P1.22 A FIVE-YEAR CLIMATOLOGY OF ELEVATED SEVERE CONVECTIVE STORMS IN THE UNITED STATES EAST OF THE ROCKY MOUNTAINS

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1. INTRODUCTION

Deep convection can be either surface based or elevated. Surface-based deep convection ingests parcels of air from near the surface, whereas elevated convection ingests parcels of air from above a frontal surface or surface-based radiational inversion. The first detailed study of elevated thunderstorms in the United States was Colman's (1990a) climatology. Colman (1990a) found that elevated deep convection typically occurs north of a surface warm front in an environment of strong baroclinicity, large vertical wind shear, and warm-air advection. His climatology also showed that nearly all winter-season storms are elevated, and a smaller proportion of warm-season storms are also elevated.

Sometimes elevated convection produces severe weather in the form of large hail, strong winds, and/or tornadoes (e.g., Johns and Doswell 1992). Grant (1995) conducted a preliminary study on elevated severe convection, examining eleven cases over two years. He found convective instability above the shallow, but strong, inversion in the proximity soundings for each event. Grant (1995) also noted that the majority of events were large hail-producing storms.

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In addition to Colman (1990a) and Grant (1995), several studies have also been performed on specific events of elevated severe convective storms (e.g., Schmidt and Cotton 1989; Bernardet and Cotton 1998; Banacos and Schultz 2005). However, to date, an in-depth study does not exist that examines when, where, and how often these elevated convective events produce severe weather. The purpose of this study is to extend previous investigations by creating a five-year climatology of elevated convection producing severe weather. Several cases from the climatology will also be evaluated to assess whether any guidance about forecasting these types of events exists.

Section 2 details the data and methodology used to obtain the climatology. The results of the five-year climatology are presented in Section 3. Section 4 presents three environments in which elevated severe storm wind-only events can occur. Section 5 discusses several remaining questions about elevated severe-wind events. Section 6 presents the conclusions of this paper.

2. DATA AND METHODOLOGY

Severe weather associated with deep convection is defined by the National Weather Service as hail 0.75 in. (1.9 cm) or greater in diameter, wind gusts of at least 50 kt (26 m s^{-1}), or tornadoes (e.g., Johns and Doswell 1992). Significant severe weather is defined by Hales (1988) as hail 2 in. or greater (5.1 cm) in diameter, wind gusts of at least

65 kt (33 m s^{-1}), or tornadoes with F2 intensity or greater. To assess the environments and conditions that cause elevated convection producing severe weather, a climatology was generated containing possible elevated severe storm events from the front range of the Rockies eastward to the Atlantic coast and to the northern and southern borders of the United States for the calendar years 1983–1987. These calendar years were chosen for the climatology for two main reasons. First, the years were selected to maximize the number of National Meteorological Center [NMC, now known as the National Centers for Environmental Prediction (NCEP)] manually analyzed 3-h surface maps archived on microfilm at the Storm Prediction Center (SPC). The use of these maps avoided the perceived degradation in the quality of the surface analyses in more recent years from the switch to automated isobar analysis (e.g., Bosart 1989). Second, several studies have documented the dramatic increase in severe reports for wind (Weiss et al. 2002), hail (Doswell et al. 2005), and tornadoes (Verbout et al. 2005) over the past 50 years. Therefore, by using severe reports from the 1980s, the inflation in the number of severe reports, many of which are marginal, is less likely.

Identifying elevated severe-weather events consisted of two steps. The first step in constructing the climatology was to examine the daily 1200 UTC surface maps in the weekly National Oceanic and Atmospheric Administration (NOAA) publication *Daily Weather Maps* for any surface boundaries. In this case, a boundary was defined as any analyzed front on the daily 1200 UTC surface map. If a surface boundary was found, the National Climatic Data Center's (NCDC) *Storm Data* was examined to determine whether any severe reports occurred on the cold side of the surface boundary. Of the 1826 days during the five-year period, 1689 (91%) had surface boundaries east of the Rockies. Of these 1689 surface boundaries, 394 (23%) had potential elevated severe storm events associated with them.

The second step was to take the 394 potential elevated severe-storm events and examine them in greater detail. Two more detailed criteria were examined to check if the event was indeed elevated. The first criterion was that the severe reports were at least 1° latitude (111 km) on the cold side of the surface boundary. The criterion was used to ensure that the reports were sufficiently far north of the surface boundary to be elevated. The criterion was examined by using the NMC's 3-h manually analyzed surface maps to determine the location of the boundary at the time the severe reports occurred. The second criterion was to examine proximity soundings for possible lower-tropospheric stable layers. If the report was on the cold side of the boundary and the proximity sounding possessed a low-level stable layer, this case was considered a probable elevated severe event. The event was also given a subjective ranking from 1 to 10 on both the confidence of being elevated and the availability of appropriate proximity soundings. Of the 394 potential elevated severe storm events, 129 (33%) of them were considered elevated severe-storm events in the climatology. Thus, of the 1689 days with surface boundaries, 8% were defined as elevated severe-storm events.

Proximity soundings were then reexamined for each case. The proximity sounding had to be on the cold side of the boundary, no more than 3° latitude (333 km) away from the reports, and within 3 h of the initial report. If the initial report was more than 3 h from sounding times, both of the soundings which surrounded the time of the initial report were examined. Finding representative soundings was most problematic for the 1800 UTC cases in which the 1200 UTC sounding showed a pronounced inversion, but the 0000 UTC sounding showed no inversion. Determining when the convection became surface based for these cases was difficult, so these cases were not given a high confidence level on the subjective ranking.

3. RESULTS

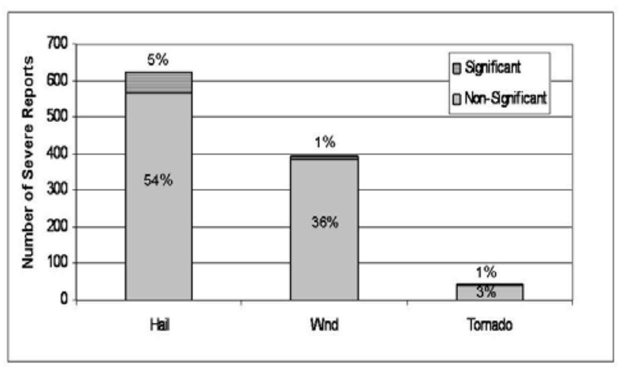

Figure 1: Distribution of severe–storm reports for the 129 elevated severe-storm events in the climatology by type of severe weather. The striped part of each bar indicates significant-severe reports.

This five-year climatology resulted in 129 elevated severe storm events with 1066 severe reports. Each case had an average of 3 severe reports associated with it. Of the 1066 severe reports, 624 (59%) of the severe reports were hail reports; 396 (37%) were wind reports, and 46 (4%) were tornadoes (Fig. 1). Of the 1066 severe reports, 73 (7%) were significant severe reports. Of the 624 hail reports, 58 (9%) were significant severe reports, whereas only 10 (3%) of the 396 wind reports were significant severe reports. Of the 46 tornado reports, 5 (10%) were significant severe reports.

Elevated severe storm events occurred most often across the Great Plains and states just to the east. Nebraska had 19 elevated severe-storm events, five more than any other state. The coastal New England states, Florida, and Illinois all tallied zero elevated severe-storm events. Elevated severe-storm events seemed to possess an annual cycle (Fig. 2). During the winter, the elevated severe-storm events were concentrated along the Gulf coast. In the spring, elevated severe-storm events occurred along the western Gulf coastal states and in the Mississippi valley. During summer, the maximum of elevated severe-storm events occurred in the High Plains. In the fall, a maximum of elevated severe-storm events occurred in September in the High Plains, but elevated severe-storm events were also concentrated near the Gulf Coast in October and November.

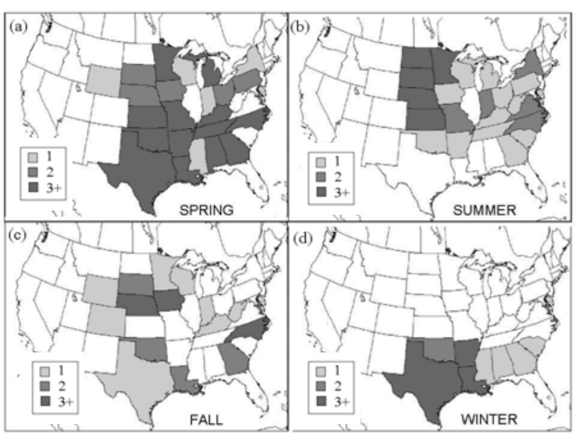

Figure 2: Seasonal distribution of elevated severe-storm events. Shades of gray indicate the number of events in the state during the season. Seasons are defined as: (a) spring (Mar–May), (b) summer (Jun–Aug), (c) fall (Sep–Nov), and (d) winter (Dec–Feb).

The 129 elevated severe-storm events had a springtime maximum in May with a secondary maximum in September (Fig. 3). This distribution looks nearly identical to Colman's (1990a) five-year climatology of elevated thunderstorms. Therefore, elevated severe-storm events may be closely tied to elevated thunderstorms. The wind-only events had a maximum in February with a second maximum in July, whereas the hail events had a similar distribution to the total of all elevated severe storm events with the same May and September maxima respectively (not shown). Twice as many hail-only events existed as compared to wind-only events, which explains the similarity between the total distribution and the distribution of hail-only events.

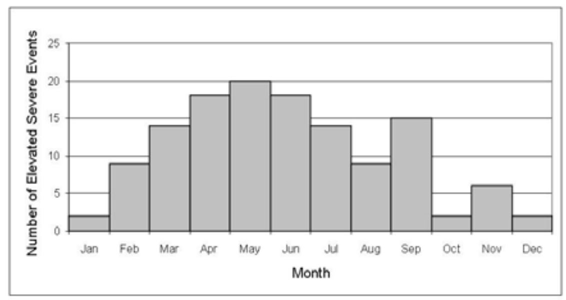

Figure 3: Annual distribution of elevated severe-storm events compiled from the five-year climatology.

Elevated severe-storm events have diurnal, as well as seasonal, variations (Fig. 4). Of the 129 elevated severe-storm events, the 34 (26%) wind/hail events and the 16 (12%) wind/hail/tornado events both had a maximum at 2100 UTC. The 45 (35%) hail-only events also had a maximum at 2100 UTC. The 26 (20%) wind-only events had a maximum around 1600 UTC. The total distribution of initial elevated severe-storm reports had a maximum at 2100 UTC, which coincided with the events with hail reports (hail-only, wind/hail, wind/hail/tornadoes).

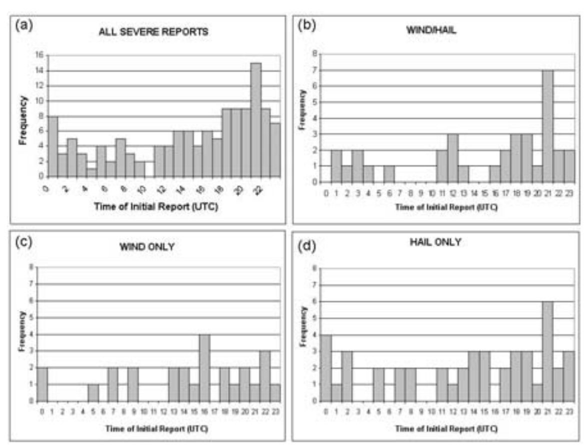

Figure 4: Diurnal cycle of elevated severe-storm reports displayed for (a) all reports, (b) wind and hail both reported, (c) wind only, and (d) hail only.

4. THREE ENVIRONMENTS CONDUCIVE FOR ELEVATED SEVERE STORM WIND-ONLY EVENTS

Elevated severe storms that produce wind-only events occur roughly five times a year and are difficult to forecast. Five events that were rated with high confidence levels (7 or greater) and had wind-only reports associated with them were chosen for further study. These events fall into three categories that we term Type A, B, and C. Type A events are characterized by strongly forced elevated squall lines. Type B events are characterized by elevated isolated cells. Type C events are characterized by elevated northwest-flow events, similar to the northwest-flow events discussed by Johns (1984). Due to our limited five-year dataset, other types of environments conducive to elevated severe-storm wind-only events may exist that are not described by these three types of events.

4.1 Type A

Three of the five events fall into this category. Each event was associated with an elevated squall line. All three Type A events occurred in the winter in the southeast United States in conjunction with low-latitude cyclones and strong upper-level forcing for ascent. Cold-air damming was also present in two of the three cases. All of the events possessed a warm-sector air mass with Most Unstable Convective Available Potential Energy (MUCAPE) values of 1000 J/kg or greater. The warm sector also had dry air at midlevels, a key ingredient for strong winds at the surface. Dry air at midlevels allows for evaporational cooling to occur, which can enhance strong downdraft potential and produce severe winds at the surface.

The first event of these three events occurred on 20 Nov 1986 across northern Georgia (Fig. 5). A strong upper-level trough was centered over the Mississippi valley. At the surface, an east–west-oriented stationary front occurred over southern Alabama and Georgia (Fig. 5a). Cold-air damming occurred east of the Appalachians with temperatures north of the stationary front in the 40s (5–10°C). The 1200 UTC Centreville, Alabama, (CKL) sounding showed a 50–100-hPa-deep inversion, just above the surface. Above this frontal inversion, 500 J/kg of MUCAPE was present with winds from 50 kt or more above 700 hPa. Dry air, a key downdraft ingredient, was also present at midlevels in the CKL sounding. South of the surface stationary front, warm-sector MUCAPE was around 2000 J/kg. Composite manually digitized radar maps (not shown) showed that a squall line formed in the early morning hours. This elevated squall line left 18 severe wind damage reports across northern Georgia (Fig. 5d).

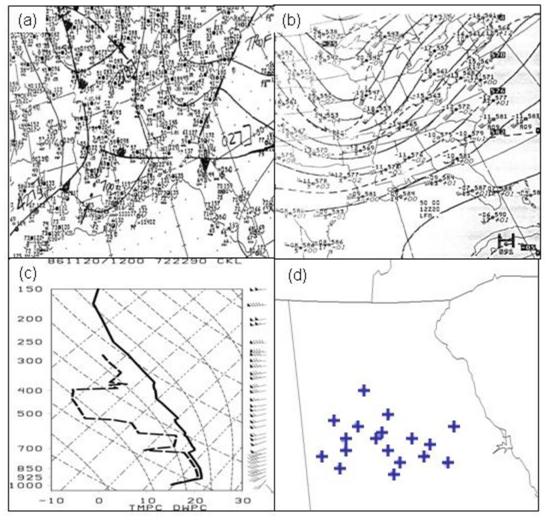

Figure 5: Type A event: 20 Nov 1986: (a) 1200 UTC surface map, (b) 1200 UTC 500-hPa map, (c) 1200 UTC CKL upper-air sounding, and (d) severe-storm reports 1300–1700 UTC.

The second Type A event occurred on 28 Dec 1983 across northern Georgia and northwestern South Carolina (not shown). As in the first event, a strong upper-level trough was centered over the Great Plains. An east–west-oriented surface front also laid across the southeast United States and cold-air damming occurred east of the Appalachians, similar to the 20 Nov 1986 event. Temperatures north of the boundary were around the freezing. South of the front, warm-sector MUCAPE values were about 1000 J/kg with temperatures in the 50s (10–15°C). The Athens, Georgia, (AHN) sounding indicates a very strong, but shallow, inversion about 50–100 hPa above the surface. Winds just above the surface were around 50 kts, but were much closer to the surface than during the 20 Nov 1986 event. Composite manually digitized radar maps (not shown) showed a squall line. This squall line had 24 severe wind damage reports associated with it.

The third Type A event occurred on 1 Feb 1983 in Mississippi (not shown). Like the previous two events, this event was characterized by a strong upper-level trough. An east–west-oriented warm front was in place at the surface with a developing surface cyclone to the west. MUCAPE values south of this warm front were 2500 J/kg or greater with surface temperatures in the 60s (15–20°C). The Jackson, Mississippi, (JAN) sounding possessed a 50–100-hPa-deep frontal inversion with dry air at midlevels. However, this case had the stronger winds much higher than in the previous two events (i.e., 50 kt around 500 hPa). Also, cold-air damming was not present in this case. A squall line was analyzed on radar, with four wind damage reports associated with it.

4.2 Type B

The fourth case occurred on 3 Nov 1983 in Iowa (Fig. 6). The upper-level pattern was similar to that for northwest-flow events defined by Johns (1984, his Fig. 11). The upper-level forcing was weak, especially considering this event occurred in November. An east–west-oriented warm front occurred at the surface. Surface temperatures in Iowa and surrounding locations were in the 60s (15–20°C), which is warm for November in Iowa. The Omaha, Nebraska, (OMA) sounding showed a 50–100-hPa-deep inversion with dry air at midlevels. Above this inversion, there was only 1000 J/kg MUCAPE with convective inhibition (CIN) of roughly 250 J/kg. On the warm side of the boundary, MUCAPE values were 2000 J/kg or greater. This cold-sector environment was capped, unlike the previous Type A cases studied.

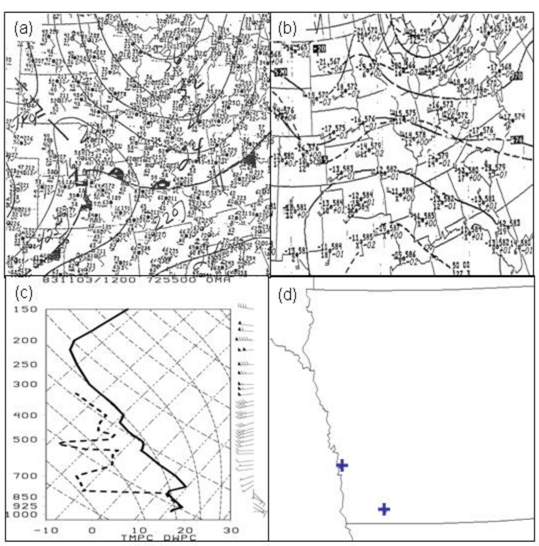

Figure 6: Type B event: 3 Nov 1983: (a) 1200 UTC surface map, (b) 1200 UTC 500-hPa map, (c) 1200 UTC OMA upper-air sounding, and (d) severe-storm reports 1600–1800 UTC.

The question in this case is not how the strong winds reach the surface, but how an elevated supercell could form with such a strong cap in November. We believe the dry air at midlevels to be an important factor in producing the severe winds at the surface for this event because the winds aloft were relatively weak below 500 hPa.

4.3 Type C

This event occurred on 31 July 1986 over Tennessee and was associated with a Mesoscale Convective System (MCS). The upper-level flow was northwesterly (Fig. 7b), which is similar to the 3 Nov 1983 Type B case in Iowa. The upper-level flow was relatively weak with a short-wave trough moving through the area, similar to a case in Johns (1984, his Fig. 7). The surface map indicated that an east–west-oriented stationary front extended from Missouri southwestward into northern Alabama. South of the stationary front in the warm sector, MUCAPE values were over 3500 J/kg. Surface temperatures across the region were in the 80s (25–30°C). The MCS formed around 0500 UTC in Illinois and moved southeast, parallel to the front. The 1200 UTC Nashville, Tennessee, (BNA) sounding possessed a surface stable layer, possibly a nocturnal inversion; however, at some point the MCS did become surface-based as evident by the 0000 UTC BNA sounding (not shown). Determining at what time the MCS was elevated versus surface-based was difficult due to the lack of upper-air data around the event time. The strongest part of the inversion at 1200 UTC had a depth of 50 hPa or less. Composite radar images indicate that the system

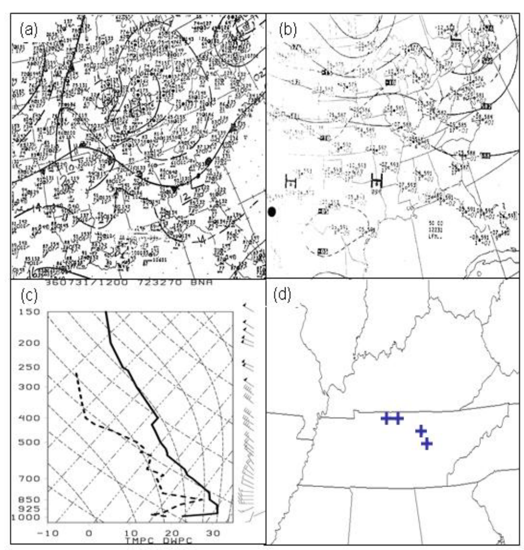

Figure 7: Type C event: 31 Jul 1986: (a) 1200 UTC surface map, (b) 1200 UTC 500-hPa map, (c) 1200 UTC BNA upper-air sounding, and (d) severe-storm reports 1400–1600 UTC.

was a MCS (not shown). There were four severe reports associated with this event (Fig. 7d).

5. DISCUSSION

After constructing the climatology and examining the five wind-only cases, two questions remain unanswered.

• *Does the strength or depth of the stable layer matter?* The five wind-only cases examined showed depths of the stable layer of less than 50 to around 100 millibars, suggesting that deeper inversions may inhibit strong surface winds. If the inversion is stronger than 100 millibars, does that keep the winds from penetrating to the surface? The small number of cases we examined prevents generalizing with any confidence.

• *What factors affect the production of strong surface winds?* If the supercell or squall line can initiate a downdraft, will a strong downdraft have ample kinetic energy to penetrate the stable layer? If a gravity wave moved through this environment on the cold side of the boundary, would it cause large enough undulations in the inversion that only a small amount of momentum would be able to penetrate? Are there other factors that also affect transfer of the strong momentum to the surface? Can surface isallobaric effects, irrespective of the presence of the stable layer, produce severe surface winds?

6. CONCLUSION

A five-year climatology of elevated convective storms producing severe weather was constructed. During this five-year climatology, 1689 (91%) of the 1826 possible days were associated with surface boundaries. Of these 1689 surface boundaries, 129 (8%) elevated severe-storm events were found. The 129 elevated severe-storm events had 1066 total severe-weather reports associated with them. The 1066 severe-weather reports consisted of 624 (58%) hail reports, 396 (37%) wind reports, and 46 (4%) tornado reports.

Elevated severe convection has an annual maximum around May with a secondary maximum in September. The geographic distribution of elevated severe convection followed the typical severe convection pattern from the Plains in the spring (Mar–May), to the High Plains in the summer (Jun–Aug), across the United States in the fall (Sep–Nov), and finally along the Gulf Coast in the winter (Dec–Feb). The diurnal maximum of elevated severe-storm events occurred around 2100 UTC, which coincided with the hail-only diurnal maximum. The wind-only events showed no pronounced diurnal maximum. Of the 129 elevated severe-storm events, 20 produced severe winds only.

Because of the difficulty in forecasting elevated convective storms that produce severe wind reports, five events are examined in greater detail. Three environments were found to be associated with these five events, which we term Type A, B, and C. Type A events were characterized by strongly forced elevated squall lines, Type B by elevated isolated cellular events, and Type C by elevated northwest-flow events. Type A events had strong forcing associated with them, whereas Type B and C events had weak upper-level flow. Type C events lacked strong forcing aloft and had a much weaker inversion.

This research represents a small contribution to understanding elevated severe convective storms. Certainly, scenarios other than Types A, B, and C are possible. Thus, future research should embark upon a larger climatology, especially storms producing severe wind and tornado reports. Numerical modeling of elevated severe convective storms may reveal the key to penetrating the inversion. The strength of the inversion, the depth of the inversion, the strength of the downdraft, another unknown factor, or a combination of these may be the cause of these events.

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