Some Climatological Aspects of Tornado Outbreaks

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(Manuscript received 19 October 1976, in revised form 3 January 1977)

ABSTRACT

Outbreaks involving ten or more tornadoes during the period 1870–1975 have been investigated in order to ascertain their climatological aspects. The data have been divided into eras before and after establishment of organized tornado spotter networks. This study indicates that three distinct types of outbreaks (local, progressive and line) occur.

1. Introduction

In a previous paper (Galway, 1975) it was noted that the majority of the tornado deaths which occur in severe weather watch areas are caused by outbreaks of six or more tornadoes. Since a comprehensive study of tornado outbreaks is not available, it seems appropriate to undertake an investigation of the climatology and meteorology of tornado outbreaks.

The present investigation is restricted to climatological aspects of outbreaks of ten or more tornadoes because Galway (1975) found that these outbreaks accounted for 73% of the tornado deaths during the period 1952–73. Since the number of tornado reports increased dramatically after 1950, the investigation is broken into two time periods, 1870–1949 and 1950–75. The increase after 1950 is probably the result of the inception of tornado spotter networks established by the National Weather Service (NWS) in cooperation with Civil Defense agencies, law enforcement agencies and interested citizens producing a large number of observers keyed to this one type of meteorological event. The establishment of these networks was a direct result of the watch and warning program of the NWS and routine tornado forecasting by the U. S. Air Force's Air Weather Service (AWS).

2. History and definitions

A tornado "outbreak" can mean many things to many people. In the state of Washington, where tornadoes are considered a rare event, residents regard the four tornadoes and six deaths on 5 April 1972 as an outbreak. Nor can the six tornadoes in Arizona on 21 June 1972, which matched a previous yearly high total, be left unmentioned as an outbreak for that state. However, the area of concern in this study is generally east of the Rocky Mountains, where tornado incidence is the greatest.

There is no established definition for a tornado outbreak. (Webster defines outbreak as "a sudden or violent manifestation of harmful activity.") Many terms, such as swarms, groups, series and families of tornadoes have appeared in literature, especially in connection with specific cases. When the Severe Local Storms Forecast Unit (SELS) of the National Severe Storms Forecast Center (NSSFC) and the Military Weather Warning Center (MWWC) of AWS were colocated in Kansas City, Mo. (1956–70), an in-house agreement was made to define the occurrence of five or more tornadoes during the life cycle of a given weather system as a "tornado outbreak." Pautz (1969) refined the concept of a tornado outbreak by introducing three outbreak categories: small (6–10 tornadoes), moderate (11–20 tornadoes) and large (>20 tornadoes). Galway (1975) defined outbreaks in nearly the same fashion as Pautz.

Historically, the first comprehensive listing of outbreaks appears in Flora (1953) covering the period 1880–1952. Wolford (1960) lists notable outbreaks between the years 1916 and 1958. However, both lists concentrate on outbreaks that resulted in a large number of deaths and/or extensive damage. The number of tornadoes constituting an outbreak in these lists ranges from 3 to 72.

A preliminary look at the data suggests that previous outbreak definitions (i.e., classification only by the number of tornadoes) are inadequate. Some outbreaks are found to be local in nature and occur in a relatively small portion of a state or portions of adjoining states. Others occur over a distance of several hundreds of miles in a general west-to-east direction. A third type of outbreak forms on a north-south axis with limited eastward progression. Further, it is observed that two or more tornadic periods can occur in succession, with time spans of over 6 h between the last reported tornado of one period and the first tornado of the next.

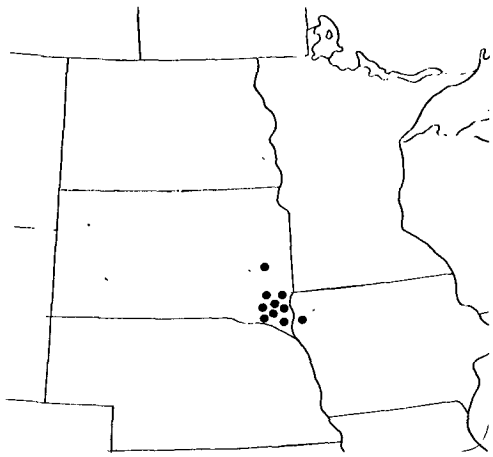

FIG. 1. Local outbreak of 7 June 1965.

While, for specific cases, it may be argued that tornado activity continued during such a quiet period, but was not observed (or if observed, was not reported), this possible bias should be reduced by considering a large number of cases. When the atmospheric conditions which produce the tornado outbreaks are considered, it is often found that the initiating weather systems are transitory and that several such systems passed through an area of severe storm potential. It is also possible that, as a result of the activity, conditions are stabilized, causing a temporary decline in the intensity of the activity. Both effects can produce periods of relative quiet. Because of this, the spatial and temporal spacing of the tornado occurrences must be considered in the definition of an outbreak.

As an example, Wolford listed a tornado outbreak for 25–27 May 1955, which spans almost three days with 72 tornadoes. Investigation of this particular case reveals periods of up to 18 h in which no tornadoes were reported. Tornado activity first began in the western portions of Texas and Oklahoma on the afternoon of 25 May 1955 and moved northeastward into Kansas and Missouri during the evening of the 25th and the morning of the 26th, ending in northeast Illinois the afternoon of the 26th. Soon after the time of the last reported tornado in Illinois on the 26th, new activity formed on a north–south axis from eastern Nebraska through eastern Kansas and western Missouri into northern Arkansas. This activity was short-lived, with the last reported tornado occurring about 2000 LST. Then on 27 May 1955 the first tornado occurred in western Kansas about 1500 LST. This activity spread across Kansas and north central Oklahoma during that afternoon and evening. Thus, in the present study, three separate outbreaks, rather than a single 3-day outbreak, are listed for 25–27 May. Table 1 shows that the majority of the 276 outbreaks presented (249 or 90%) occurred in a time span of 2–13 h. The average life span of an outbreak is slightly under 9 h.

The three general types of outbreaks are defined as follows:

LOCAL—An outbreak in which activity is confined to a roughly circular envelope of $\sim 1.0 \times 10^4$ n mi^2, with a duration rarely exceeding 7 h. The 34 cases classed as local averaged $5\frac{1}{2}$ h. Fig. 1 is an example of a local outbreak.

PROGRESSIVE—An outbreak that progresses (advances) generally from west to east with time. The distance between the first and last tornado report is normally greater than 350 n mi. The 152 progressive outbreaks averaged 394 n mi in length, with the mean envelope of activity encompassing about 5.4×10^4 n mi^2 and lasts an average of $9\frac{1}{2}$ h. Fig. 2 is an example of a progressive outbreak.

LINE— An outbreak with limited eastward progression that forms on an axis, generally oriented north–south. The tornadoes tend to occur at widely separated locations along the line at approximately the same time. The aver-

TABLE 1. Cumulative percentage of outbreaks with respect to duration.

Number of outbreaks	Percentage of total	Duration (h)
169	61	5–10
208	75	4–11
221	80	2–11
236	86	4–14
249	90	2–13

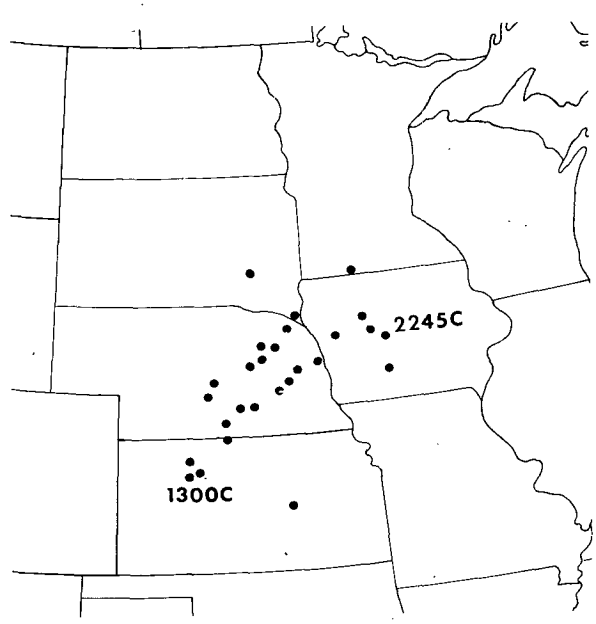

FIG. 2. Progressive outbreak of 7 June 1953.

age line outbreak has a duration of about 8 h, and covers $\sim 5.9 \times 10^4$ n mi^2. Fig. 3 is an example of a line outbreak.

To some extent combinations of progressive and line outbreaks occur, but generally the characteristics of one or the other dominate during the life cycle of the outbreak. For example, some progressive outbreaks have a tendency to fan out so that the last few reports take on a north-south orientation. Also, during some line outbreaks, a portion of the north-south line of activity advances eastward similar to a progressive outbreak. About 16% of the line and progressive outbreaks have this ambiguity. However, for simplicity, outbreaks were placed in the category that predominated.

Many tornado situations involving ten or more tornadoes were not considered outbreaks because areal or temporal criteria were not met. Fig. 4 is an example of what is not considered an outbreak. The distribution and times of occurrence preclude the possibility that the same weather system was the cause of all reports.

3. Data acquisition and limitations

The data bank at NSSFC includes a listing of all reported tornadoes for the period 1950–75. Computer processing was performed to obtain the outbreak cases which occurred in this period. The data for the 1870–1949 period required manual processing with the primary sources of information consisting of the MONTHLY WEATHER REVIEW (MWR), 1870–1949; Report of the Chief Signal Officer (RCSO), 1871–90; Report of the Chief of the Weather Bureau (RCWB), 1891–97 and 1916–34; and *U. S. Meteorological Yearbook* (USMY), 1935–49. Finley (1884, 1885, 1887) provides additional data not contained in the preceding sources. Lists of tornadoes for individual states have been compiled by various authors, e.g., Flora (1915, 1928), Stevens (1925), Giles (1927), Cole (1927), Asp (1962), Darkow (1966), Burley and Waite (1964), Wilson and Changnon (1971), Purvis (1967), Spohn and Waite (1962), and Vaiksnoras (1971). Since these were compiled from the primary data sources, they have been utilized to verify the accuracy of the data extraction.

Finley attempted a systematic collection of tornado reports during the 1880's, having at one time over 2400 "tornado observers" across the country sending in reports and newspaper clippings (RCSO, 1889). Finley's activity in this area never reached its potential since he was assigned other duties after 1885. A listing of tornadoes for the years 1889–96 by Henry (1896) is the only other effort of this sort prior to 1916.

There is a virtual void in tornado reporting for the period 1897–1907. An occasional note on an individual tornado occurrence appears in the MWR, but no outbreaks of ten or more tornadoes were reported during this period. Flora (1915) lists no tornado activity in Kansas between 1897–1913, while Spohn and Waite

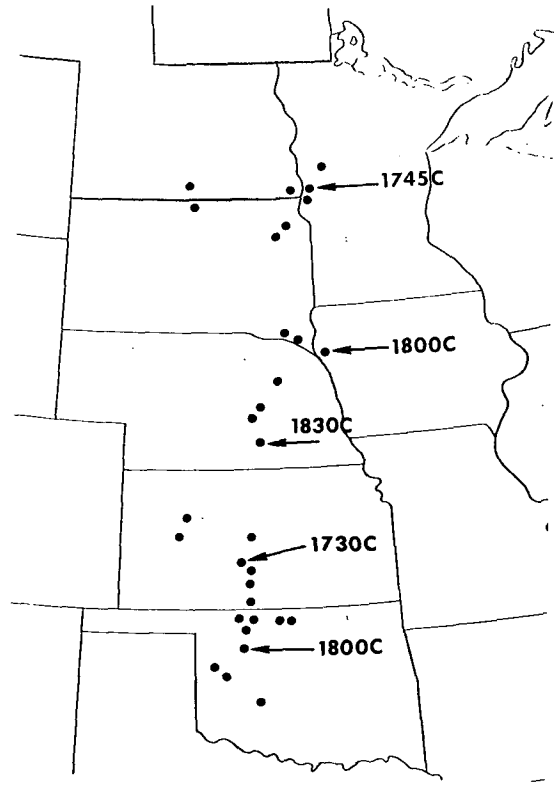

FIG. 3. Line outbreak of 5 May 1964.

record only one tornado in Iowa for the years 1901–06. This is puzzling since in 1897 Moore, then Chief of the Weather Bureau, wrote of "the great importance of an accurate record of the occurrence of tornadoes" and ordered the collection of reliable statistics on their occurrence. More frequent reporting of tornadoes reappears in the literature beginning in 1907, and seven outbreaks were obtained for the period 1907–15. Annual tabulation of tornadoes began in 1916.

While reports and accounts of tornadoes increase after 1907, those before 1950 lack quality and completeness. One account of a long-track tornado notes that it entered the southwest corner of Tennessee and exited through the north central portion 30 min later, a distance of ~ 150 n mi. The same report implies that the tornado passed simultaneously through or near two towns with an east-west lateral separation of almost 60 n mi. Loveland (1913), writing on the Iowa–Nebraska tornadoes of 23 March 1913, relates that there were well-defined tornadoes in Nebraska with the usual characteristics but quotes the Iowa Section Director as saying that "most of the manifestations on this side of the river (Iowa) indicated, over the large part of these courses, only straight line winds." Of the 181 deaths with these tornadoes, 33 occurred in Iowa. Late in the evening of the 23rd and early on the 24th, four deaths occurred in eastern Iowa and northern Illinois

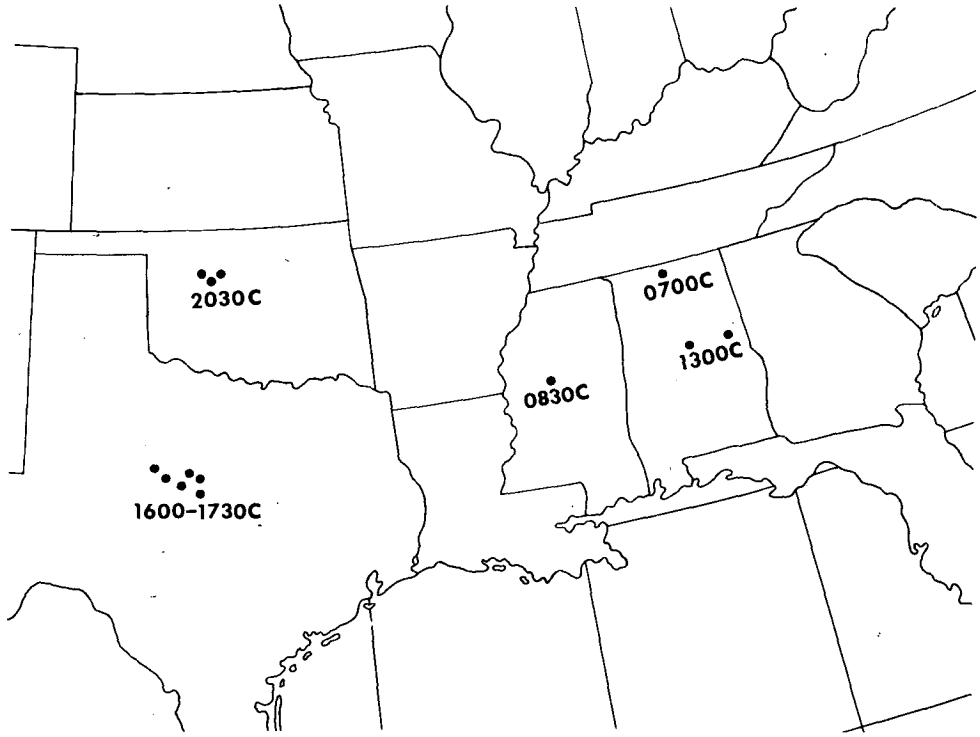

FIG. 4. Tornadoes of 26 May 1970—not an outbreak.

in storms spawned by the same weather system. The deaths and a report of "twisted" damage were said to be caused by "severe windstorms." Often accounts give a detailed description of a particular tornado track and damage, and then conclude with "Other tornadoes were also reported during the afternoon and early evening."

Also, there are biases in early tornado investigations. Loomis (1842) states that the months of May and June have the highest tornado frequency, while Finley (1890) concludes that April and May are the months with the highest frequency. Hazen (1890) states that tornadoes rarely occur other than during the warmer months of the year. This concentration on the warmer months led to the belief that late fall and winter periods are virtually free of widespread tornado activity. Thus, tornado reports during that portion of the year were often discounted except for an occasional unusually destructive occurrence.

A comment on the unreliability of the death figures for the period prior to 1916 is also in order. No consistent or continuous record of tornadoes or tornado deaths was established before 1916. MWR accounts of tornadoes through the 1870's and 1880's repeatedly use phrases such as "many killed," "several casualties," "a great loss of life" and the like, but no final total is given. This trend continued through 1909, as is seen in an account (Bate, 1909) of a rash of tornadoes in Tennessee which reports 60 deaths but states that the "list is not complete."

While population distribution and an unorganized tornado reporting system can account for the major difference in the number of outbreaks between the two periods considered in this study, there is another factor. Deaths were reported with 62 (92.5%) of the 67 outbreaks listed for 1870–1949, while there were deaths with only 90 (43.1%) of the 209 outbreaks listed for the 1950–75 period. It is likely that, prior to the early 1950's, there was a bias for collecting and recording statistics on tornado outbreaks which resulted in deaths. This is quite evident when it is realized that the population of the United States has grown by a large factor since 1870 but the death rate from tornadoes has not increased by the same factor. The normalized death rate (deaths per unit average population density during the period, per reported tornado, per year) for the contiguous United States was 1.1×10^{-3} during the period 1916–49, and 1.2×10^{-4} during 1950–75. Thus, there was a reduction in the normalized death rate by a factor of 10, despite the nearly four-fold increase in the number of reported tornadoes. However, if the normalized death rate is computed considering only tornadoes that caused deaths, the results are 4.7×10^{-3} during the period 1916–49 and 3.2×10^{-3} for 1950–75, a reduction of about 30%. Part of this reduction may be a reflection of the effectiveness of the watch and warning

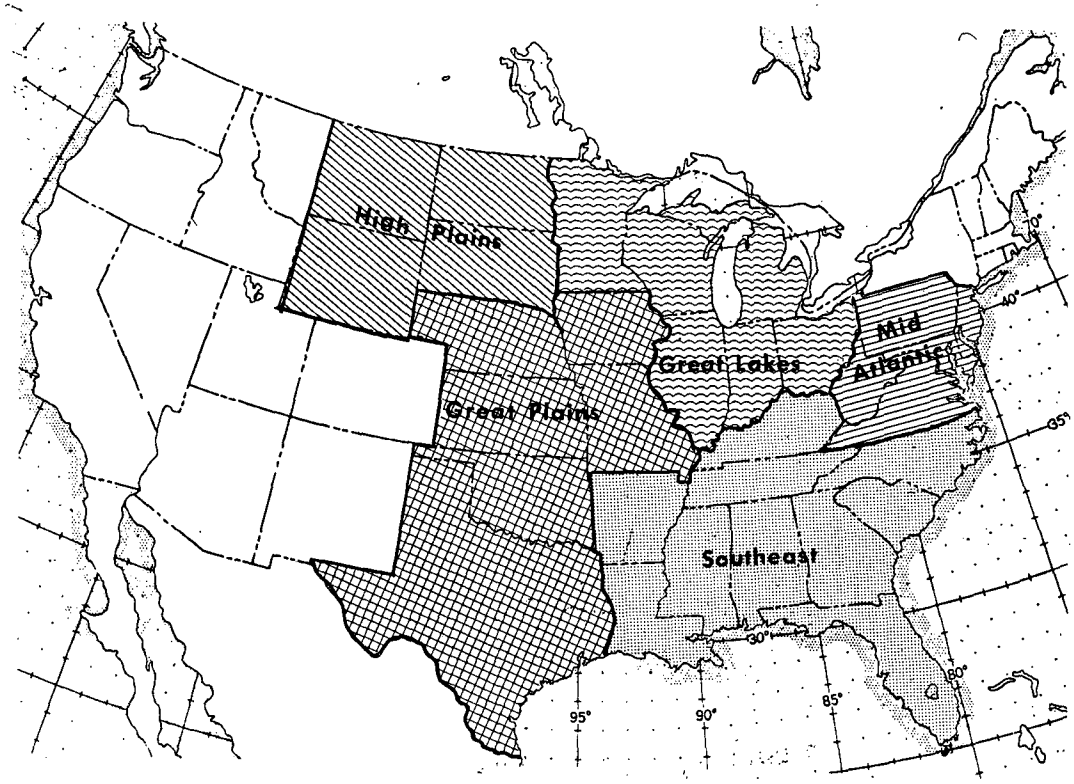

FIG. 5. Selected geographical regions.

program of the National Weather Service since the number of killer tornadoes also decreased by about 30% (from about 34 per year in the early period to about 24 per year in the recent period).

4. Data presentation

The data have been stratified by the number of outbreaks, geographical regions involved, type of outbreaks, number of tornadoes in the outbreak by categories, deaths in the outbreaks and length in hours of the outbreaks. As weather defies geographical boundaries, such boundaries must be chosen somewhat arbitrarily. Fig. 5 depicts the geographical regions defined for this study. If tornadoes occur in more than one region, the region with the greatest number of tornadoes is selected as the region of outbreak.

TABLE 2. Percent of total outbreaks for each decade by region and type with associated deaths.

		Region					Type			
Period	Number of outbreaks	Great Plains	South-east	Great Lakes	High Plains	Mid Atlantic	Local	Progres-sive	Line	Number of deaths
1870–79	2	50	50	0	0	0	0	100	0	123
1880–89	12	25	25	42	0	8	17	33	50	505
1890–99	6	50	33	17	0	0	0	50	50	499
1900–09	3	0	100	0	0	0	33	33	33	441
1910–19	10	60	40	0	0	0	20	50	30	481
1920–29	13	39	54	7	0	0	8	46	46	836
1930–39	12	67	33	0	0	0	8	58	33	997
1940–49	9	67	33	0	0	0	11	56	33	416
1870–1949	67	48	40	10	0	2	12	49	39	4298
1950–59	59	63	22	15	0	0	12	61	27	657
1960–69	80	64	18	11	7	0	14	50	36	563
1970–75	70	50	31	13	6	0	11	61	27	559
1950–1975	209	59	23	13	5	0	13	57	30	1779
Total	276	56	28	12	4	*	12	55	33	6077

* Less than 1%.

TABLE 3. Percent of total outbreaks for each month by region and type with associated deaths.

Period	Number of outbreaks	Region					Type			Number of deaths
		Great Plains	South-east	Great Lakes	High Plains	Mid Atlantic	Local	Progres-sive	Line	
1870–1949										
January	0	0	0	0	0	0	0	0	0	0
February	3	0	67	33	0	0	0	100	0	203
March	19	32	58	10	0	0	11	47	42	1212
April	18	50	50	0	0	0	11	67	22	1632
May	15	73	20	7	0	0	20	47	33	895
June	5	60	20	20	0	0	0	40	60	139
July	0	0	0	0	0	0	0	0	0	0
August	1	0	0	0	0	100	100	0	0	6
September	3	67	0	33	0	0	0	0	100	86
October	1	100	0	0	0	0	0	0	100	4
November	2	0	50	50	0	0	0	0	100	121
December	0	0	0	0	0	0	0	0	0	0
Yearly total	67	48	40	10	0	2	12	49	39	4298
1950–75										
January	7	29	71	0	0	0	0	71	29	38
February	8	0	75	25	0	0	0	88	12	201
March	21	52	38	10	0	0	14	67	19	245
April	46	59	26	15	0	0	11	52	37	793
May	59	86	9	3	2	0	14	49	37	379
June	33	58	3	18	21	0	15	49	36	42
July	5	40	0	20	40	0	0	80	20	0
August	3	0	0	100	0	0	67	0	33	15
September	3	67	0	33	0	0	0	100	0	4
October	6	67	33	0	0	0	17	66	17	9
November	11	36	46	18	0	0	0	82	18	32
December	7	14	72	14	0	0	29	57	14	21
Yearly total	209	59	23	13	5	0	12	57	31	1779
1870–1975	276	56	28	12	4	*	12	55	33	6077

* Less than 1%.

Table 2 shows the distribution of the 276 outbreaks with respect to region and type, for each decade from 1870. The effect of tornado reporting networks is obvious in that 209 of the 276 outbreaks (76%) are in the 1950–75 period. It comes as no surprise that the Great Plains has reported the majority of outbreaks after 1950. The nearly equal number of outbreaks in the Great Plains and Southeast for the period 1870–1949 probably can be attributed to changes in population distribution.

The monthly distribution of the data with respect to region and type is given in Table 3. Note that the month of maximum outbreaks shifts from the March–May period during 1870–1949 to April–June in 1950–75. However, the March–May quarter accounts for the greatest death toll of both periods, 87% and 80%, respectively. Note also the existence of a secondary maximum of Great Plains outbreaks in the fall.

TABLE 4. Total deaths and total tornadoes with percent of outbreak deaths and tornadoes.

Period	Total deaths	Percent of total in outbreaks	Total tornadoes	Percent of total in outbreaks
1916–19	1043	38.8	356	32.6
1920–29	3169	26.4	1325	14.9
1930–39	1944	51.3	1685	13.8
1940–49	1786	23.3	1554	11.1
1916–49	7942	33.4	4920	14.6
1950–59	1409	46.7	4793	22.5
1960–69	934	60.3	6823	19.6
1970–75	763	76.3	5249	24.8
1950–75	3106	57.3	16865	22.0
1916–1975	11048	40.1	21785	20.3

Table 4 presents the percent of total deaths and tornadoes in outbreaks since 1916 when the Weather Service began a continuous listing of tornadoes and tornado-related deaths. The number of outbreaks for 1920–75 may be obtained from Table 2. There were six outbreaks from 1916–19. The most significant feature of Table 4 is the fact that 33.4% of the total deaths occurred with outbreaks of ten or more tornadoes during the 1916–49 period, while the years 1950–75 showed a dramatic rise to 57.3% of the total. These data support the contention that before 1950 there was a bias toward collecting and recording statistics on tornadoes which resulted in deaths, with non-killer tornadoes often remaining unreported. As further evidence for this notion, Table 5 lists five outbreaks

with less than ten tornadoes which occurred prior to 1950. The 1461 deaths of these five cases approach the total death toll of 1779 in the 209 outbreaks during the 1950–75 period.

The percent of the total number of tornadoes in outbreaks of 10 up to greater than 50 by decade is given in Table 6. Again, the result of the present-day reporting system is evident as indicated by the marked increase in each of the groups during the 1950–75 period. The group 10–19 is more prevalent, occurring 72% of the time and accounting for 52% (3181) of the outbreak associated fatalities.

5. Concluding remarks

The establishment of tornado spotter networks has shown that the tornado is not the rare event it was considered to be 75–100 years ago. These networks have also provided data for the climatological and meteorological study of tornado outbreaks which were not available prior to 1950. The data indicate that three distinct types of outbreaks occur—local, progressive and line. A statistical climatology of these types of outbreaks has been presented. The next step in our investigation of tornado outbreaks will be to examine the meteorological processes which are associated with each of the three types of outbreaks in the hope that unique precursor conditions for each category can be identified.

Acknowledgments. I would like to express my gratitude to the following members of the Techniques Development Unit, NSSFC: Dr. Charles A. Doswell for his most helpful suggestions and reviews during the preparation of this paper, Dr. Joseph T. Schaefer for his interest and encouragement, Donald L. Kelly for his programming assistance, and Deborah A. Barbieri in manuscript preparation. The help of Horace R. Hudson, NSSFC, for additional programming aid and the RADU staff, NSSFC, in data preparation, is gratefully acknowledged. Part of this work was performed under interagency agreement AT 49-25-1004 between the Office of Nuclear Regulatory Research, Nuclear Regulatory Commission, and the National Weather Service, NOAA.

TABLE 5. Five outbreaks with less than ten tornadoes and accompanying deaths.

Date	Number of tornadoes	Number of deaths	Region
18 March 1925	7	740	Missouri, Illinois, Indiana, Kentucky, Tennessee
20 April 1920	6	221	Alabama, Mississippi, Tennessee
23 March 1913	8	181	Nebraska, Iowa
9 April 1947	5	167	Texas, Oklahoma, Kansas
23 June 1944	6	152	West Virginia, Pennsylvania, Maryland
Total		1461	

TABLE 6. Number and frequency (percent) of tornado outbreaks of various sizes.

Period	Size of outbreak* 10–19	20–29	30–39	40–49	>50	Totals
1870–79	1 (50)	1 (50)	0	0	0	2
1880–89	8 (67)	3 (25)	0	0	1 (8)	12
1890–99	6 (100)	0	0	0	0	6
1900–09	3 (100)	0	0	0	0	3
1910–19	6 (60)	3 (30)	1 (10)	0	0	10
1920–29	11 (85)	2 (15)	0	0	0	13
1930–39	8 (66)	2 (17)	2 (17)	0	0	12
1940–49	6 (67)	2 (22)	1 (11)	0	0	9
1870–1949	49 (73)	13 (19)	4 (6)	0	1 (1)	67
1950–59	39 (66)	12 (20)	6 (10)	2 (4)	0	59
1960–69	60 (75)	10 (13)	8 (10)	1 (1)	1 (1)	80
1970–75	51 (73)	12 (17)	4 (6)	2 (3)	1 (1)	70
1950–1975	150 (72)	34 (16)	18 (9)	5 (2)	2 (1)	209
1870–1975	199 (72)	47 (17)	22 (8)	5 (2)	3 (1)	276

* Column headings represent the number of individual tornadoes per outbreak.

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