11A.3 A RELATIONSHIP BETWEEN A SURFACE THETA-E RIDGE AND DOMINANT LIGHTNING POLARITY

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1. INTRODUCTION

Rust et al. (1981) were the first to document that some severe storms produce positive (+) cloud-to-ground (CG) lightning and they suggested that +CG activity is "related to certain stages in severe storm development." For instance, Reap and MacGorman (1989) noted that storms producing +CG flash rates of at least 30 per hour were more likely to have severe weather reports. They found "… that hailstorms may be prolific producers of +CG in the Oklahoma-Kansas region." MacGorman and Burgess (1994) studied relationships between +CG flashes and severe weather in fifteen severe storms. In agreement with previous studies, they found that many storms dominated by +CG lightning produced large hail and tornadoes. They also discovered that, if the +CG rate was at least 1.5 per minute and, if the storm produced tornadoes, then the strongest tornado occurred after the peak +CG flash rate. Furthermore, Smith et al. (2000) found that 46% of positive storms were tornadic while only 26% of negative storms produced tornadoes.

Similar to the dominant polarity switching in some storms, the region in which storms are dominated by +CG flashes often appears to be separate from the region in which storms are dominated by –CG flashes on a given severe storm day. Several studies have suggested that this is caused by differences in environmental conditions. Branick and Doswell (1992) found that on one day, the severe storms dominated by +CG flashes were northwest of those dominated by –CG flashes. Similarly, MacGorman and Burgess (1994) noted that if storms dominated by +CG flashes became dominated by –CG flashes, the transition tended to occur in the same geographic region for all storms. They hypothesized, therefore, that environmental factors play an important role in producing +CG flashes.

To examine possible environmental influences, Smith et al. (2000) studied three tornado outbreaks in which some storms were dominated by +CG flashes; some, by –CG flashes; and others experienced a switch in dominant polarity. They found that storms dominated by +CG flashes throughout their lifetime formed and remained in a strong gradient of the surface equivalent potential temperature (theta-e) upstream of the axis of maximum theta-e. If the storm switched dominant polarity, it did so when it crossed the axis of maximum theta-e and moved into lesser values of theta-e. If a storm formed and remained downstream of the theta-e maximum, –CG flashes dominated during its lifetime.

Smith et al. (2000) hypothesized that theta-e affects the convective energy of a storm and that this, in turn, affects CG polarity. However, they offered no specific mechanism by which theta-e would influence a storm characteristic that controls CG polarity. It is possible that the theta-e feature they studied is related systematically to some other atmospheric property that is the one to affect CG polarity.

The intent of this study is to examine the relationship between dominant CG polarity and surface theta-e for a greater number of cases than investigated by Smith et al. (2000) to determine the frequency of their observations. The methodology used by this study is described in Section 2. Section 3, which presents the results of the study, is broken into subsections which each discuss relationships based on different ways in which storms were categorized. The results are then related to the work done by Smith et al. (2000).

2. METHODOLOGY

This study examines severe thunderstorm days during all of 1999 in Oklahoma, Kansas, Nebraska, South and North Dakota, Minnesota, Wisconsin, Iowa, Illinois, Missouri, and Arkansas. Using SVRPlot2 written by John Hart of the Storm Prediction Center, severe weather reports were plotted for each UTC day of 1999 in the analysis region to determine the period and states within which severe weather was reported. The severe weather period examined in the rest of our analysis extended from an hour before severe weather to an hour after. Thus, storms were said to *begin* an hour before storms produced severe weather.

The cloud-to-ground data used in this study, collected by the National Lightning Detection Network (NLDN), included the location and polarity of CG flashes. Periods in which storms produced no +CG flashes were eliminated from the study. Only six such cases were found and all were in 1999. The NLDN data were tabulated on a 40 km by 40 km grid to determine the total number of CG flashes and the ratio of +CG flashes to all CG flashes for each hour. Hereafter, this ratio, expressed as a percentage, will be called the +CG percentage. If the +CG percentage was more than 50%, +CG flashes are said to have dominated the grid box, and the grid box was termed *positive*. A box containing 50% or fewer +CG flashes was termed *negative*.

The intent for this study is to analyze severe storms in which a large density of +CG flashes dominated. To find suitable cases, the gridded +CG percentage and total CG counts were contoured on a map of the analysis region. A case was chosen for further analysis only if there were at least ten CG flashes in at least one of the grid boxes dominated by +CG flashes. This was done to try to discriminate against +CG occurrence in dissipating

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storms, in anvils, or in stratiform precipitation regions, all of which tend to produce a low density of CG flashes.

The surface theta-e data used for the comparison with CG flash polarity were produced from observations by National Weather Service surface stations observations, then gridded using the Barnes objective analysis provided by Gempak, with 0.75 degrees of latitude between stations. Theta-e was contoured at 2 K intervals to resolve meso-scale features. For this analysis, a theta-e *ridge* was defined as either a local maximum in theta-e along an axis or a closed local maximum of theta-e.

For times and regions in which severe weather occurred, hourly variations of the dominant lightning polarity within contours of more than ten CG flashes were examined and related to the theta-e field. Our definition of a *storm,* using gridded lightning data, was somewhat subjective. When examining CG flash counts, one cannot be certain if a broad region of high flash counts is one storm or several storms.

Our method of analysis has several limitations: (1) It is possible that some of the flashes counted at a grid point were from a different storm than the one that produced severe weather, so our categorization of dominant polarity may differ from the dominant polarity of the severe storm. (2) It was not possible to identify or track severe storms during periods in which they produced few, if any, CG flashes. (3) Focusing only on times near periods of severe weather may have prevented us from seeing +CG domination or transitions of CG polarity outside of this period or from knowing where storms initiated. However, if the relationship observed by Smith et al. (2000) between surface theta-e and dominant CG polarity is generally true, these limitations should not interfere with observing this relationship in the cases we analyze.

3. RESULTS

During 1999, 168 periods of severe weather were examined hour-by-hour. Storms were put into several categories for comparisons. Storms were classified based on their dominant polarity, on where relative to a theta-e ridge they began producing severe weather, on their movement relative to a theta-e ridge, and on whether the dominant CG flash polarity changed.

3.1 *Dominant Storm Polarity*

As in Smith et al. (2000), a storm is called *positive* if +CG flashes dominate throughout the entire lifetime. If –CG flashes dominate, the storm is called *negative*. Storms that experience a change from positive to negative are called *reversal* storms. *Initially positive* storms included both positive and reversal storms. Of the 168 storms examined, 66 were initially positive and 102 were negative. Fourteen of the initially positive storms were always positive; 52 of them were reversal storms.

3.2 *Storm Beginning*

The location at which a storm began producing severe weather was categorized by its position relative to a theta-e ridge. A storm began *upstream* of a theta-e ridge if it moved into higher values of theta-e with time. A storm began *downstream* of a theta-e ridge if it moved into lower theta-e values with time. A storm began *away* from a theta-e ridge if it moved parallel to horizontally oriented theta-e contours. Sixty-one of 66 (92%) initially positive storms and 67 of 102 (66%) negative storms began upstream (Fig. 1). Also, all storms that began away from a ridge were negative. Smith et al. (2000), using fewer samples, also found that a majority (96%) of initially positive storms began upstream of a ridge, but that only 3% of negative storms did.

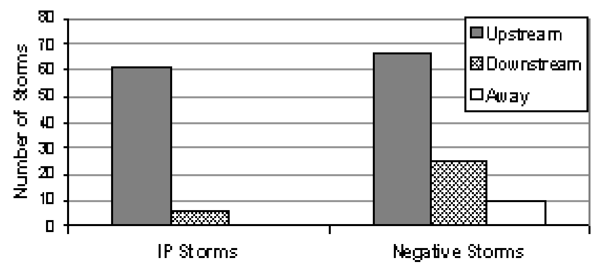

Fig. 1. Number of initially positive (IP) and negative storms located upstream, downstream, and away from a theta-e ridge when they began producing severe weather.

3.3 *Storm Motion Relative to a Theta-e Ridge*

Five categories for storm movement were used in this study: *crossed* a ridge, *moved adjacent* to a ridge, *remained away* from a ridge, *dissipated upstream* of a ridge, and *remained downstream* from a ridge. A storm crossed a ridge if it began upstream, moved through the local maximum axis, and continued moving downstream of the ridge. Examples from 3-4 May 1999 are shown in Fig. 2. Storm B crossed a ridge axis in this figure. Storm A initially crossed the axis in the previous hour (not shown).

A storm moved adjacent to a ridge if it began upstream and traveled in a direction roughly parallel to the ridge axis. By definition, these storms did not cross the ridge axis. Storms that remained away from a ridge were those same storms that began producing severe weather away from a ridge. A storm dissipated upstream of a ridge if it began upstream, but was no longer severe by the time it reached or showed movement adjacent to the ridge axis. Finally, storms that traveled downstream were those storms that remained downstream the entire time they produced severe weather.

Storms that crossed a theta-e ridge were usually initially positive (43 out of 61); moreover, all of the initially positive storms that crossed a ridge were reversal

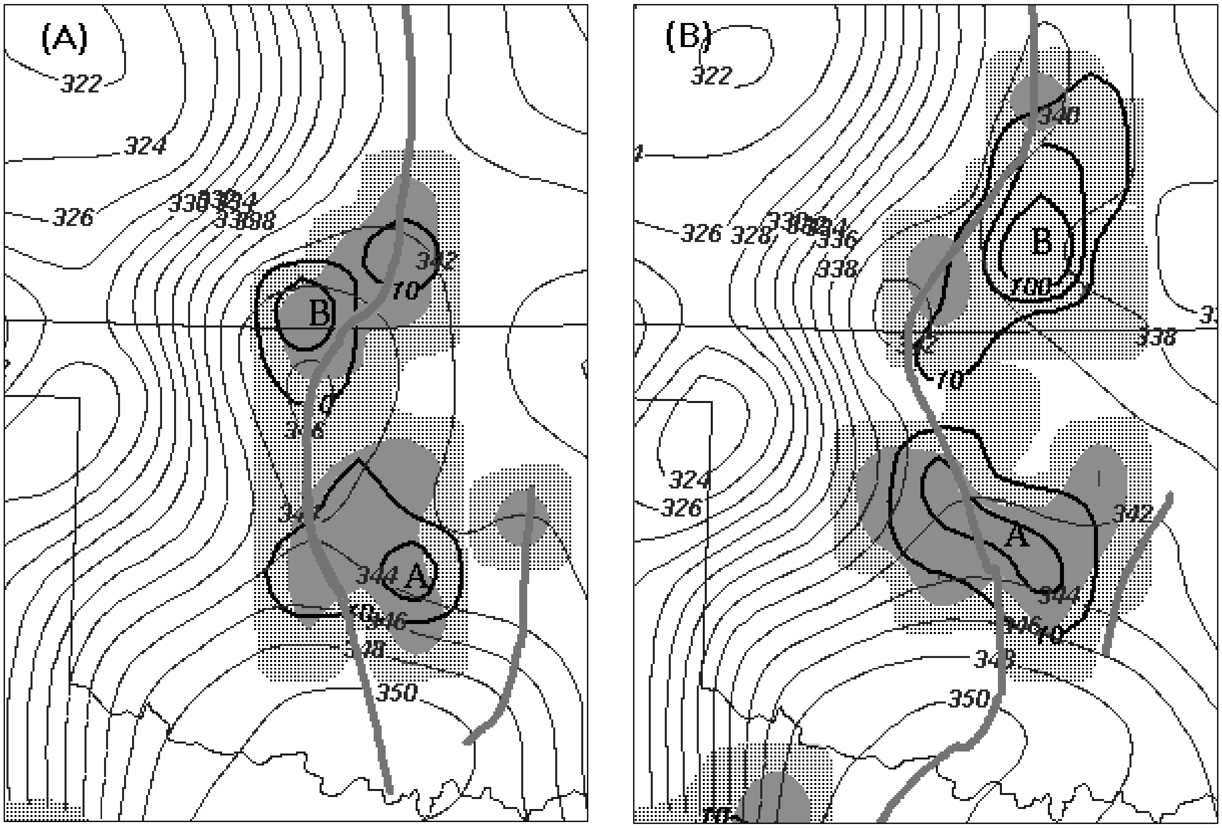

Fig. 2. Example of a positive storm crossing and reversing polarity over a surface theta-e ridge axis on 3-4 May 1999. Area shown is northern Oklahoma and southern Kansas. Theta-e is contoured at 2 K intervals (thin black curves). Grid boxes dominated by –CG flashes are stippled and positive grid boxes are shaded. Thick contours enclose regions of 10, 50, and 100 CG flashes per hour, and thus, signify storms as defined in Section 2. The thick solid gray line denotes the theta-e ridge axis. Storm B is positive at 0000UTC (a) and negative at 0100 UTC (b). Storm A was positive and upstream an hour earlier than shown and transitioned at 0300 UTC (not shown).

storms (Fig. 3). The majority (19 of 27) of storms that began upstream, but dissipated before crossing, were negative storms. Storms that moved adjacent to the ridge axis were usually negative (30 out of 40). Out of 10 initially positive storms that moved adjacent to a ridge axis, only 2 were reversal storms. Thus, both the +CG

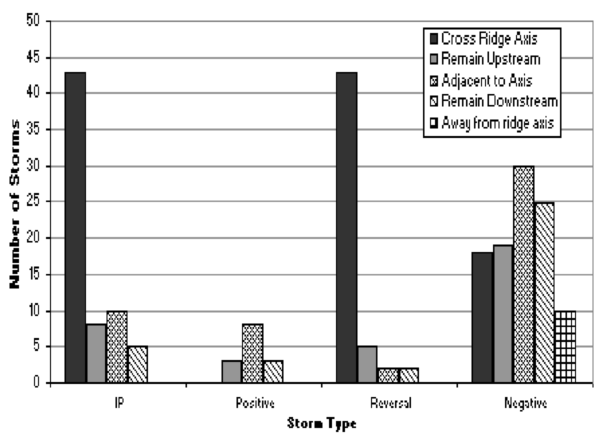

Fig. 3. Movement of storms relative to a theta-e ridge.

and the –CG dominated storms tended not to transition if they moved adjacent to a ridge axis. Negative storms dominated those that began and remained downstream (25 out of 30). This is consistent with Smith et al. (2000) who found that 99% of downstream storms were negative. Furthermore, negative storms were the only storms that began and remained away from a ridge.

3.4 *Storm Transitions*

Storms were also categorized by where their dominant CG polarity changed. Storm polarity either transitioned *in the ridge, adjacent to the ridge, upstream of a ridge, away from a ridge,* or *downstream of a ridge*. This classification is similar to the classification of storm movement: storms that crossed a ridge and transitioned when they crossed were said to transition *in the ridge* and similarly for the other classifications.

Almost all transitions occurred in a theta-e ridge. Eighty-two percent of 52 reversal storms crossed, and transitioned in a ridge (Fig. 3). Only 10% of reversal storms transitioned before they dissipated upstream of a ridge, and the remaining reversal storms either began and remained downstream of a ridge or moved adjacent to a ridge. Results from Smith et al. (2000) are similar: 90% of reversal storms crossed a ridge, 5% moved adjacent to a ridge, and 5% began downstream. Examining storm movement and the location of storm transitions (Fig. 3), one can note that no positive storms crossed a ridge. Thus, all initially positive storms that crossed a ridge transitioned (i.e., were reversal storms). Smith et al. (2000), however, observed that 33% of positive storms crossed a ridge. In both studies, however, the majority of storms that were always positive moved adjacent to a ridge, as 57% did in this study and 67% in Smith et al's (2000) study. Equal percentages of the remaining positive storms either dissipated upstream or began producing severe weather downstream of a ridge. Unlike positive or reversal storms, negative storms preferred no particular mode of movement relative to a theta-e ridge. This contradicts observations by Smith et al. (2000); they found that 97% of negative storms preferred movement downstream. In this study, negative storms did not transition except for three storms that became positive during the last hour of CG activity. This phenomenon is discussed by Williams et al. (1994).

4. CONCLUSIONS

This study, along with the research by Smith et al. (2000), indicates that a connection exists between storm polarity and surface theta-e. In two important respects, our results agree with those of Smith et al.: 92% of severe storms dominated by +CG flashes began producing severe weather upstream of a theta-e ridge, and 65% of these crossed a theta-e ridge. Furthermore, the dominant polarity of all initially positive storms that crossed the ridge changed to negative for the remainder of the storm's duration. Fifteen percent of initially positive storms moved adjacent to the ridge axis; these usually (80%) remained positive. However, unlike the storms observed by Smith et al., 66% of storms that began as negative storms also were upstream of a theta-e ridge. Negative storms upstream of the ridge usually moved adjacent to a ridge axis, but also crossed the axis. Regardless of where they began or moved, nearly all negative storms remained negative throughout the analyzed period. Smith et al. (2000) found that most negative storms began east of the ridge axis and moved into regions of smaller theta-e.

Smith et al. (2000) hypothesize that the increase in buoyancy that corresponds to increased theta-e may be responsible for alterations in storm structure, which, in turn, alters the electrical structure of the storm, resulting in more -CG flashes.

This relationship between dominant storm polarity and surface theta-e may provide a means to forecast the most intense period of a thunderstorm. Several studies have linked dominant storm polarity with storm severity (e.g. MacGorman and Burgess 1994, Seimon 1993, Perez et al. 1997, Knapp 1994, Smith et al. 2000). Knowing which storms +CG flashes will dominate is a prerequisite for forecasting the time and location of severe weather based on +CG flashes rates. It also is necessary to examine whether some types of severe weather are located preferentially in some region relative to theta-e for those of our cases that differed from the cases observed by Smith et al. Furthermore, before using a relationship between surface theta-e and dominant storm polarity, one would like to understand the underlying physical basis for the relationship. These topics are high priorities for future research of +CG lightning in severe storms.

5. Acknowledgements

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