A CASE STUDY OF A POSITIVE STRIKE DOMINATED SUPERCELL THUNDERSTORM THAT PRODUCED AN F2 TORNADO AFTER UNDERGOING A SIGNIFICANT CLOUD-TO-GROUND LIGHTNING POLARITY SHIFT

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Abstract

Shortly before 1700 UTC on 16 December 2000, a relatively low topped supercell moved into Lauderdale County, Mississippi and produced an F2 tornado with a twelve mile track. The tornado was the first to form on an active severe weather day which later produced 12 tornadoes in Alabama, including an F4 tornado in Tuscaloosa County from the same supercell that produced the tornado in Lauderdale County. Prior to the tornado formation, the supercell exhibited interesting cloud to ground lightning signatures, including a significant polarity reversal from positive to negative. The primary focus of this paper will be a discussion of the utility of lightning data to help improve the tornado warning process for the initial tornado touchdown from a Positive Strike Dominated low topped supercell thunderstorm.

1. INTRODUCTION

The reliable and timely detection and dissemination of Cloud-to-Ground (CG) lightning data from the privately owned National Lightning Detection Network has been available to National Weather Service (NWS) forecasters on the Advanced Weather Interactive Processing System (AWIPS) since at least 1999. The data which are readily available and displayable are the geographic location and the polarity of CG lightning strikes. These lightning data can be quickly and easily overlaid on radar reflectivity products to provide additional information about the life cycle of thunderstorms in a local NWS forecast office's County Warning Area (CWA). Prior to the availability of the AWIPS system to the operational NWS forecasters, numerous research studies indicated relationships between CG lightning flash rates and polarity changes to tornadic development during the life cycle of severe thunderstorms.

A few examples of previous studies include Kane (1991) who analyzed the lightning data from several tornadic storms in the northeastern United States. He noted that the tornadoes and large hail followed the peak 5-minute lightning rates by 10 to 15 minutes and were accompanied by a rapid decline in CG strikes. MacGorman and Burgess (1994) studied the lightning characteristics of 15 severe storms. In MacGorman and Burgess' dataset, the majority of storms dominated by positive CG flashes produced tornadoes. They noted that the storm's most damaging tornado began after positive CG flash rates decreased from their peak value, before or near the time when negative flashes became dominant. During some storms, the CG flash rates decreased to near zero after positive CG flash rates decreased from their peak value, and before a polarity shift to predominantly negative CG flashes in the storm. Seimon (1993) studied lightning data associated with the F5 tornado in Plainfield, Illinois in August of 1990. He noted an anomalous

predominance of positive-polarity CG flashes during the development of the severe thunderstorm that produced the tornado, a 20 minute span of reduced CG activity coinciding with tornado formation and intensification, and a reversal in dominant CG flash polarity from positive to negative at the time of tornado touchdown. Finally, Knapp (1994) conducted a thorough study of 264 tornadic thunderstorms east of the Continental Divide. For Positive Strike Dominated (PSD) tornadic storms, he noted that storms often went through a rapid polarity shift from PSD to Negative Strike Dominated (NSD), about 10 minutes prior to tornado occurrence. He also noted a rapid increase in flash rates, beginning 20 minutes prior to tornado touchdown.

At approximately 1630 UTC on 16 December 2000, a relatively low topped (echo top around 30 kft) supercell developed in Jasper County, Mississippi (MS) and moved northeast at around 45 knots. This storm moved into Lauderdale County, in east central Mississippi. The supercell produced an F2 tornado at 1730 UTC in central Lauderdale County, about 6.4 km (4 mi) northeast of Meridian. The tornado moved northeast for 19.3 km (12 mi) before lifting about 2.4 km (1.5 mi) southeast of the community of Lauderdale at 1745 UTC. This tornado was the first to develop on an active severe weather day which later produced 12 tornadoes in Alabama, including an F4 tornado in Tuscaloosa County, approximately 90 km (55 mi) northeast of the point in Mississippi where the F2 tornado had lifted. The F4 tornado in Tuscaloosa County was produced by the same supercell that had produced the Lauderdale County tornado.

The main focus of this paper is to analyze a dataset of CG lightning data associated with the supercell from the early stages of the supercell development in Jasper County until the formation of the tornado in Lauderdale County. The importance of utilizing CG lightning information as a tool in the warning process for predicting the initial formation of a tornado from a PSD supercell thunderstorm will be discussed.

2. PRE-STORM ENVIRONMENT

At 1200 UTC on 16 December 2000, the 500 mb analysis showed a shortwave trough from a closed low in Iowa southward into eastern Texas. An associated 50 ms^{-1} mid level speed maximum was developing eastward around the base of the deepening trough over the central plains. At the surface, a cold front was moving into western Mississippi. Ahead of the cold front, low- level southerly winds had advected warm and moist air into eastern Mississippi and western Alabama. By 1600 UTC, the official observation from the Meridian, MS Airport (KMEI) had a temperature of 21C and a dewpoint of 19C.

The 1200 UTC Jackson, MS (KJAN) sounding (Figure 1) was very favorable for the development of severe convective storms. The upper air sounding was analyzed using the N/AWIPS - Skew-T/Hodograph Analysis and Research Package (N-SHARP, Hart, et al., 1997). The Convective Available Potential Energy (CAPE) value was 1045 Jkg^{-1}, and the surface to 3 km Storm Relative Environmental Helicity (SREH) was 398 m^2s^{-2}. The 1200 UTC sounding for Birmingham, AL (KBMX) (Figure 2) exhibited even more favorable parameters for tornadic potential. The CAPE from the 1200 UTC KBMX sounding was 1199 Jkg^{-1} and the surface to 3 km SREH was 583 m^2s^{-2}. If the KJAN sounding were modified for the 1600 UTC KMEI surface temperatures, the estimated CAPE value for east central Mississippi would increase to around

1600 m^2s^{-2}. Based on the surface to 3 km SREH values at 1200 UTC at KBMX and KJAN, the surface to 3 km SREH in the Meridian area, located about halfway between KBMX and KJAN, was most likely over 400 m^2s^{-2}.

A comparison of the observed and modified sounding parameters to a climatology developed by Rasmussen and Blanchard (1998) shows this event had surface to 3 km SREH values over the 90 percentile level for soundings in environments that produced tornadic storms. For CAPE, the values at 1200 UTC for both the KJAN and the KBMX soundings were slightly below the mean for tornadic storms. However, modifying the KJAN sounding with the 1600 UTC surface data from KMEI brought the CAPE value to the 50 to 75 percentile value for soundings in a tornadic environment.

With many parameters coming together for a potential tornado outbreak in eastern Mississippi and for much of Alabama, the Storm Prediction Center (SPC) in Norman, Oklahoma issued a Tornado Watch at 1600 UTC. The watch was valid from 1615 UTC to 2200 UTC, and was highlighted as being a "Particularly Dangerous Situation" (PDS). A PDS watch indicates that the SPC is anticipating a significant threat of long-lived strong or violent tornadoes (F2 or greater) in the watch area. The western portion of the box contained much of east central and northeast Mississippi, including Lauderdale County. The greatest risk of tornadoes for eastern Mississippi was expected to be in the earliest hours of the watch.

3. ANALYSIS OF THE SUPERCELL STORM

a. Methodology

National Weather Service Forecast Offices receive CG lightning information via the AWIPS system. The lightning data are relayed to the NWS from Global Atmospherics Inc., the private contractor who owns and operates the United States (U.S.) National Lightning Detection Network (NLDN). The NLDN is a network of over 100 CG lightning sensors across the continental U.S. The CG lightning data can be plotted on AWIPS in increments of 1, 5, 15, or 60 minutes. Individual CG strikes are plotted on a geographic map with a median accuracy of 500 m and a detection efficiency rate (percentage of CG lightning discharges that are detected) of 80 to 90 percent (Cummins et al. 1998).

Archived CG lightning data for eastern Mississippi and western Alabama on 16 December 2000 were purchased from Global Atmospherics Inc. for use in this study. The data consist of the time, latitude, longitude, polarity, and amplitude of each strike. The Arcview software program was used to plot the lightning location and polarity data on maps. The plots show a positive lightning strike as a red "X", and a negative lightning strike as a blue "X". The CG lightning strike plots are displayed in 10 minute increments from 1640 UTC to 1750 UTC, before, during, and after the tornado touchdown in Lauderdale County, MS. Additionally, the 1710 UTC to 1720 UTC lightning data are also plotted in 5 minute increments to show the significant changes in the CG lightning activity during this period of time. The numerical analysis of the plots counted only those strikes in the vicinity of the main supercell (generally within 15 km) as the storm moved from Jasper County into Lauderdale County in Mississippi.

b. Analysis of CG Lightning Distribution

At around 1630 UTC, a supercell thunderstorm was developing in west central Jasper County, MS. From 1640 UTC to 1650 UTC a small number of CG strikes occurred with only six total strikes (Figure 3a). Of these strikes, only two were positive (33%). In the next ten minute period from 1650 UTC to 1700 UTC (Figure 3b), the storm continued to develop. The total CG activity increased to 48 strikes, of which 54.2% were positive. The storm began to show severe characteristics on the WSR-88D displays. The lowest level (0.5 degree) Storm-Relative Velocity (SRM) image at 1649 UTC (Figure 4) showed a broad circulation developing, and the Warning Decision Support System (WDSS) utilized by the Jackson, MS Weather Forecast Office (Gerard and Conway 2000) indicated a mesocyclone associated with the storm. The CG lightning activity continued to increase, and a total of 69 strikes occurred with the Jasper County storm from 1700 UTC to 1710 UTC (Figure 3c). Of these strikes, 68.1% were positive. These strikes occurred between 20 and 30 minutes prior to the development of the tornado in Lauderdale County.

From 1710 UTC to 1720 UTC, the CG activity continued to be mostly positive. The total strikes in the vicinity of the storm decreased from 69 in the ten minute period ending at 1710 UTC to 50 strikes in the ten minute period ending at 1720 UTC. However, the CG activity for the latter period from 1710 UTC to 1720 UTC increased to 86% positive in the vicinity of the supercell storm (Figure 3d). More dramatically, during the five minute period from 1710 UTC to 1715 UTC (Figure 3e), 32 CG strikes occurred, of which an overwhelming 93.8% were positive. This five minute period of intense CG activity with predominantly positive lightning activity occurred between 15 and 20 minutes before the initial tornado touchdown. The five minute period from 1715 UTC to 1720 UTC (Figure 3f) began to show a decline in total CG activity (18 strikes compared to 32 strikes between 1710 UTC and 1715 UTC) but the strikes continued to be overwhelmingly positive (72.2%).

As the total CG lightning activity was declining between 1710 UTC and 1720 UTC, the low level reflectivity images (not shown) on the KJAN WSR-88D appeared to indicate the storm was weakening. However, the lowest level (0.5 degree) SRM still showed a low level circulation with a mesocyclone (Figure 4). After 1720 UTC, the CG activity underwent a polarity shift along with a continued decline in total CG activity. A total of only 17 CG strikes occurred from 1720 - 1730 UTC in the vicinity of the supercell (Figure 3g). Only four (23.5%) of these strikes were positive in the 10 minute period leading up to the tornado touchdown in Lauderdale County.

An NWS storm survey indicated that an F2 tornado touched down 6.4 km (4 mi) northeast of Meridian in Lauderdale County at 1730 UTC. The tornado had a path length of 19.3 km (12 mi), and stayed on the ground for 15 minutes before dissipating about 2.4 km (1.5 mi) southeast of the town of Lauderdale in the northeastern part of the county. During the first 10 minutes the tornado was on the ground, only six CG strikes occurred, with two strikes positive (Figure 3h). Only seven total CG strikes occurred from 1740 UTC to 1750 UTC, with just one positive strike (Figure 3i).

A bar graph showing the total CG strikes for each 10 minute period from 1630 UTC through 1750 UTC (Fig. 5) clearly shows the predominance of positive CG strikes and the large number of total CG strikes prior to the formation of the tornado. The decline in total CG activity and the reversal to predominantly negative CG activity in the 10 minute period prior to the tornado touchdown is also clearly seen in Figure 5.

4. DISCUSSION AND WARNING IMPLICATIONS

This case of a cool season, low topped tornadic supercell in a very favorable supercell environment showed many similarities to previous studies which compared CG lightning activity with the development of tornadoes. The 16 December 2000 Lauderdale County, MS tornado touched down about 10 minutes after a significant polarity reversal from PSD to NSD, and about 15 minutes after the total CG activity began to significantly decline. The lightning activity that occurred with this tornadic supercell correlate well with the studies mentioned in the introduction of this paper, especially Kane (1991), MacGorman and Burgess (1994), and Knapp (1994). As in the Lauderdale County tornado case, these studies generally found peak CG flash rates, which were PSD, about 10 to 20 minutes prior to tornado touchdown and a significant polarity reversal from PSD to NSD around 10 minutes prior to touchdown. Previous studies also indicated that the total CG activity often showed a rapid decrease from around 10 to 15 minutes prior to tornado touchdown. The actual times for the decrease in lightning activity and the polarity reversal prior to a tornado touchdown had minor variability in these previous studies.

For this Lauderdale County, MS tornado case, the lowest level storm relative velocity data (previously shown in Figure 4) did not show a tornadic circulation. The total CG lightning activity rapidly decreased in the 15 minute period leading up to the tornado touchdown. Therefore, the storm appeared to be dissipating. This supercell storm occurred at a distance of about 115 km (70 mi) from the KJAN radar. At this distance, the lowest radar elevation angle was over 2100 m (almost 7,000 ft) above the ground so the radar operator could not see if a tight low-level circulation was developing. For a tornado such as this Lauderdale County case, an understanding of the lightning behavior of many tornadic supercell thunderstorms is a very important tool in the tornado warning process.

Since CG lightning location and polarity data are readily available to the operational NWS forecaster through the AWIPS system, the data should be utilized in the warning decision process. The CG activity alone is not enough to make a warning decision. However, forecasters making warning decisions in a favorable tornadic environment should understand the possible relationship of CG lightning patterns in a supercell to the development of a tornado. Once a thunderstorm has been identified as being a supercell, forecasters should monitor the CG activity in the storm. For a PSD supercell, if a rapid increase in mostly positive strikes is observed, followed by a rapid decrease in total CG activity and a corresponding polarity shift to negative, the forecaster should strongly consider the possibility of tornadogenesis within 10 minutes. This utilization of lightning data may provide a valuable clue to assist forecasters in the warning process and could improve tornado warning lead times by as much as 10 minutes in some cases. Forecasters may also be able to warn more effectively for tornadoes that may otherwise be missed completely, especially when storms are over 100 km from the radar.

This Lauderdale County tornado case is only one example, but the lightning patterns of this tornado-producing supercell correlate well with many previous studies. Additional tornadic supercell cases should be analyzed to determine how the CG lightning patterns available on the AWIPS display could best be utilized in conjunction with WSR-88D radar data in the tornado warning process. A few null cases (where CG patterns appear to be favorable for a tornado touchdown, but no tornado is observed) should also be studied.

5. ACKNOWLEDGMENTS

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6. REFERENCES

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Figure 1. The 1200 UTC 16 December 2000 upper air sounding for Jackson, MS.

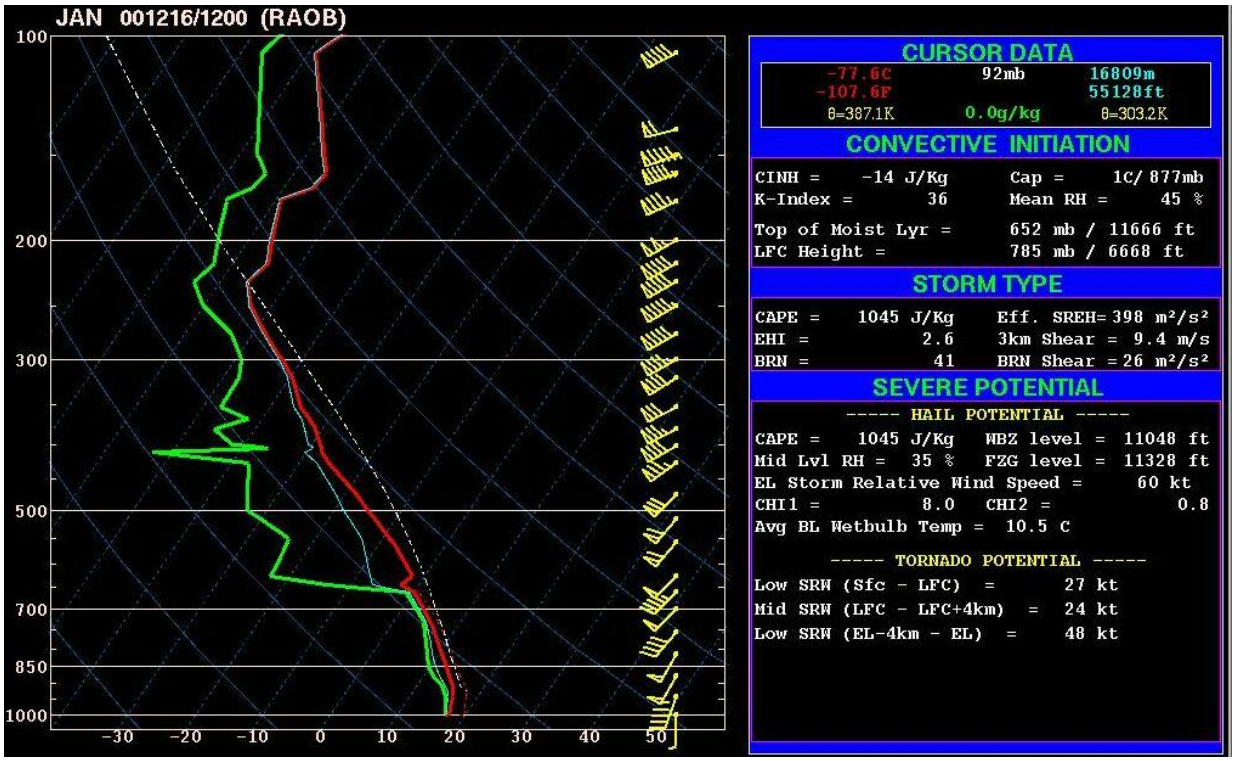


Figure 2. Same as Fig. 1, only for Birmingham, AL. Note that the Effective Storm Relative Environmental Helicity (Eff. SREH) shown in this figure is much lower than the surface to 3 km SREH of 583 m^2s^{-2} that was calculated for this sounding.

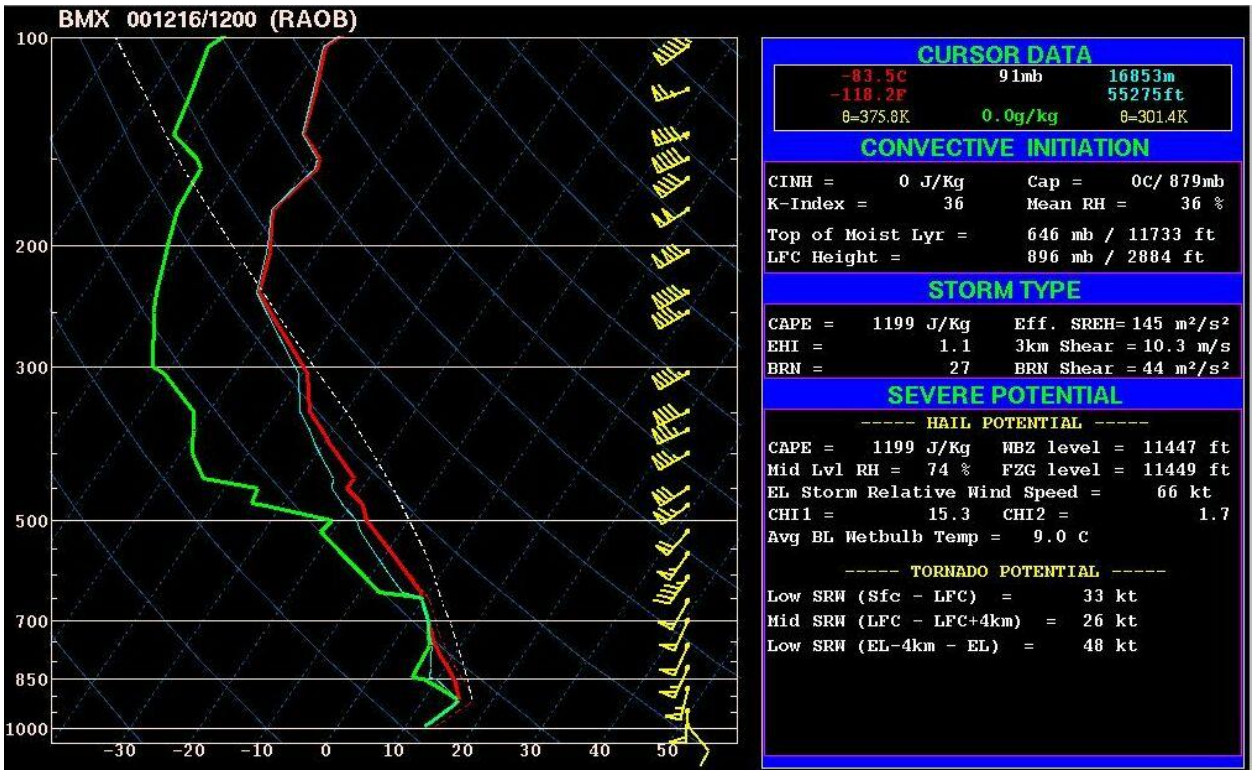


Figure 3a. Cloud-to-Ground (CG) lightning data from 1640 to 1650 UTC 16 December 2000. Positive lightning strikes are shown in red, negative lightning strikes are shown in blue.

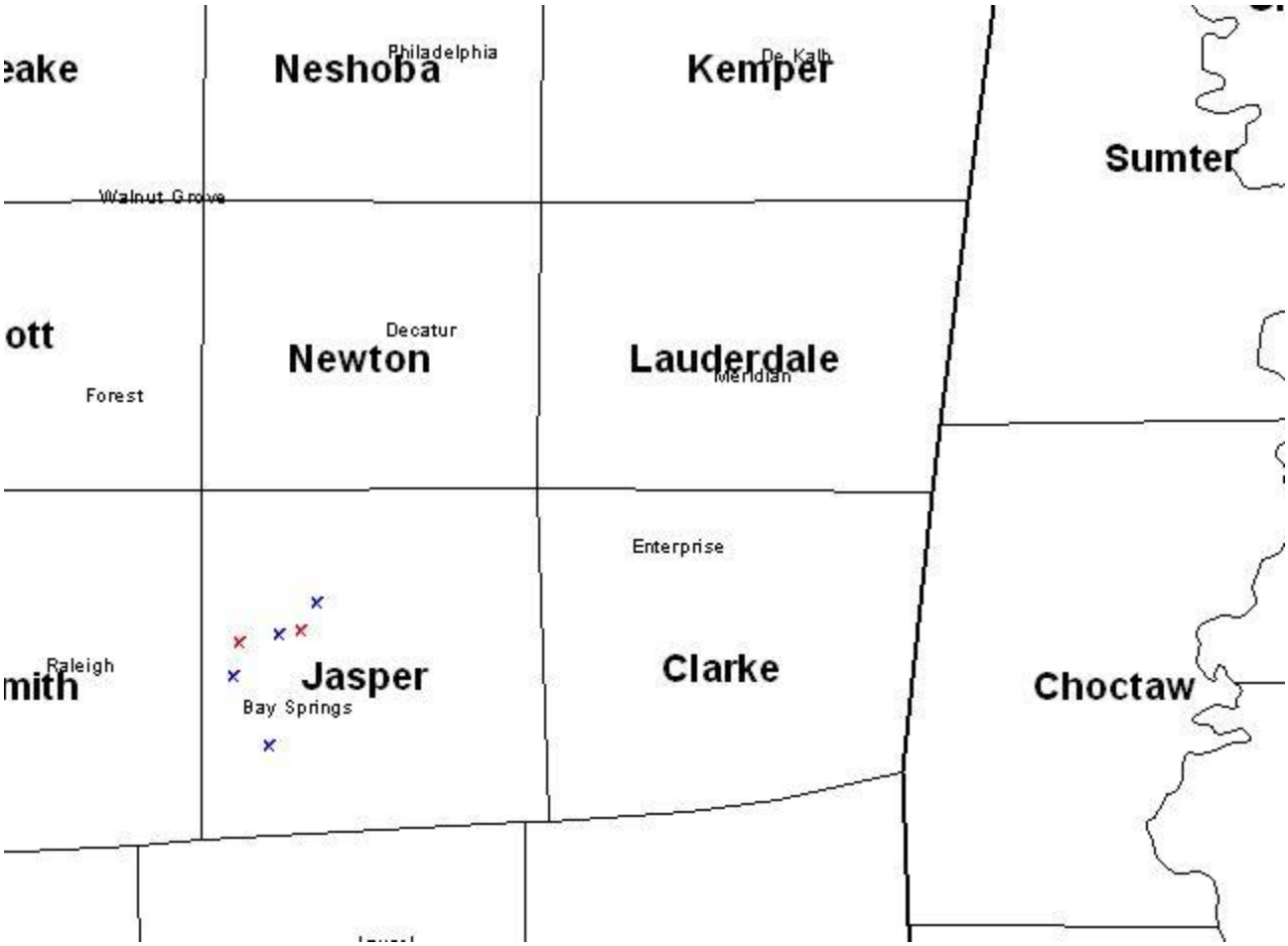


Figure 3b. Same as Fig. 3a, only from 1650 to 1700 UTC.

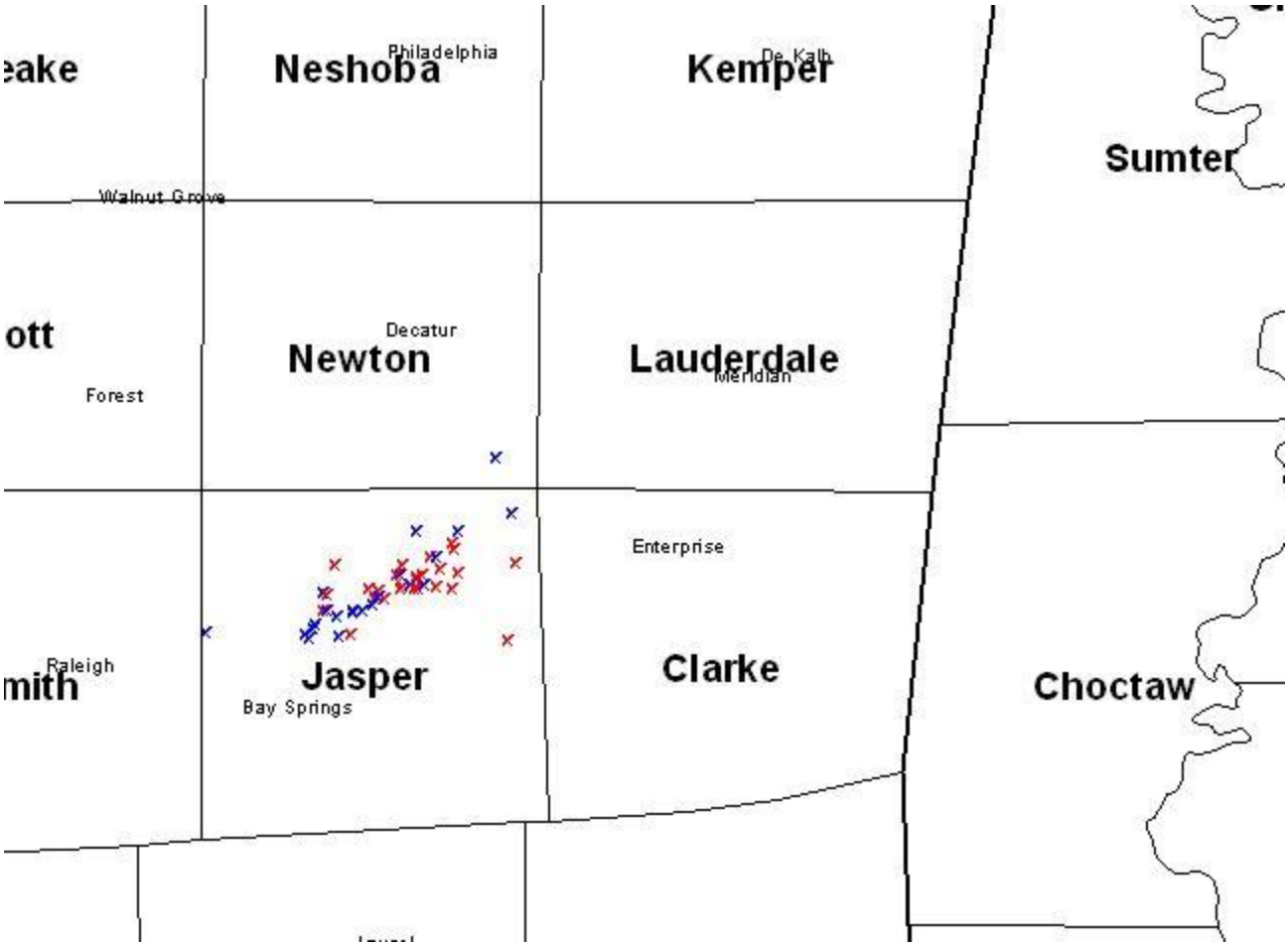


Figure 3c. Same as Fig. 3a, only 1700 to 1710 UTC.

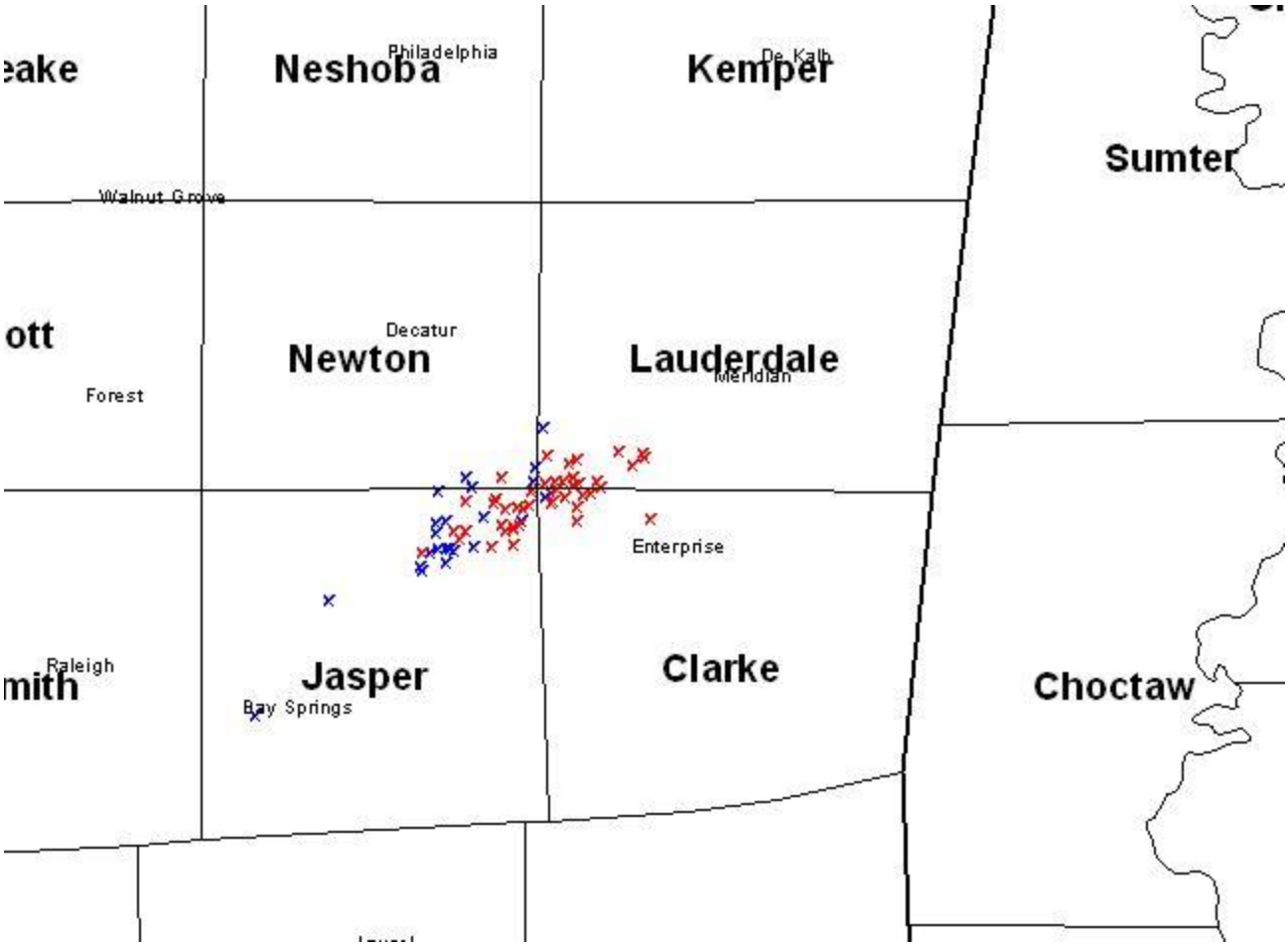


Figure 3d. Same as Fig. 3a, only 1710 to 1720 UTC.

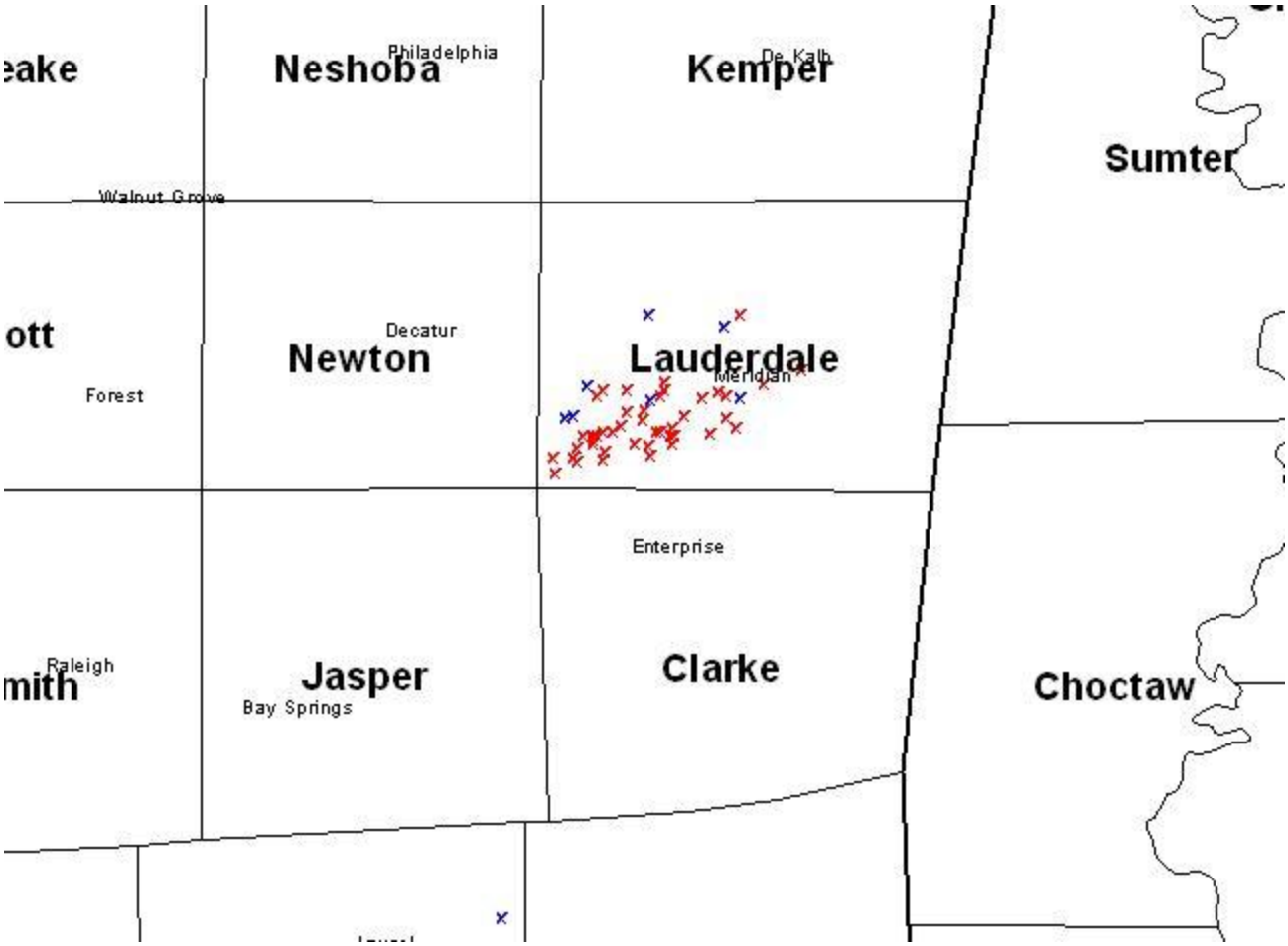


Figure 3e. Same as Fig. 3a, only 5-minute data 1710 to 1715 UTC.

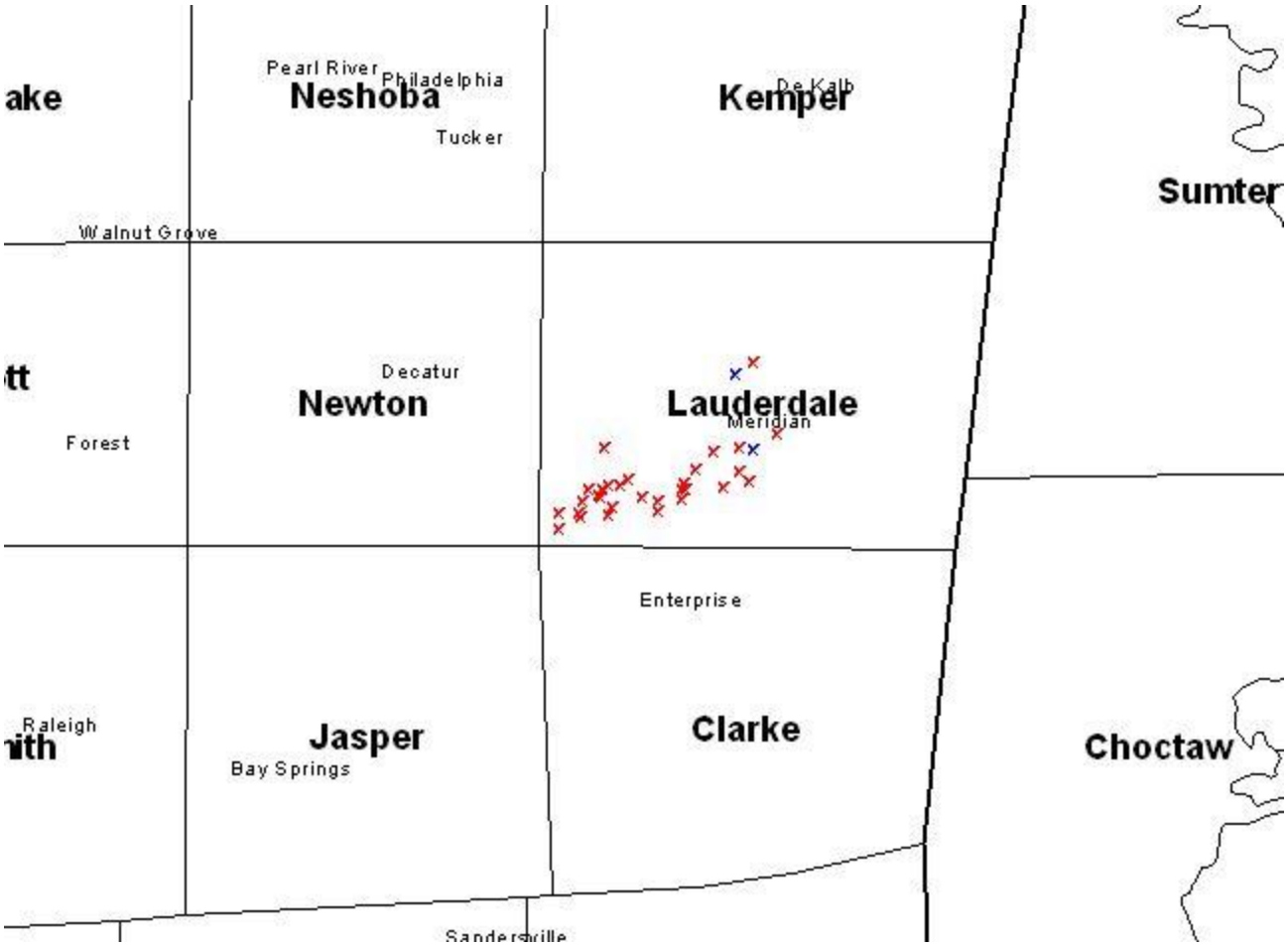


Figure 3f. Same as Fig. 3a, only 5-minute data 1715 to 1720 UTC.

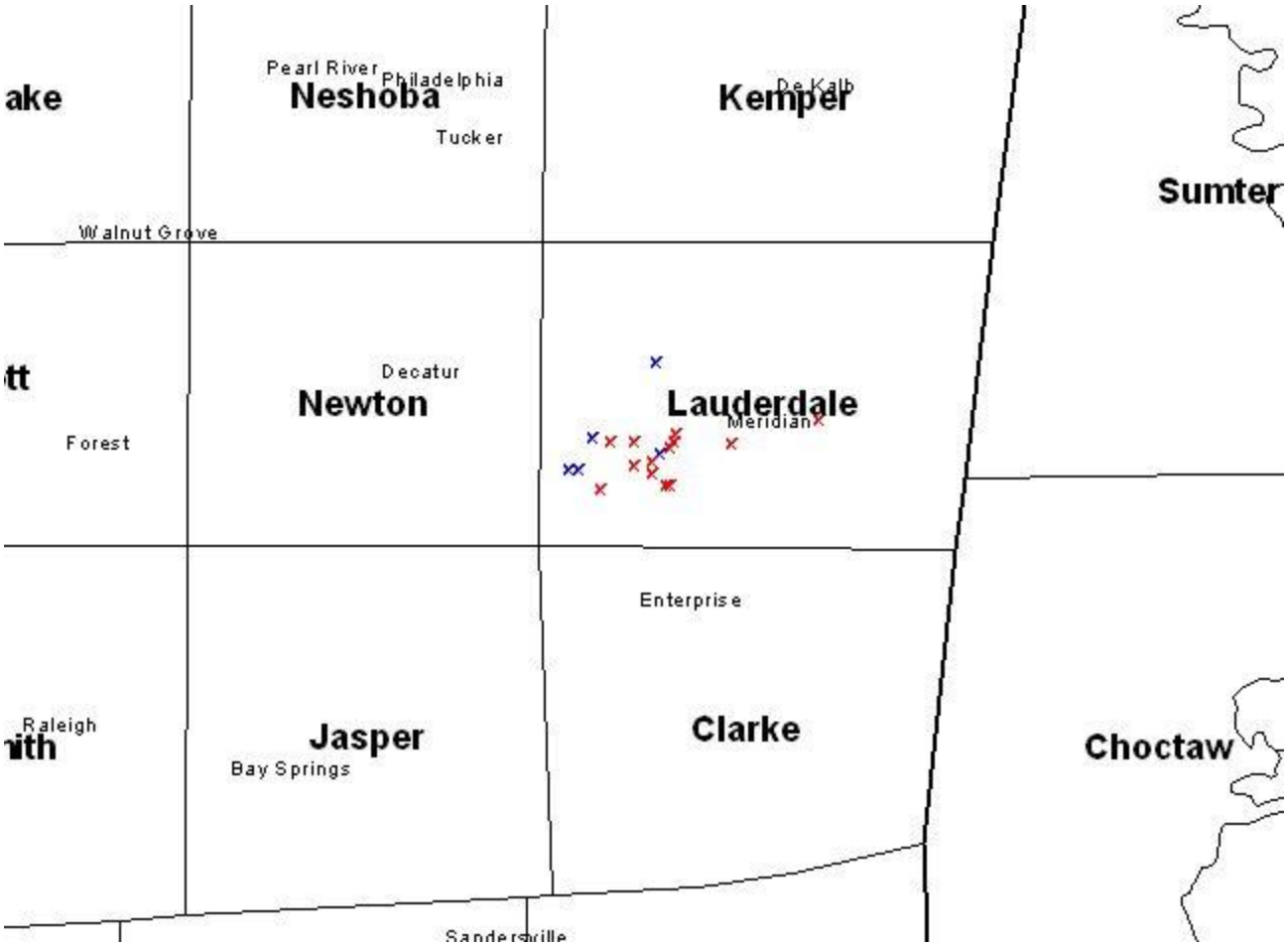


Figure 3g. Same as Fig. 3a, only 1720 to 1730 UTC.

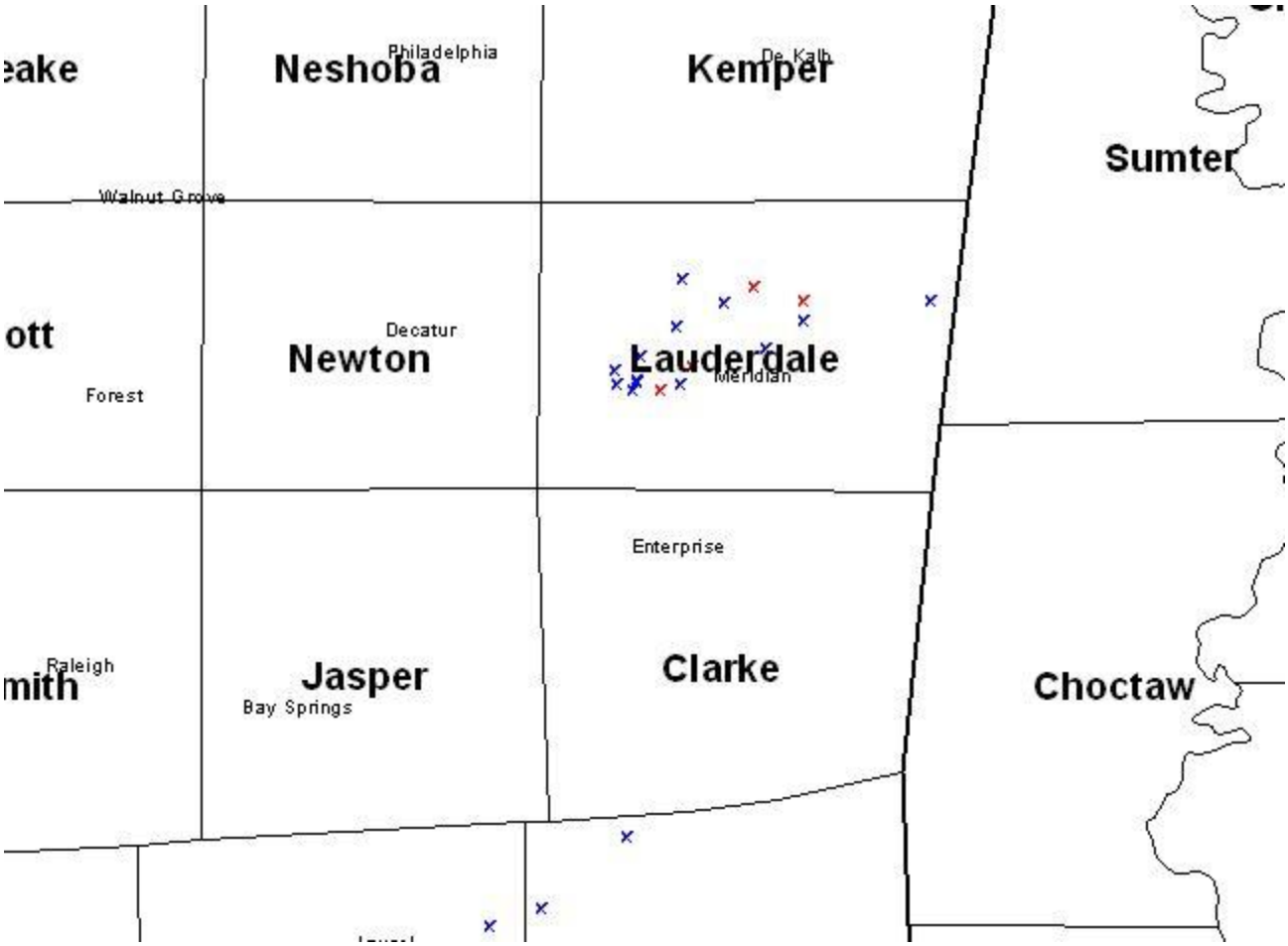


Figure 3h. Same as Fig. 3a, only 1730 to 1740 UTC.

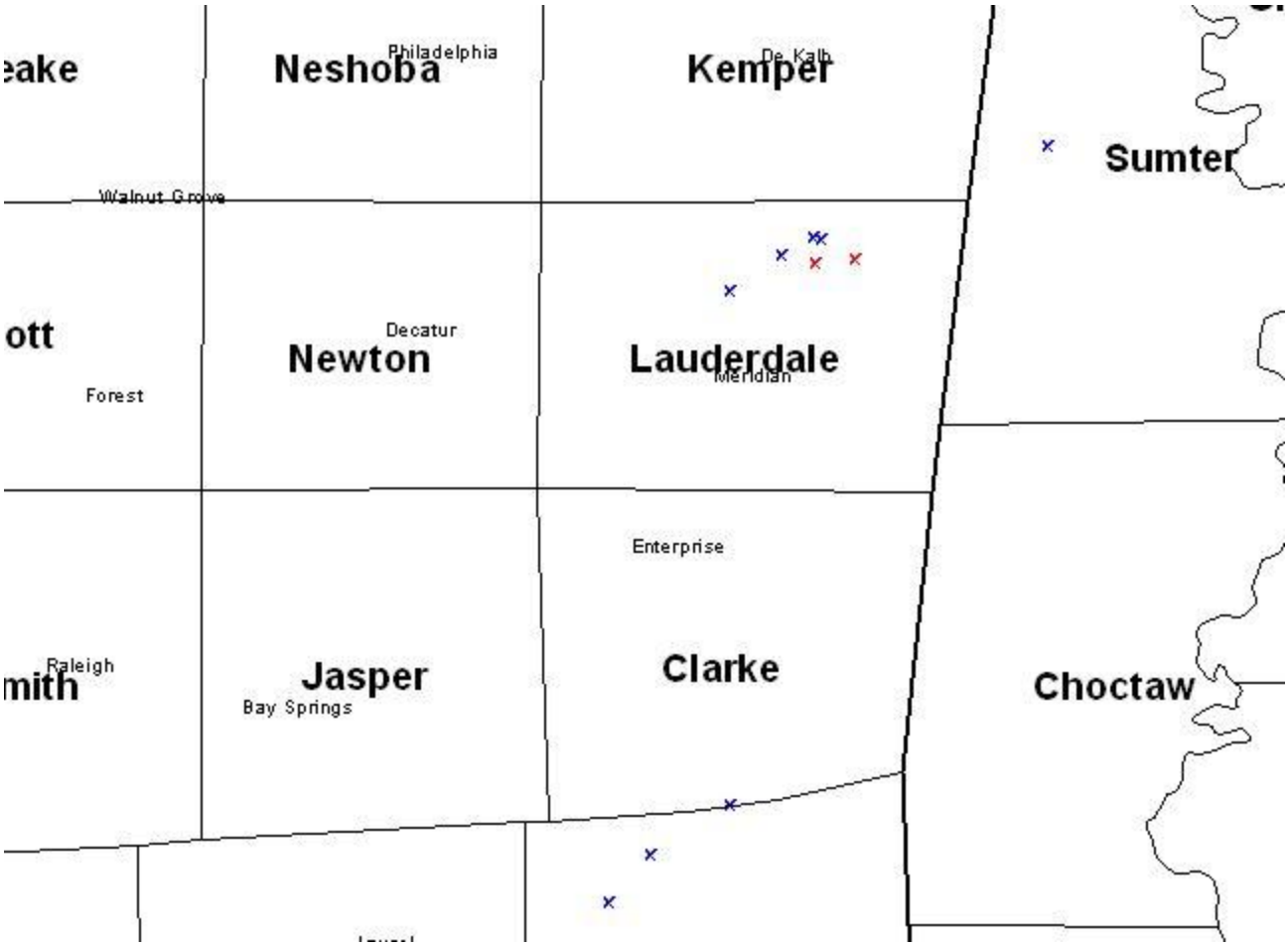


Figure 3i. Same as Fig. 3a, only 1740 to 1750 UTC.

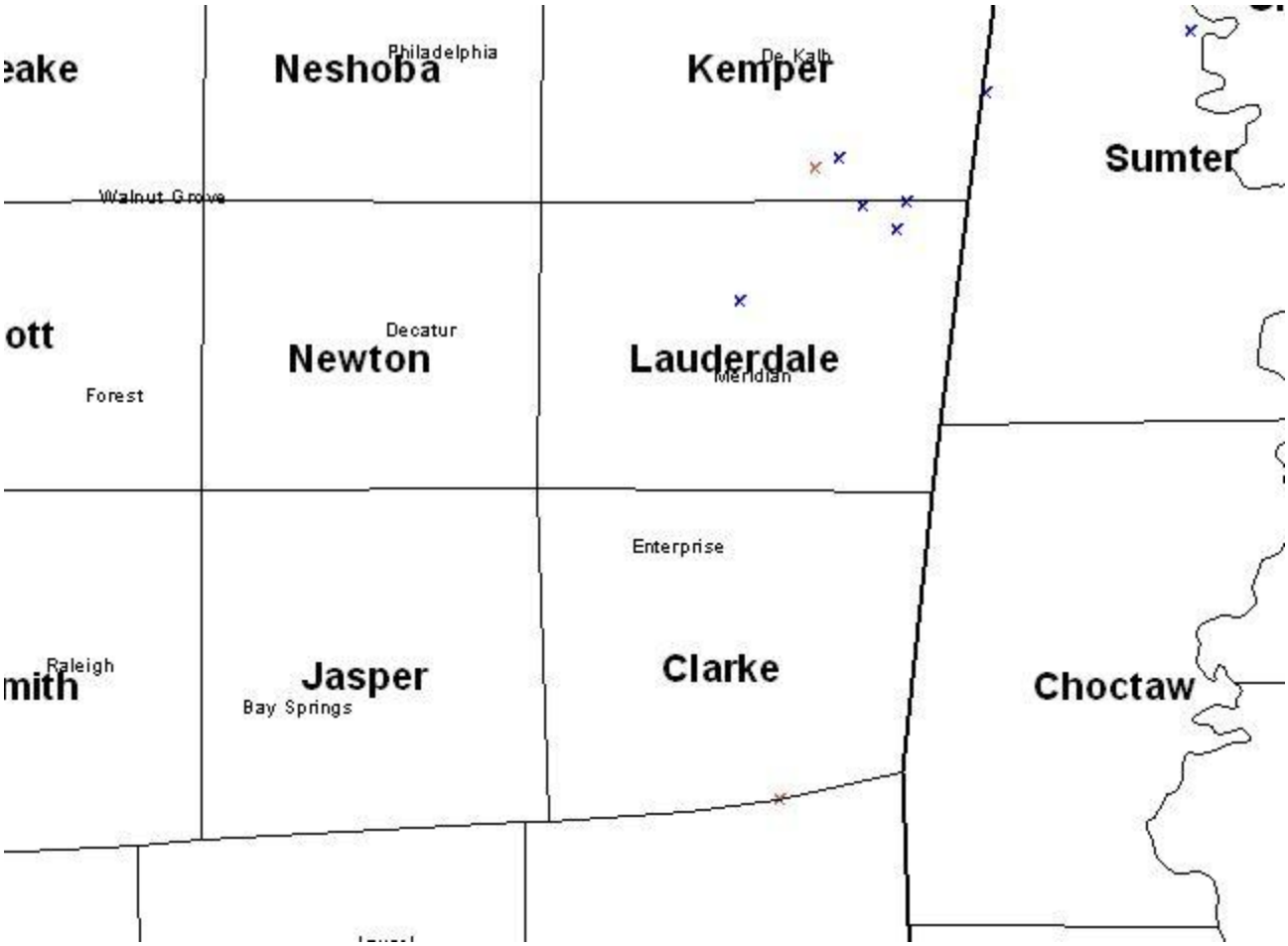
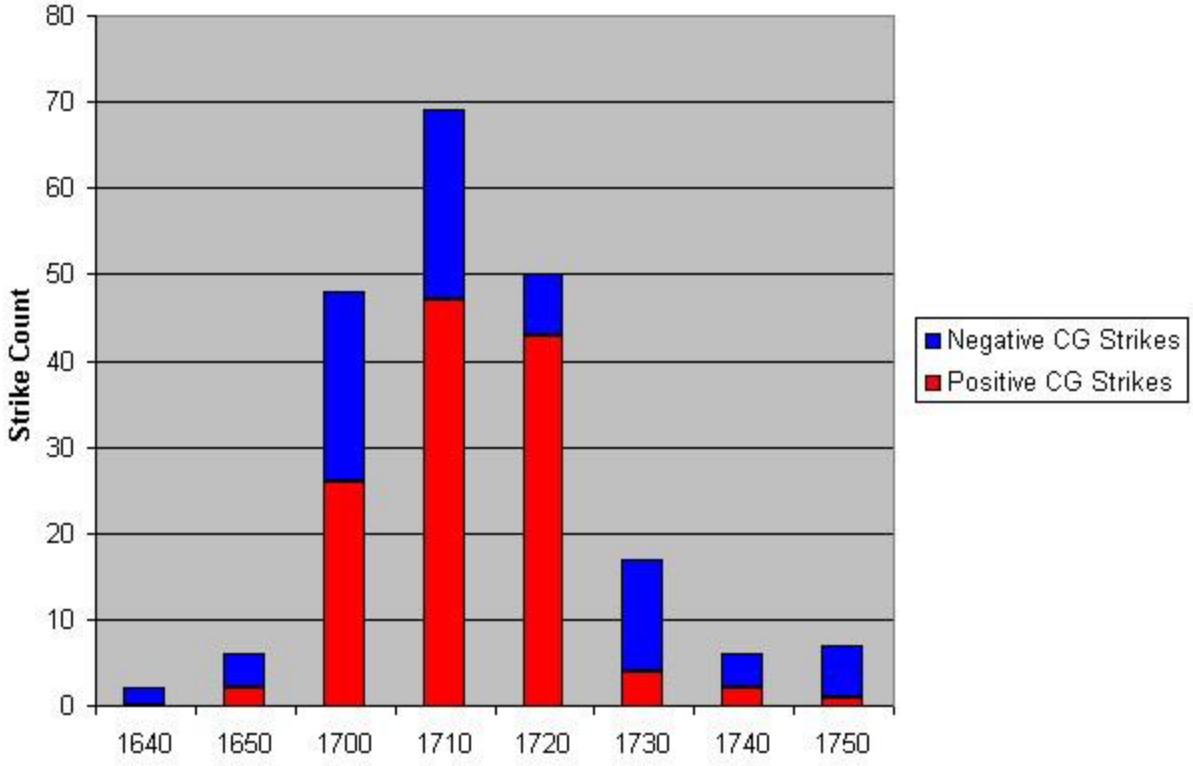


Figure 5 Total number of CG lightning strikes from the supercell thunderstorm that produced the F2 tornado in Lauderdale County on 16 December 2000.
The total number of CG strikes are plotted in 10 minute increments ending at each UTC time shown in the x axis. The tornado was on the ground from 1730
to 1745 UTC, which corresponds to the last two data bars on the graph.


Strike Count
80
70
60
50
40
30
20
10
0
1640
1650
1700
1710
1720
1730
1740
1750
Negative CG Strikes
Positive CG Strikes