only if the distribution of tornado intensities and swath areas are comparable from one part of the country to the other. There is a second implied assumption that the tornado data collection methods are uniform as well. Unfortunately, the latter is not the case since it has been well demonstrated that the frequency of tornadoes reported in a locale is not solely a meteorological function. It often depends upon such non-meteorological items as population density; the zeal of the Civil Defense or meteorological group gathering the data, and the primary time of day of severe weather occurrences. This problem exists today and has been extenuated by recent changes in the NWS's state climatological program.

A major effort of classifying tornadoes by intensity, path length and path width was begun in 1971 by Fujita and Pearson. Refer to Fujita (1973) and Fujita and Pearson (1973). A simple numerical system was devised to aid state climatologists in preparing estimates of the tornadoes maximum wind speed (as inferred from damage), path length and mean path width. The estimates remain subjective and the quality of the incoming reports vary considerably across the country. Nevertheless, the classification system has succeeded in providing discrete numerical values for each tornado so that the smoothing process clearly differentiates a tornado with a 100 mile path length from one that is on the ground for less than 400 feet. The authors cited are in the process of preparing FPP estimates for tornadoes prior to 1971, utilizing all available newspaper clippings stored at the National Severe Storms Forecast Center.

It seems reasonable, although it cannot be proven, that the major increase in tornadoes during the past 20 to 25 years has been due to a greater efficiency in the reporting of the relatively small and weak tornado, i.e. those with FPP values of 111 or less. Fujita and Pearson (1973) showed that 60 percent of the tornadoes in 1972 had path lengths of 3.1 miles or less and path widths of 55 yards or less, with 20 percent of the tornadoes having path lengths of less than one mile and path widths of less than 17 yards. Short lived tornadoes of this type can go undetected unless the population density is very high. There may be scores of the smaller tornado which escape detection today in the rural areas of the central plains.

The longer lived tornado has a much greater likelihood of being detected and Fig. 1 shows reported tornadoes with path lengths of 3.2 miles or longer and path widths of 56 yards or greater for the period 1950-63. This presentation is very similar to the Brown and Roberts map for the 1890-1931 period. The 1950-63 periods suggest a concentration in central Oklahoma with other concentrations in Arkansas, eastern Kansas, southern Mississippi and Illinois. The position centroid for this period, shown as a double circle on Fig. 1, is located in southern Missouri.

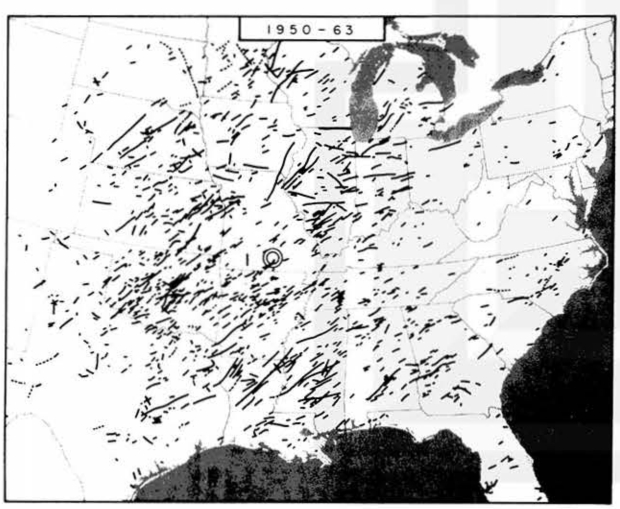

Fig. 1. Distribution of tornadoes with FPP equal to or larger than 222 during 1950-63.

During the next seven year period (1964-70) the pattern appears to have shifted, with the highest concentration in Wisconsin, southeastern Minnesota, and the northern half of Illinois. The position centroid for this period has shifted northward to a location 20 miles south of St. Louis, Missouri (see Fig. 2). There has been a marked reduction in Arkansas, northern Louisiana and southern Illinois.

Fig. 2. Distribution of tornadoes with FPP equal to or larger than 222 during 1964-70.

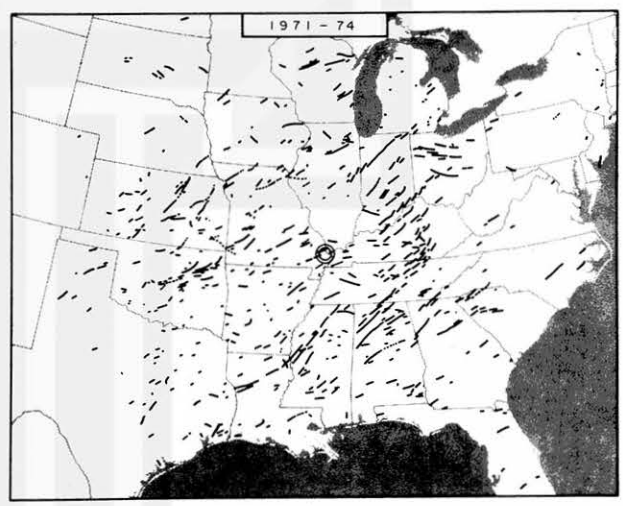

Fig. 3. Distribution of tornadoes with FPP equal to or larger than 222 during 1971-74.

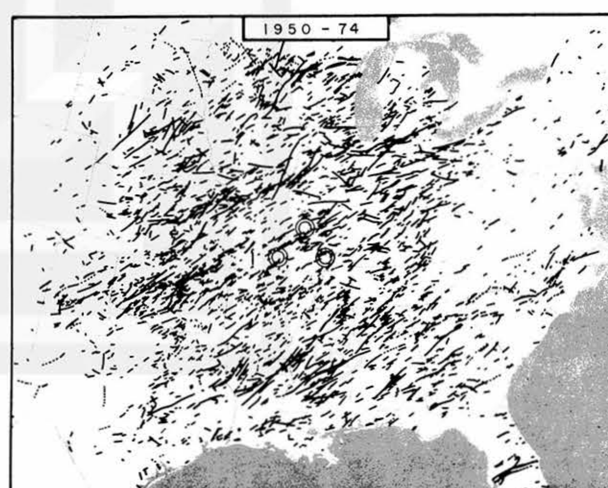

Fig. 4. Paths of tornadoes with FPP equal to or larger than 222 during the 25-year period, 1950-74.

For the next 4 year period, 1971-74 the centroid has shifted to southeastern Missouri, near Cairo, Illinois, and a greater number of long tracks appear to be to the east of the Mississippi River (see Fig. 3).

Figure 4 is a composite of Figs. 1-3 for the 1950-74 period. An attempt is being made to classify the tornadoes prior to 1950, and to add the data sample to the later period in an attempt to determine the long-term variations, if any, of the longer path distribution.

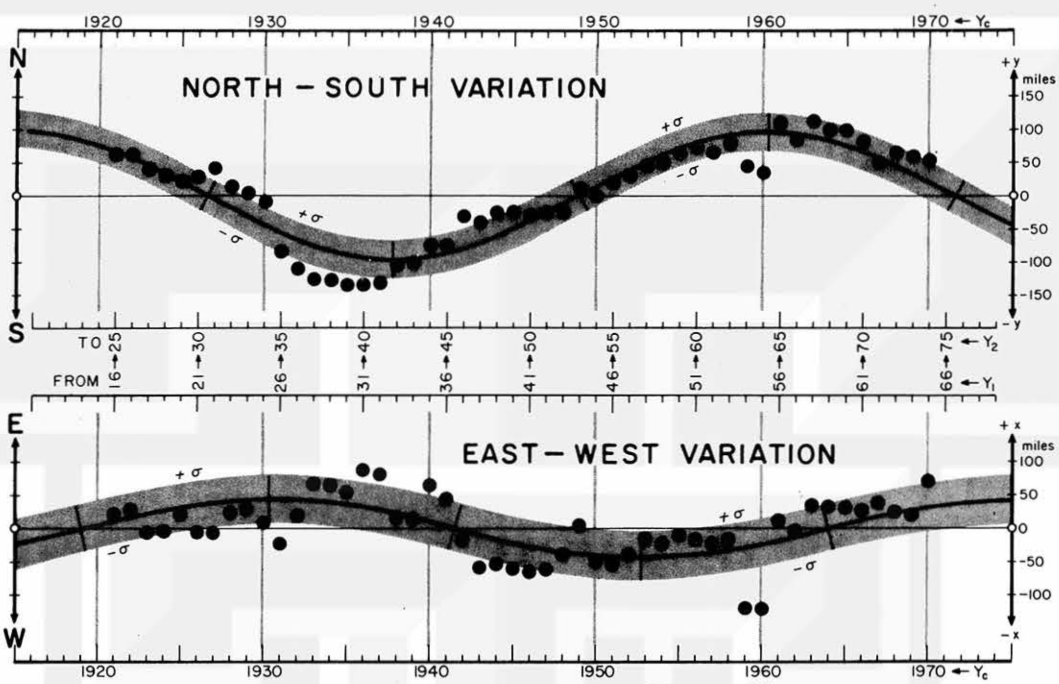

Fig. 5. North - south and east - west variation of the fatality centroid for the successive 10 year period between 1916 and 74. Y_1 and Y_2 are the first and the last year of each period, and Y_c is the center year.

3. MAXIMA IN TORNADO FATALITIES

Where there is no population there are no tornado fatalities. Conversely, tornado deaths would not occur in populated areas unless there were significant tornadoes. While there are many other factors that can be considered (building standards, local alerting procedures, population density); fatalities from tornadoes may be regarded as a rough measure of tornado activities.

Earlier, it was noted that the U.S. Weather Bureau had not made a concerted effort to report tornadoes prior to 1953, but the same did not hold true for tornado-related fatalities. If the location of tornadoes are random, the fatalities in any specific area should be nearly random as well, when adjusted for population. But if there is any type of systematic variation in tornado activities, it might be possible to infer the variation from the tornado-related fatalities.

In an attempt to learn the variation, random or systematic, the fatality centroids for successive 10-year periods were computed. The formulae for computations are

$$x = \frac{\Sigma N_i x_i}{\Sigma N_i}, \quad y = \frac{\Sigma N_i y_i}{\Sigma N_i}$$

where N_i denote the number of tornado-related deaths in each state; x_i, y_i are the coordinates of each state weighted by the locations of deaths; and x, y are the coordinates of the fatality centroid for the specific period.

Let the first and the last years of the 10-year period be Y_1 and Y_2, the year of the period center is expressed by

$$Y_c = \frac{1}{2}(Y_1 + Y_2 + 1yr)$$

where Y_c may be called the center year. The x and y values may be expressed as a function of

$$Y_c = Y_1 + 5yrs = Y_2 - 4yrs$$

$$\text{or} \quad Y_1 = Y_c - 5yrs = Y_2 - 9yrs$$

$$\text{or} \quad Y_2 = Y_c + 4yrs = Y_1 + 9yrs$$

Figure 5 shows the results of computations. Three types of years, Y_c, Y_1, and Y_2 are entered in the figure.

The north - south variation is very significant, with the regression function

$$y_f = y_o + b \sin \frac{2\pi(Y_c - 1949)}{P}$$

where y_o is computed to be 36°22′N, b = 96.1 statute miles, and P = 45 years.

The east - west variation is less significant than the north - south. Nevertheless, the best fit regression function was obtained by the Fourier analysis as

$$x_f = x_o + a \sin \frac{2\pi(Y_c - 1964)}{P}$$

where x_o is computed to be 89°48′ W, a = 43.7 statute miles, and P = 45 years.

As shown in Fig. 6, the sinusoidal regression function reduced the total variance significantly. The residual standard deviation turned out to be 26.6 statute miles which correspond to the 28% of the amplitude. The east-west variation resulted in the residual standard deviation of 35.8 statute miles which is 59% of the amplitude of the regression sinusoidal curve (see Fig. 7).

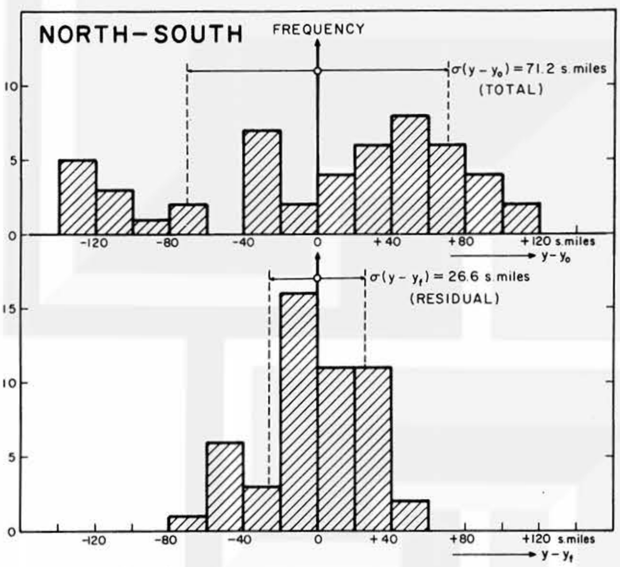

Fig. 6. The total and the residual standard deviation of the north-south variation of the fatality centroid.

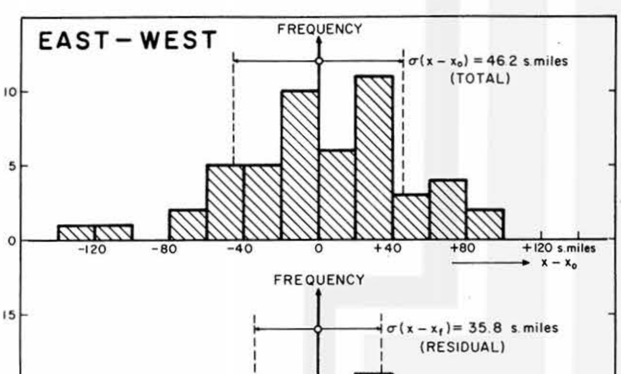

Fig. 7. The total and the residual standard deviation of the east-west variation of the fatality centroid.

Figure 8 shows the number of fatalities, by states, during the latest 45-year period 1930-74. The centroid of tornado fatalities was located in extreme northeast Arkansas.

In an attempt to see if geographic patterns of fatalities fluctuate with the fatality centroids, four bi-state areas were selected around the fatality centroid shown in Fig. 8. The states selected are:

Quadrant	Selected States	1970 Population	Area in sq. mi.	1930-74 Deaths
Northeast	Ind. & Ohio	15.8 millions	77,000	409
Southeast	Ala. & Ga.	8.0	109,000	1091
Southwest	Okla. & Tex.	13.7	331,000	1284
Northwest	Kans. & Nebr.	3.7	158,000	318

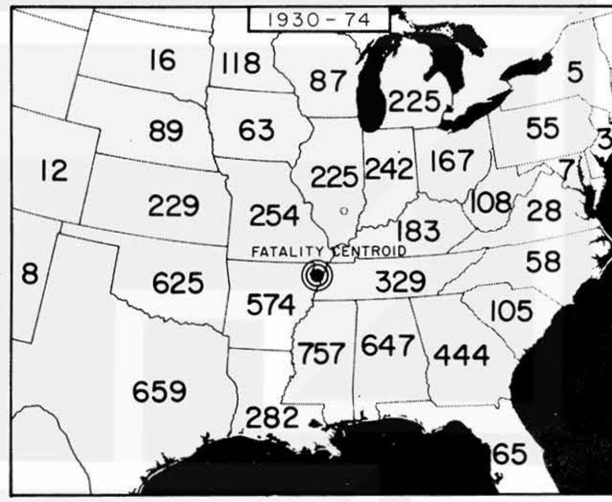

Fig. 8. Tornado-related deaths during the recent 45 years; 1930-74.

The variation of the bi-state population during the last 90 years is shown in Fig. 9. The increase is most pronounced for Oklahoma-Texas and least for Kansas-Nebraska. The population trends suggest that the western states population density was extremely low in the last century so that any of the data from these areas will be questionable. Such is not the case however for Indiana-Ohio or Alabama-Georgia.

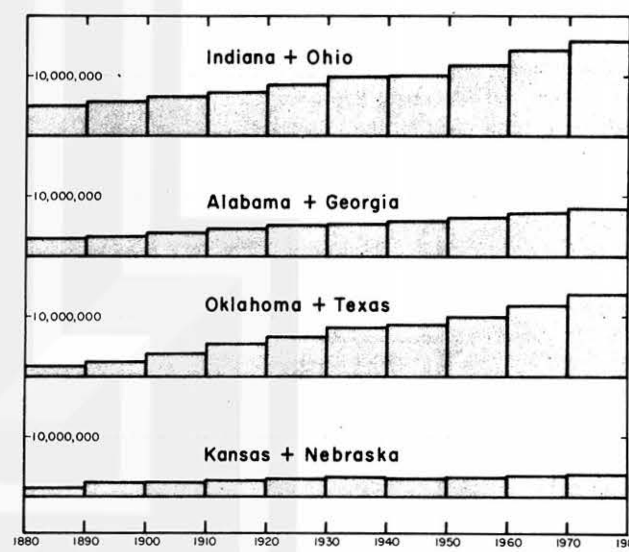

Fig. 9. Increase in the bi-state population during the past 90 years.

To aid in visualizing the information, the tornado fatalities for each state were normalized for the 45-year period, 1930-74, i.e. 150 denotes a 50% increase in fatalities over the long term normal. This method has the advantage of highlighting the positive anomalies. Such values were computed for each state using alternate 7 or 8 year mutually exclusive periods.

The selection of the 7 or 8 year period is based on the two sinusoidal curves in Fig. 5. Within the 45-year period, x_f is positive (or east) half of the time and y_f is positive (or north) half of the time also. A combination of these periods permits us to produce the sub-periods with alternating 7 and 8 years.

Years	1911-18	19-25	26-33	34-40	41-48	49-55	56-63	64-70	71-78
Period	8 yrs	7	8	7	8	7	8	7	8
x_f	W	E	E	E	W	W	W	E	E
y_f	N	N	S	S	S	N	N	N	S

If we use these sub-periods, a 45-year period can be subdivided by three 8-year and three 7-year sub-periods.

Figure 10 shows a plot of the tornado fatality variations for the sub-periods mentioned above. It is of interest to see that peak values are frequently found in bi-states, the quadrants of which are identical to those defined by x_f and y_f for each sub-period.

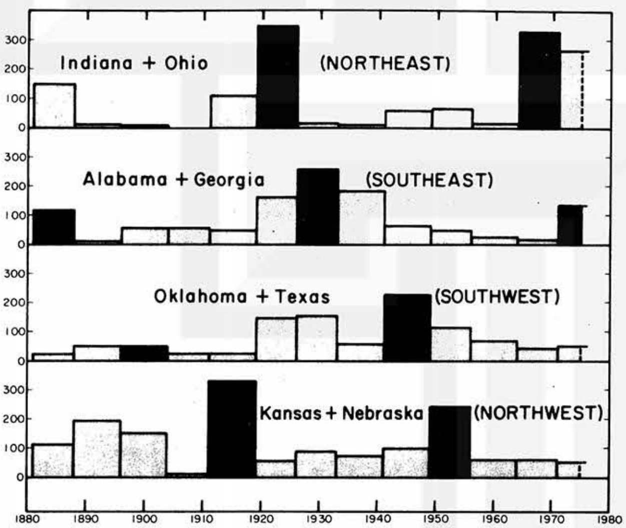

Fig 10. Tornado death anomaly during the past 94 years. The deaths prior to 1915 is not accurate.

By interjecting a few known outbreaks of the last century, notably the great outbreak of February 19, 1884 in the southeastern states, as recently reported by Ludlum (1975), some inferences can be made in support of an apparent systematic fluctuation.

4. MOVEMENT OF MAXIMUM FATALITY AREA

There is a suggestion of a lag correlation in Figs. 5 and 10 and it is worthwhile to see if this can be visualized in maps for the 7 or 8 year sub-periods.

Figure 11 is an analysis of the normalized fatalities for the 1911-18 period, with the plotted value in each state the percentage for the period using the 1930-1974 period as normal, i.e. 100%. The deviation from normal was contoured with isopleths of 118%, 236% and 59% which correspond respectively to the areal mean value, twice the mean and one-half the mean. The location of the maximum is indicated by a plus sign.

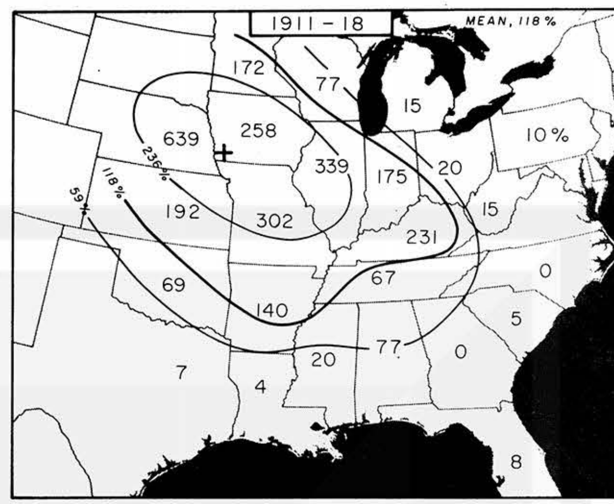

Fig. 11. Distribution of fatality anomaly in per cent, using the 1930 - 74 period for each state as normal.

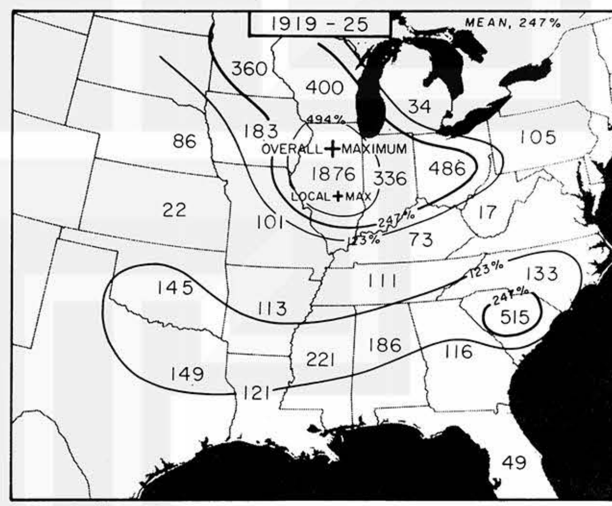

Fig. 12. Fatality anomaly during 1919 - 25.

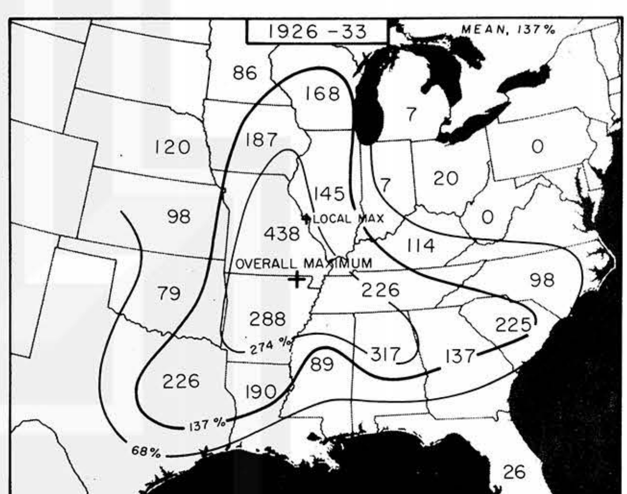

Fig. 13. Fatality anomaly during 1926 - 33.

During the 1919-25 period shown in Fig. 12, a local maximum is seen in southern Illinois almost solely due to the Tri-state tornado. Three adjoining states, Ohio, Wisconsin and Minnesota also showed very significant increases. The fatality anomaly for the next sub-period, 1926-33 was high near the center of the map (see Fig. 13).

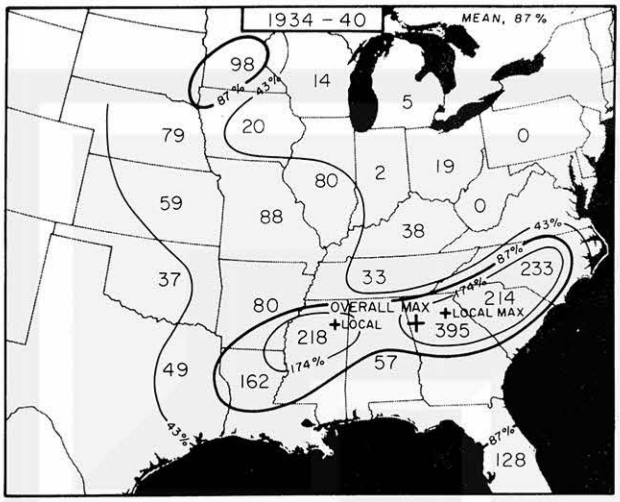

Fig. 14. Fatality anomaly during 1934 - 40.

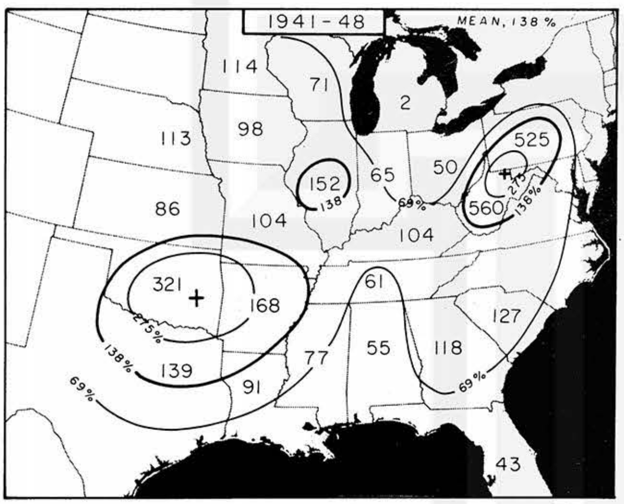

Fig. 15. Fatality anomaly during 1941 - 48.

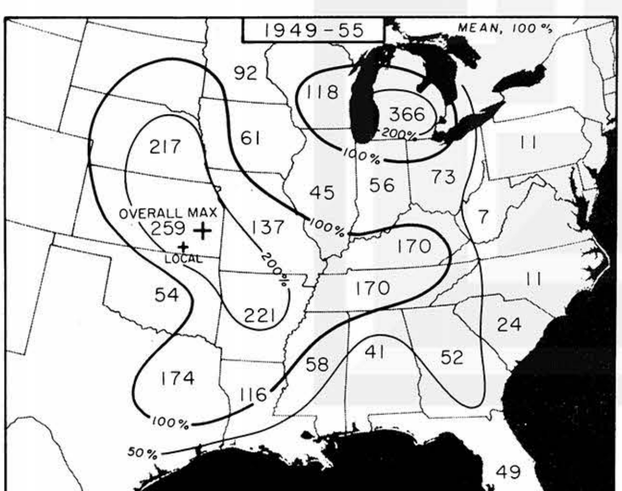

Fig. 16. Fatality anomaly during 1949 - 55.

The dust storms occurred during the second half of the 1930's. During the 1934-40 period, the tornado fatality maxima shifted towards the southern states extending from Louisiana to North Carolina (see Fig. 14).

With the exception of a significant peak in Pennsylvania and extreme northern West Virginia, Oklahoma had the highest anomaly for the 1941-48 period. The mean anomaly for the eight year period rose 51% over the previous period (see Fig. 15).

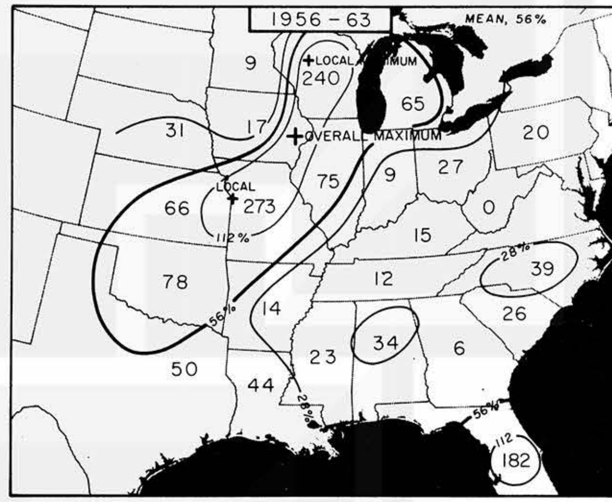

Fig. 17. Fatality anomaly during 1956 - 63.

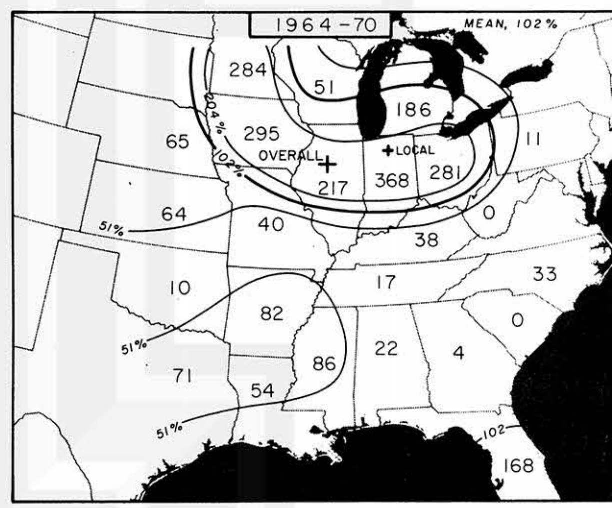

Fig. 18. Fatality anomaly during 1964 - 70.

During the 1949-55 period, the fatality anomaly was very high within a band extending from Nebraska-Kansas to Arkansas (see Fig. 16). The maximum shifted to the Wisconsin-Missouri zone in the 1956-63 period (see Fig. 17). A significant band of positive anomalies extends from Minnesota to Ohio for the 1964-70 period (see Fig. 18).

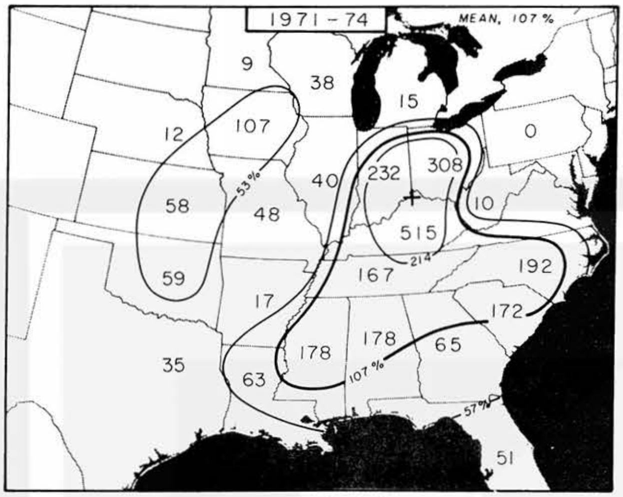

Fig. 19. Fatality anomaly during 1971 - 74.

Then, in the latest 4-year period, 1971-74, the highest death anomaly spreads over a large area to the east of the Mississippi River (see Fig. 19). During this period the total number of deaths in these eastern states was 522. About 60% of the deaths occurred during the April 3-4 superoutbreak. Since the 8-year sub-period, beginning in 1971 and ending in 1978, has four more years to go, more data will have to be added before concluding the fatality anomaly pattern for this period.

5. CONCLUSION

The variations of the tornado fatality anomalies appears to move in a systematic manner although there is insufficient data for the 19th century to confirm or deny its existence. No attempt has been made to give a physical reason for the fluctuation (see Fig. 20). It is believed that a concentrated effort in data gathering will permit future studies which could lead to a definitive answer.

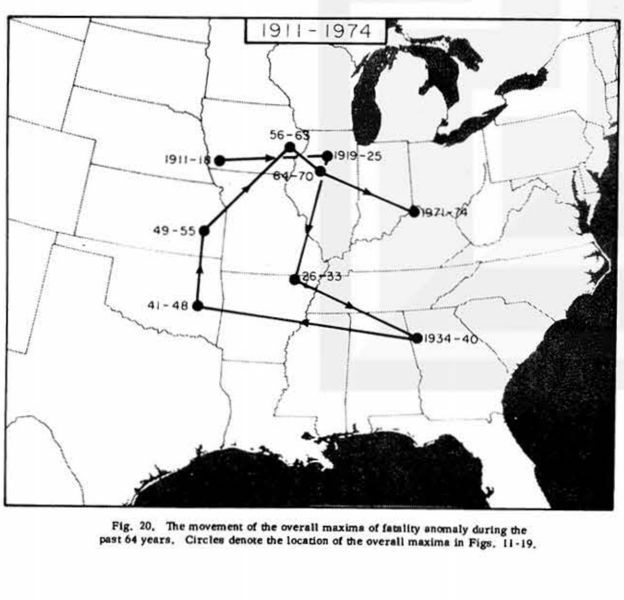

Fig. 20. The movement of the overall maxima of fatality anomaly during the past 64 years. Circles denote the location of the overall maxima in Figs. 11-19.

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