Climatography of Thunder Events in the Conterminous United States. Part II: Spatial Aspects

STANLEY A. CHANGNON, JR.

University of Rochester, Rochester, New York*

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ABSTRACT

The average temporal and spatial distributions of thunder events (periods of discrete thunder activity heard at a point) in the conterminous United States were found to be generally similar to those of thunder days. Annual averages of thunder events peak along the Gulf Coast (>100) and are also quite high in the central United States (Kansas, Missouri, Illinois with >75 events), and in the southwest (Arizona with 60 events). Thunder events are least along the west coast (<20) and in the northeast (<30). Multiple events per day are greatest in the Midwest (Illinois, Iowa) averaging 1.7 events per summer day, and are also high in the southwest (Arizona) with 1.5 events. This causes these two maxima in thunder event activity to be more pronounced than those found on the pattern of average thunder days.

The average patterns for the thunder event frequencies, multiple events per day, and durations reveal that convective activity is weakest and shortlived along the west coast and in the northeast. The high incidence of events per day in the Midwest reflects multiple storm incidences likely related to MCCs and nocturnal storm activity. The peak in thunder event activity is present in the central United States in all months and rotates from the lower Mississippi Valley to the central Great Plains–Midwest and then back, and its position is always closely related to the major center of cold frontal activity. The thunder peak in the southwest is related to the summer monsoon intrusion of moist tropical Pacific air and related frontal activity. The summer-fall peak in thunder events along the Gulf Coast–Florida is a result of sea breeze induced convergence, localized heating, and occasional tropical disturbances.

1. Introduction

This climatological study of thunder events investigated various spatial and temporal aspects. Changnon (1988, henceforth referred to as Part I) presents temporal results on average thunderstorm (event) durations; day versus night differences in storm durations; 30-year trends in thunder events, and the time relationship of events in July-to-July cyclonic activity for 1948–77.

This paper addresses certain spatial aspects of thunder events. The first section presents the average monthly and annual patterns of thunder events. The second section assesses the average relationships between thunder days and thunder events. Those temporal and spatial results that collectively reflect thunderstorm-producing conditions are also presented. The sources of data on thunder events are described in Part I, and the stations with data are labeled in Fig. 1 of Part I. The limitations of the data and the analytical approaches are also described in Part I.

* Also affiliated with the Illinois State Water Survey.

Corresponding author address: Dr. Stanley A. Changnon, 801 Buckthorn Circle, Mahomet, Illinois 61853.

2. Spatial distribution of thunder events

Key information about the climatology of thunderstorms in the United States relates to their average monthly and annual patterns (Court and Griffith 1981). Figure 1 presents the pattern based on the average annual number of thunder events across the continental United States (Fig. 1 in Part I identifies the stations). Figure 1 shows three maximums: the primary one in the Florida region; a secondary one in the central United States; and a third in Arizona. There is a relatively high incidence of thunder events throughout the southeastern and central United States. Areas of least frequent thunder events are along the west coast, in southern Texas, the northern Great Plains, and in the extreme northeastern United States. Differences in the magnitudes between the high and low averages are about 5:1. The high frequency zone along the Gulf of Mexico has 100 or more events each year, on the average, whereas the lowest area on the west coast averages less than 20 thunder events annually.

Figure 2 presents the average monthly patterns based on the average number of events per month. The winter months, December–February, have comparable patterns with a maximum in the lower Mississippi River Valley of three to four events per month, and with a slight secondary maximum along the west coast (which is the season of greatest thunder activity there).

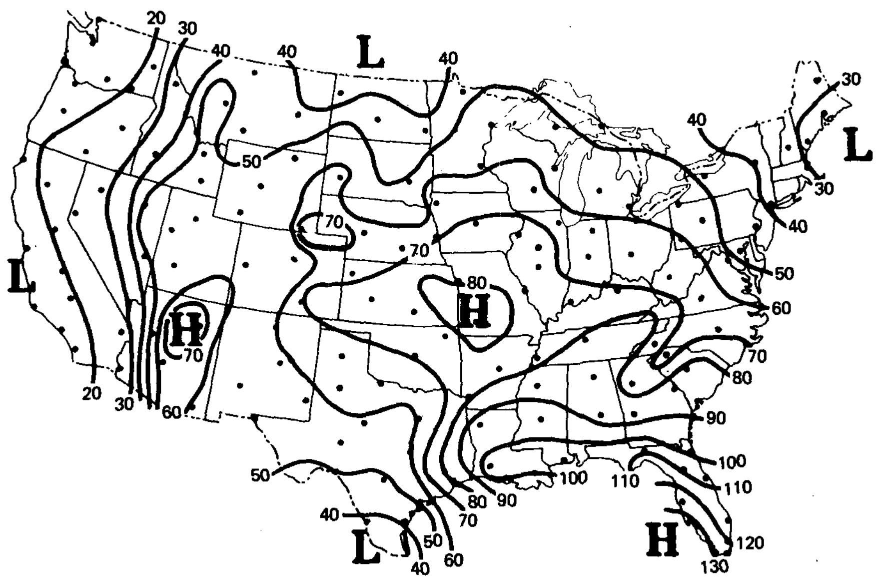


FIG. 1. Average annual number of thunder events.

During the spring months (March–May) several interesting new features are present. In March and April, the patterns are similar with a "bulls eye" shaped maximum in the south central United States (although magnitudes are relatively greater in April than March) with lesser values elsewhere throughout the nation. The pattern for May, however, is quite different. The May pattern shows a high at Cheyenne in eastern Wyoming, which suggests the development of the "lee of the Rockies" influence, but the major maximum is in the central Great Plains. Caution is urged in drawing conclusions about anomalous point (single station) values in areas of complex terrain such as Cheyenne. A high also appears in southern Florida. In all three spring months, the lowest frequencies are on the west coast and in the northeast.

The summer (June–August) months (Fig. 2f–h) have patterns that are similar. June is the peak month of thunder event activity in many areas, whereas July values are greatest in the western mountains and parts of the Great Plains. The summer monthly patterns have two distinct features: a high in eastern Wyoming and extending throughout the Great Plains, and the high in the southeastern United States and centered in southern Florida. Again, all three months exhibit their lowest values in the extreme northeastern United States and along the west coast, with a minor low in south Texas.

The fall season patterns (September–November) reveal a return to winter patterns. September events (Fig. 2i) show three maximums, one in the intermontane region, one in the central section (but now separate from the mountains), and one in the extreme southeast. Patterns continue to shift during October and November with only a central United States maximum in November. Activity increases in southern California in November.

The seasonal development and movement in the frequency of thunder events are displayed in Fig. 3a. This expansion is shown by the average two-event isoline from January through June, when most of the United States is encompassed by two more events. Also shown on Fig. 3a are the centers of the three major maximum areas of activity, and the numbers denote the months of occurrence. The midwinter peak moves from the southern Mississippi Valley to the Great Plains by June. Then this maximum retreats to the central United States during fall. The maximum in southeast Florida appears during the June–October period, and that in Arizona and Utah occurs in July–September. Comparison of the monthly patterns (Fig. 2) plus the centers of maximum activity (Fig. 3a) with the mean monthly cold frontal maxima (Fig. 3b) shows a good relationship. Movement of the frontal frequencies (Morgan et al. 1975) is in close alignment with the movement of the thunder event maxima in the central United States and western mountains. However, the high in the incidence of cold frontal activity along the East Coast in May–September is not associated with a regional peak in thunder events. The retreat of two-event isolines in the fall months is not depicted on Fig. 4a, but the October position closely approximate that in April and the November position of the two-event line is close to that in February.

3. Relationship of thunder events to thunder days

Many climatological studies of thunderstorms in the United States have been concerned with the incidence of "thunder days" (U.S. Weather Bureau 1947; Court

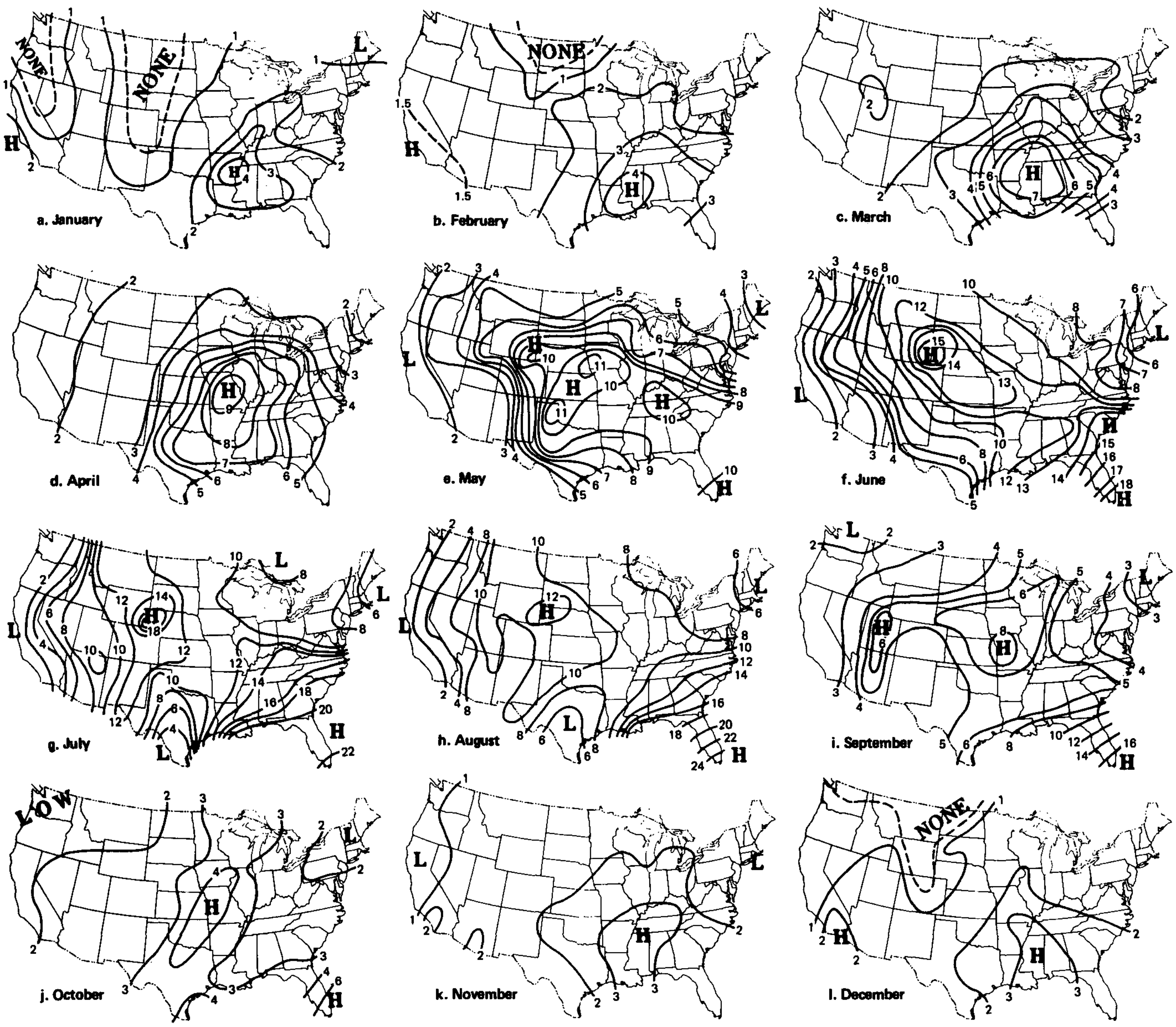
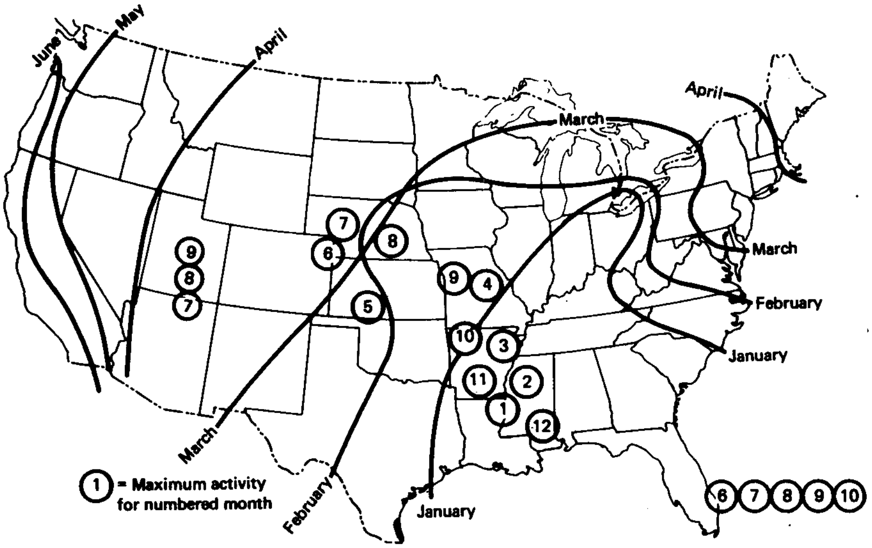


FIG. 2. Monthly average number of thunder events.

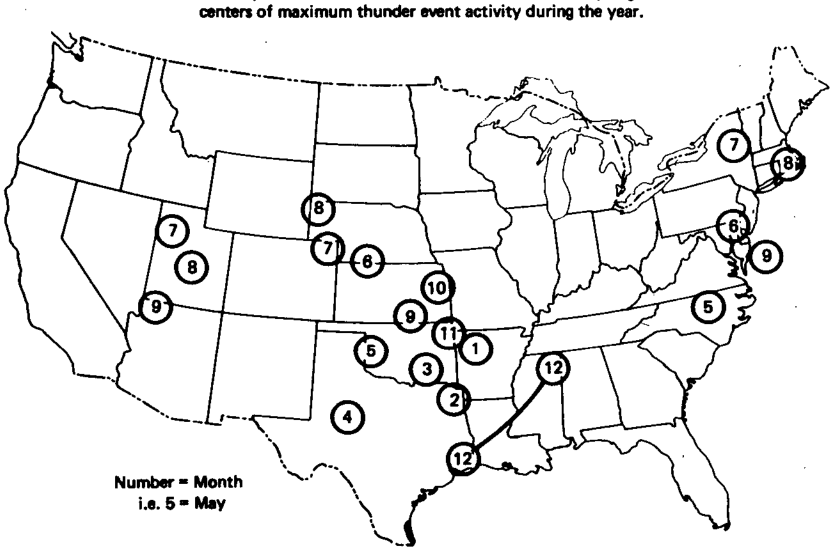
and Griffiths 1981). Each day with thunder is composed of one or more "thunder events," the discrete localized incidences of one or more thunderstorms that create the thunder day. Obviously, the occurrence of thunder events and thunder days is well related. However, key questions include how close is the relationship; how many events tend to occur on a given day with thunder; and are there spatial and temporal differences? The relationship between the average number of thunder days during 1948–77 and the average frequency of thunder events was investigated to help address these questions.

Court and Griffiths (1981) present an average annual pattern of thunder days for 1951–75. It shows a peak of 80 to 90 thunder days in Florida with 70 along the Gulf Coast, and a gradual decrease to lows of less than 10 days along the west coast and to 20 days in Maine. This agrees favorably with the event pattern (Fig. 1). However, the event pattern reveals a localized high in the central United States not present in the thunder day pattern.

Figure 4 presents the ratio between the average annual frequency of thunder events and the average annual frequency of thunder days for the 1948–77 period. The maximum is found in the central United States with ratios of ≥ 1.5. Areas with largest frequency of events, given a thunder day, are on the west and east coasts.



a. Monthly movement of isoline of 2 thunder events in spring and centers of maximum thunder event activity during the year.



b. Centers of maximum monthly frequencies of cold front occurrences (Morgan, et al., 1975).

FIG. 3. Location of centers of maximum thunder activity and centers of cold frontal activity.

In general, the ratio pattern agrees well with the average event frequency pattern (Fig. 1) indicating that the areas of greater frequency of events tend to occur partially as a result of multiple events on a given day with thunderstorm activity. The ratios of 1.1 or less on the East Coast (Fig. 4) indicate that on an average day with thunder, they are almost always produced by a single thunderstorm event, whereas in the central United States (Missouri, Iowa, Indiana, and Illinois), thunderstorm days are much more frequently produced by two (or more) discrete thunder events. Mesoscale convective complexes (MCC) originate along the Rockies and these systems grow into a large group of thunderstorms and showers as they move eastward across the High Plains and Midwest (Maddox 1980). Analysis of 43 such systems in 1979 revealed that 80% reached their "maximum effect" (areal extent) in the area defined by the high (>1.5) ratios (Fig. 4). This indicates that MCCs are likely a prime factor for the multiple events at a point in the central United States. Another interesting result is the wide range of ratios, from less than 1.1 to 1.6, a difference of about 50%.

Monthly event-day ratios were used to identify periods with high and low ratios. The two consecutive months with the highest ratios at each FOS were plotted, and the resulting pattern shows nine pairs (Fig. 5). They reflect seasonal movement in the occurrence of multiple storm events. Beginning in extreme southern Texas, the greatest ratio of frequency of events to days of thunder is in January and February. The areas shift

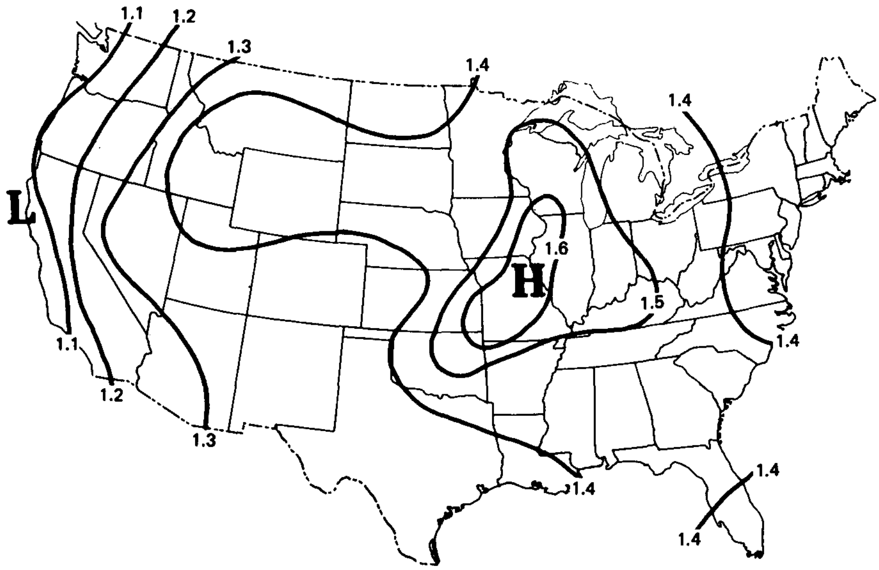


FIG. 4. Ratio pattern based on average annual frequency of thunder events to average frequency of thunder days.

seasonally with a peak of thunder events (given a day of thunder) in March–April in the southern Mississippi Valley and in the southeast. The pattern (Fig. 5) reveals a continuing movement of peak ratios northward in April and May. The movement northward of multiple storm activity along the East Coast in late spring and summer relates well to the centers of cold frontal activity shown in Fig. 3b. The mountainous area of the west finds its two peak monthly ratios in the May–September period; that is, multiple thunder events given a day of thunder are greatest there in the warm season reflecting effects of local heating and frontal activity peaking in Arizona–Utah (Fig. 3b). Ratio values for these two peak months were 1.7 to 1.8 in the Midwest, 1.5 to 1.6 in Arizona, and less elsewhere, 1.3 to 1.4. The peak two months in southern Florida are due to effects of tropical disturbances coupled with sea breeze induced convergence and local heating.

The analysis of monthly event/day ratios also indicated that in addition to a strong warm season peak, there was often an "off season" month/s with a singular but lesser maximum in the cold season. These isolated high ratio months produce the pattern shown in Fig. 6. This reveals that in portions of the central United States, certain winter months (November–January period) achieve anomalously high ratios; that is, there is a relatively large number of events given a day with thunder. This outcome relates to certain extensive cyclonic storm systems that, although infrequent in winter, produce more than one thunderstorm event at a point during a day. Zishka and Smith (1980) present the average pattern of cyclones in January (based on 1950–77 data), and the pattern shows a peak frequency of storms in the area where January thunder events are repetitive (Fig. 6).

4. Thunderstorm conditions

This two-part study produced information relating to the conditions that produce thunderstorms and that are reflected in their areal frequencies, speeds, and sizes of storms. Although temporal and spatial analyses of events have been presented, one must remember that these results are based on "point" measurements of thunderstorm activity.

Two areas of the United States clearly have the least amount of convective activity; the northeast and the west coast. Both areas exhibit fewer thunder events, and when they occur, the shortest durations. Days with thunderstorms in these areas also seldom have more than one discrete event at a point. Weak synoptic forcing is evident.

In other parts of the United States where thunder events are more frequent and/or duration of events is greater, the results reflect various atmospheric influences on thunderstorm activity. Three centers of event activity are notable: one is the southeast, the Gulf Coast and Florida; a second is the central United States (High Plains and Midwest); and third in the southern intermontane area (Arizona, and parts of Utah and Nevada).

In the southeastern United States, and Florida in particular, thunder events (thunderstorms) are quite frequent in summer and early fall (the national maximum). Yet, thunder events in this area typically do not achieve relatively long durations nor are there reactively high frequencies of multiple events per thunder day which is indicative of multiple storm occurrences. This is one of the two major areas of the United States where the daytime events last longer, on the average, than those at night. Clearly, the incidence of storm

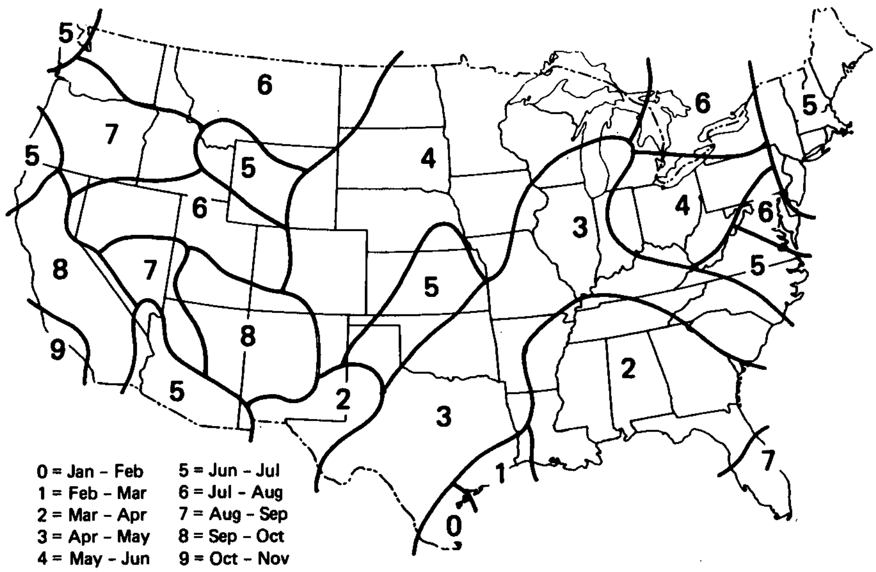


FIG. 5. Regions based on two consecutive months with the highest ratios of thunder events to days.

conditions in this area is often strongly related to daytime convective heating and sea breeze-induced convergence. These conditions cause many days to have thunderstorm events, but the events to not last relatively long at a point nor are there many instances of repeated events at a point (FOS). Regardless, the high incidence of events in the Gulf Coast–Florida lead to point annual averages of more than 10 000 minutes with thunderstorms. Tropical disturbances account for the peak in multiple thunder events (per day) found in Florida during August–September.

In the central United States one finds a May–September maximum in the incidence of thunderstorm events and in their durations. Here, there is also a maximum in the ratio of events to thunder days, but it is displaced eastward (Missouri–Iowa–Illinois) from the duration maximum (Kansas–Oklahoma). Big storm systems and mesoscale convective complexes (Maddox 1980) related to frontal activity are the primary cause of multiple daily events at a point. The total annual duration of thunderstorms from these events results in a point maximum of over 10 000 h with thunderstorm activity at points in the Kansas–Missouri area. Much of the interannual variability in July thunderstorm activity in this area is related to cyclonic activity.

A major maximum of thunder event activity is found

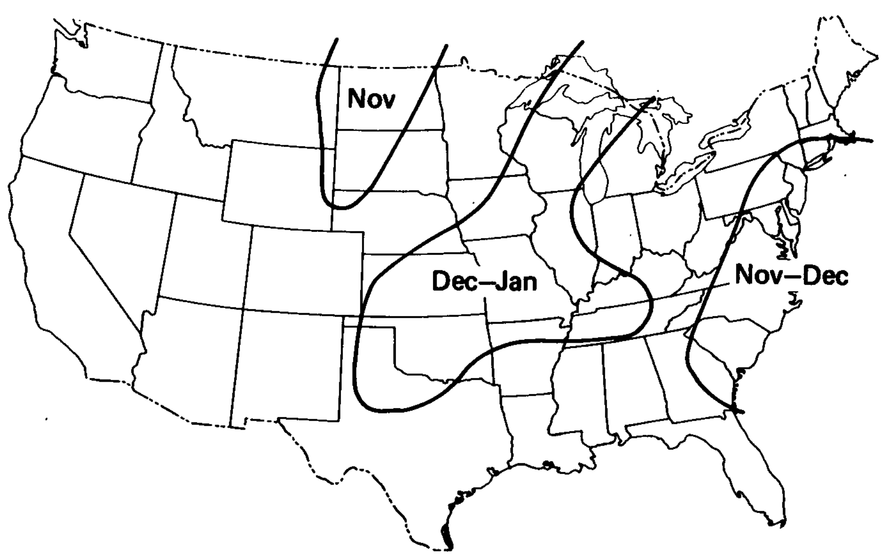


FIG. 6. Areas with singular winter months with high ratios of thunder events to days.

somewhere in the central United States in all months. It has a seasonal rotation, moving from the southern Mississippi Valley in January, north and then westward to Kansas in May, and then retreating southward in fall. This movement relates well to that found in major cold frontal activity and reveals the strong influences of cyclonic activity on thunderstorms in the central United States (Court and Griffiths 1981). Greater instability associated with these frontal systems, coupled with MCCs and nocturnal storm activity in summer (Means 1944), lead to the high number of events in the central United States. Large-scale cyclonic storm activity along the west coast in the winter is the prime factor on the thunder event maximum in that area in winter (Court and Griffiths 1981).

The other area with a high in thunder event activity and durations is found centered in Arizona. This is largely due to the summer "monsoon" conditions in July–September (Bryson and Lowry 1955) brought on by intrusions of moist Pacific air (Hales, 1974). As a result, multiple storm incidences occur in summer.

5. Summary and conclusions

By definition, there is a good relationship between thunder events and thunder days because a thunder day is composed of one or more events. In general, their average patterns are alike, both annually and monthly. However, there are certain dissimilarities worth noting. The incidence of multiple events on a single thunder day peaks along the Texas–Louisiana coast in January–February and spreads north and west from the Gulf Coast during March and April to the intermontane western area in June–August. The months with the highest ratios (relatively more events per day of thunder) vary from 1.1 in the west to 1.7 in the Missouri–Illinois–Wisconsin area. There is also a tendency in parts of the nation for isolated months of high ratios (events to days) during the winter season. These occur in November and/or December along the East Coast (Georgia to New York); and in the central United States during November, December, and January. These apparently relate to extensive areas of thunderstorms in the occasional winter cyclonic storm capable of thunderstorm production.

A major difference between events and thunder days occurs in the central United States. Here thunder days are relatively high, but are not as relatively high as are the thunder event frequencies. This peak in events, which is centered in the Kansas–Missouri–Illinois area, apparently is related to the nocturnal thunderstorm maximum in this area (Means 1944), to a maximization of MCCs, and to a high frequency of squall lines (Porter et al. 1955).

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REFERENCES

Bryson, R. A., and W. Lowry, 1955: Synoptic climatology of the Arizona summer precipitation singularity. *Bull. Amer. Meteor. Soc.*, **36**, 329–339.

Changnon, S. A., 1988: Climatography of thunder events in the conterminous United States. Part I: Temporal aspects. *J. Climate*, **1**, 389–398.

Court, A., and J. F. Griffiths, 1981: Thunderstorm Climatology. *Thunderstorm Morphology and Dynamics*, University of Oklahoma Press, 9–39.

Hales, J. E., 1974: Southwestern United States Summer Monsoon Source—Gulf of Mexico or Pacific Ocean? *J. Appl. Meteor.*, **13**, 331–342.

Maddox, R. A., 1980: Mesoscale Convective Complexes. *Bull. Amer. Meteor. Soc.*, **61**, 1374–1387.

Means, L. L., 1944: The Nocturnal Maximum Occurrence of Thunder Storms in the Midwestern States. Dept. of Meteor., University of Chicago, Misc. Rep. 16, 82 pp.

Morgan, G. M., D. Brunkow and R. C. Beebe, 1975: Climatology of Surface Fronts. Circular 122, Ill. State Water Survey, Urbana, 48 pp.

Porter, J., L. L. Means, J. E. Hoode and W. B. Chappell, 1955: A Synoptic Study on the Formation of Squall Lines in the North Central United States. *Bull. Amer. Meteor. Soc.*, **36**, 390–396.

U.S. Weather Bureau, 1947. Thunderstorm Climatology and Thunderstorm Rainfall. Hydrometeorological Rep. 5, Vicksburg, MS, 147 pp.

Zishka, K. M., and P. J. Smith, 1980: The Climatology of Cyclones and Anticyclones over North America and Surrounding Ocean Environs for January and July, 1950–77. *Mon. Wea. Rev.*, **108**, 387–401.