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# An Investigation of North Alabama Lightning Mapping Array Data and Usage in the Real-Time Operational Warning Environment During the March 2, 2012, Severe Weather Outbreak in Northern Alabama

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## 1. INTRODUCTION

The North Alabama Lightning Mapping Array (NALMA) is a very high frequency (VHF) detection network (Koshak et al. 2004, Goodman et al. 2005) consisting of 11 sensors spread across north central Alabama and two sensors located in the Atlanta, Ga., metropolitan area. The primary advantage of this network is that it detects total lightning, or the combination of both cloud-to-ground and intra-cloud lightning, instead of cloud-to-ground lightning alone. This helps build a complete picture of storm evolution and development, and can serve as a proxy for storm updraft strength (Williams et. al. 1999, Goodman et. al. 2005), particularly since intra-cloud lightning makes up the majority of all lightning in a typical thunderstorm.

While the NALMA data do not directly detect the occurrence of severe weather, they can indirectly indicate when a storm is strengthening (weakening) due to increases (decreases) in updraft strength, as the updraft is responsible for charging mechanisms within the storm. Data output are VHF radiation sources, which are produced during lightning breakdown processes. These sources are processed into 2x2 km source density grids and are ported into the Advanced Weather Interactive Processing System (AWIPS) for NWS offices in Huntsville, Ala., Nashville, Tenn., Morristown, Tenn., and Birmingham, Ala., in near real-time. An increase in sources, or source densities, correlates to increased lightning activity and trends in updraft magnitude as long as the storm is within about 240 km of the center of the network.

Operationally, these data have been used at the Huntsville NWS office since early 2003 through a collaborative effort with NASA's Short-term Prediction Research and Transition Center (SPoRT; Darden et. al. 2002, Goodman et al. 2004). Total lightning observations have become a useful tool for forecasters during real-time warning operations (Bridenstine et. al. 2005, Nadler et al. 2009, Darden et. al. 2010, Stano et al. 2011, White et al. 2012). One of the operational advantages of the

NALMA is the two-minute temporal resolution of the data, which provides forecasters with two to three data updates during a typical volume scan of the WSR-88D radar. The total lightning data can increase a forecaster's confidence to issue or not issue a warning since the NALMA data provide additional insight into the storm's evolution between successive radar volume scans.

While the 2 March 2012 tornado outbreak is best-known for its violent tornadoes across the Ohio Valley, the first tornadoes of the day occurred farther to the south in northern Alabama. Two significant tornadoes occurred in just over one hour: a long-track EF-3 from 1510 to 1600 UTC, and a relatively short-lived EF-2 from 1610 to 1615 UTC. (Another brief, weak tornado occurred from 1608 to 1610 UTC.) An additional round of severe weather occurred later in the afternoon, beginning around 1955 UTC. The second round of storms was characterized more by large hail (including reports of hail as large as baseballs and softballs) than tornadoes, though four additional weak, (EF-0 and EF-1) brief tornadoes occurred between 1955 and 2146 UTC. Figure 1 shows the March 2, 2012 tornado tracks over northern Alabama and adjacent areas of southern Tennessee.

Atmospheric conditions during the morning portion of the event were generally more favorable for tornadogenesis, characterized by higher low-level wind shear and lower lifting condensation level (LCL) heights as compared to the afternoon. Figure 2a and 2b illustrate RUC proximity soundings from 1600 UTC, during the most active part of the morning event, and 2000 UTC, during the most active part of the afternoon event. Surface-based CAPE decreased slightly (1841 J $kg^{-1}$ to 1502 J $kg^{-1}$) but 0-3 km storm-relative helicity decreased from 508 $m^2$ $s^{-2}$ to 342 $m^2$ $s^{-2}$, and the LCL height increased from 875 m to 1225 m. While the afternoon values still suggested the possibility for tornado development, it appears that there were fewer (if any) low-level boundaries in place to facilitate or enhance tornadogenesis (Markowski 1998).

## 2. LMA DATA AS A DECISION SUPPORT TOOL

On the morning of March 2, 2012, the NALMA data were used as a short-term decision support tool to assess and anticipate the potential for severe weather at the onset of the event. Figure 3 is an AWIPS four panel display at approximately 1446 UTC (NALMA data at 1444 UTC), preceding the initial severe thunderstorm and tornado warnings that morning. At this time, showers and thunderstorms were aligned generally from southwest to northeast across the area. The Huntsville NWS radar (KHTX) indicated reflectivity values around 60-65 dBZ east of the town of Red Bank in northern Lawrence County (Figure 3, upper right). Maximum source density values from the NALMA were just over 200, collocated with the strongest updrafts and adjacent to the areas of heaviest rainfall (Figure 3, upper left). A broad area of cyclonic rotation and moderately low Correlation Coefficient (CC) values were also evident in northern Lawrence County (Figure 3, lower left). The KHTX 3.4 degree elevation scan (corresponding to about 24 kft AGL and temperatures around -20C in this area) showed a core of maximum reflectivity values around 55 dBZ (Figure 4, upper right), which is near generally accepted empirical values for severe hail (Donovan and Jungbluth 2007). While a synthesis of the data suggested that hail was present in the storm, the lack of a deep core of high reflectivities and only moderately low CC values indicated that the hail was not likely at severe criteria (one inch or greater).

With radar data not yet suggesting severe hail was present, and with no severe weather reports from nearby storm spotters, a warning was not issued at this time. However, numerical model guidance and mesoscale analyses suggested that environmental conditions would become more favorable for storm organization as time progressed, so strengthening was considered possible. The NALMA data from 1446 UTC made it clear that the storm was indeed strengthening. A sudden increase in source densities was noted (Figure 5, upper left), with maximum densities climbing to over 400 sources. This represented more than a 200% increase in source densities in just two minutes, indicating the increase in total lightning and inferring the strengthening updraft within the storm.

Successive NALMA data between radar volume scans from 1446 UTC to 1450 UTC indicated a sustained increase in total lightning activity (Figure 6), suggesting a likely increase in overall storm strength. With this new information and other radar data (e.g., relatively high reflectivities, and moderately low CC values) approaching generally accepted threshold values for severe weather, the first severe warning of that morning was issued at 1451 UTC. At 1458 UTC, the first severe weather report of quarter size (1 inch) hail was received at the Huntsville NWS office. As the storm moved downstream, hail up to the size of golf balls (1.75 inches) and 70 mph winds were reported by local law enforcement at 1508 UTC. This storm also produced a tornado in the Canebrake community just south of Athens in central Limestone County beginning at 1510 UTC, which continued for approximately 55 km 34 miles through Limestone and Madison Counties, producing up to EF-3 scale damage.

Overall, the NALMA data showed a rapid increase in total lightning and source densities before the onset of severe weather (large hail), and then a decrease before the tornado developed. These data allowed for extra warning lead time in this particular situation, perhaps the full seven minutes before the first severe weather report was received. This represented a particularly good case, in which the NALMA data served as an important decision support tool, indicating that a sub-severe thunderstorm was likely to undergo rapid strengthening, and that a warning was necessary.

## 3. MORNING SIGNIFICANT TORNADOES

The original supercell that prompted the severe thunderstorm warning at 1451 UTC also produced a long-track tornado shortly thereafter. The tornado touched down in the Canebrake community just south of Athens in central Limestone County at 1510 UTC, and continued along a 54.8 km path through Limestone and Madison Counties, producing peak winds of 63 m $s^{-1}$ (EF-3 on the Enhanced Fujita Scale).

As discussed, a pronounced increase followed by a sharp decrease in sources occurred prior to the tornado touchdown. However, incorporating supplemental data sets such as total lightning into the operational environment often becomes more difficult as a severe weather event unfolds. Due to heavy workload demands and the time critical nature of operations during an active tornadic event, forecasters primarily rely on radar observations with supplemental satellite and near real-time storm reports. This time sensitive environment can limit the interrogation of additional data, such as that from the NALMA. This begs the question: can total lightning provide additional useful information about a tornado in real time?

To that end, total lightning source density values for the long-track EF-3 tornado were plotted versus time (Figure 7). A prolonged lightning jump can be observed from 1536 to 1544 UTC, increasing more than sixteen times the 10-min running standard deviation. The jump preceded the most intense portion of the tornado path across northeastern Madison County, AL, by approximately 6 minutes. Around the same time, a second lobe of NALMA sources developed and exhibited a jump in its own right (200 to 400 sources from 1546 to 1548 UTC). The subsequent decreases in both lobes correspond to a general weakening trend, and the tornado lifted at 1600 UTC.

Similar trends were observed with the second significant tornado of the morning (Figure 8), an EF-2 that touched down barely 10 minutes after the first had lifted, but lasted a much shorter time. Figure 8 displays the same total lightning temporal trend; much like the first tornado, the second tornado reaches a relative intensity maximum at the same time as sources reached a peak. Additional research on long-track tornadoes is planned to determine if this trend is common, or dependent on storm type and/or environment.

## 4. AFTERNOON WEAK TORNADOES AND LARGE HAIL

A second wave of severe thunderstorms occurred during the afternoon of 2 March, beginning at 1955 UTC. Low-level wind shear decreased while deep-layer shear remained robust, resulting in a transition to damaging winds and large hail. The majority of the severe weather reports occurred after 1900 UTC, including all of the "giant" hail (> 5 cm) reports. Four weak (EF-0 or EF-1) tornadoes also were reported, all of which occurred within a 24 km radius. Three of the four tornadoes and all of the giant hail reports occurred with just two supercells, which will be analyzed in this paper.

The first supercell developed across Colbert and Lawrence counties around 1930 UTC. A significant jump in sources (greater than 4 standard deviations) occurred at 1944 UTC, and the first tornado of the afternoon, an EF-0, followed at 1955 UTC in northwestern Limestone County, AL (Figure 9). The total lightning trend followed the expected conceptual model, with the tornado occurring well after the initial jump and as the sources fell sharply. Quarter-size hail was also reported with the supercell at 2000 UTC.

Subsequent hail reports associated with this supercell were all preceded by sharp increases, if not full two-standard deviation lightning jumps as suggested by Schultz et al. (2009). There is some difficulty in determining whether jumps preceded severe weather since there were multiple source increase/decrease combinations during the life cycle of the storm. However, it is worth noting that sources dropped off markedly by 2030 UTC, as the supercell moved into southern Tennessee. Sources exceeded 20 just once after that time, yet the storm continued to produce large hail to the size of baseballs as it moved into southeastern Tennessee. This problem is most likely due to degraded detection efficiency of the NALMA network, which suffered damage during the 27 April 2011 outbreak and was operating with 6 sensors centered on the Huntsville area, instead of the normal 11. The network has since been restored to full capability as of spring 2012.

A second supercell developed over extreme northeastern Mississippi and crossed the Alabama border around 2000 UTC. In short order, it produced quarter-size hail (2007 UTC), baseball-size hail (2015 UTC), and softball-size hail (2035 UTC) across Colbert and Lauderdale counties. NALMA data are comparatively unimpressive during this span, exceeding 20 sources just four times (Figure 10). Relatively small increases preceded two of the three hail reports, but they are not large enough to be called jumps and could easily be dismissed as noise by operational meteorologists in the heart of an event. The small values and subtle increases can likely be attributed to the degraded state of the network, since source density products are more susceptible to network degradation compared to flash density products. SPoRT will transition to providing flash density products to partner WFOs in the future as the AWIPS II software is implemented within the NWS.

A more robust increase—more than three standard deviations—preceded an EF-0 tornado in Limestone County by just two minutes. Another increase occurred eight minutes later and preceded an EF-1 tornado in Limestone County by 6 minutes. Both of these increases occurred as the storm moved into the heart of the NALMA network, increasing the likelihood that total lightning would be properly detected.

In general, the afternoon storms were characterized by smaller source density values than the morning storms, and consequently increases were much more subtle and difficult to detect. The largest jumps occurred as the storms entered the heart of the NALMA network, but these jumps corresponded well to severe weather reports and tornadoes.

## 5. Summary and Future Work

Total lightning information from the North Alabama Lightning Mapping Array was highly beneficial to operational meteorologists at WFO Huntsville during the morning of 2 March 2012. A pronounced lightning jump alerted the warning forecaster that a seemingly-marginal severe thunderstorm was more likely to produce severe weather, providing increased lead time over the use of Doppler radar data alone. However, diminished detection efficiency hurt the utility of the data in real time during the afternoon despite the continuing severe weather threat.

The launch of GOES-R in 2015 will help eliminate such detection efficiency issues while bringing total lightning detection to a much larger domain (Figure 11). The Geostationary Lightning Mapper (GLM) instrument will provide total lightning to almost a full-disk domain, but at a lower spatial resolution than existing ground-based networks (8 km at nadir versus 1 km or 2 km).

Additional tools also are under development to help alert forecasters to lightning jumps. A tool jointly developed by WFO Huntsville and SPoRT will provide real-time trending information as a time series (example in Figure 12) so that forecasters can visualize trends more easily. This is part of a larger collaborative effort with the Meteorological Development Laboratory to create a moving trace tool for any dataset in AWIPS II. This makes total lightning more relevant and useful in a time-sensitive operational environment. In addition, the NWS is funding a project to automate the lightning jump detection outlined by Schultz et al. (2009). The automated lightning jump algorithm would eliminate the need to interrogate the raw total lighting information, expediting the warning decision-making process while increasing forecaster confidence and warning lead time.

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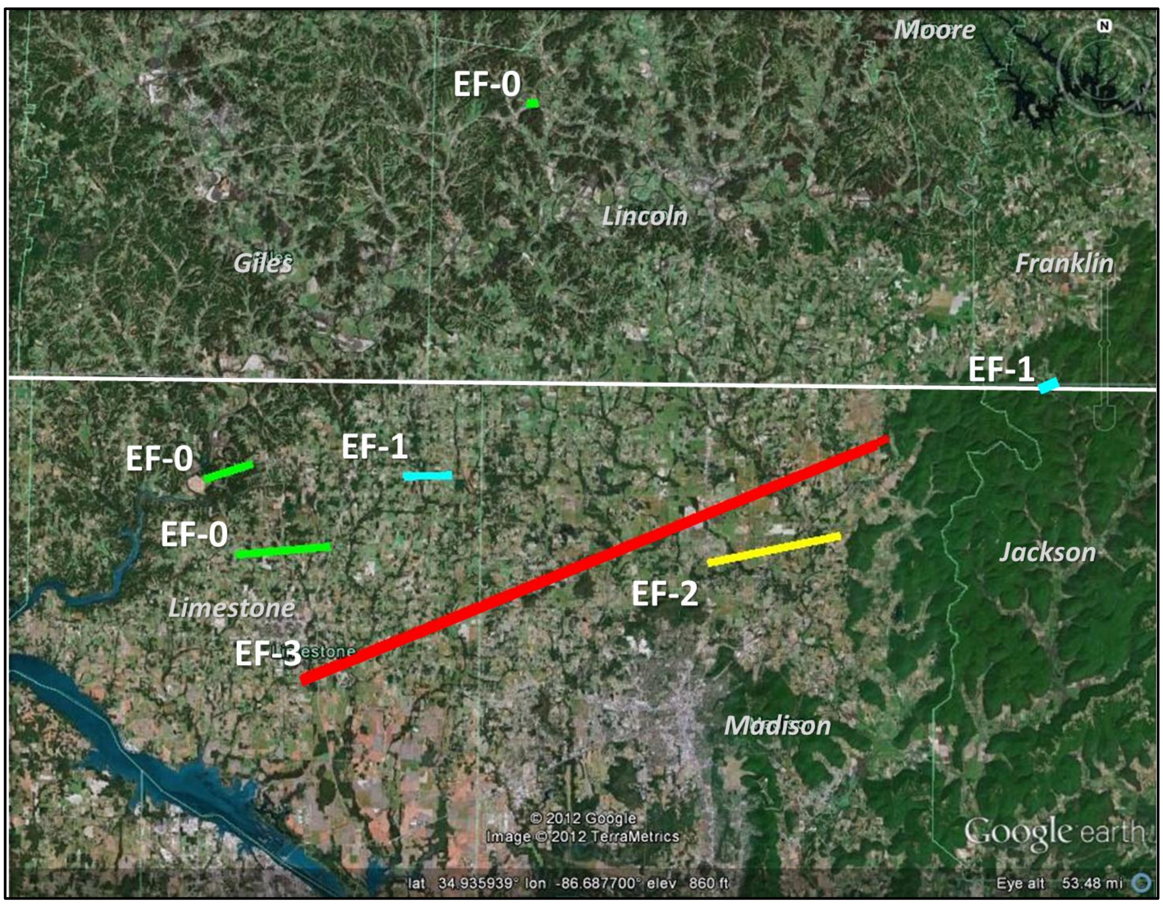

Figure 1: Tornado tracks from 2 March 2012 across northern Alabama and southern Tennessee.

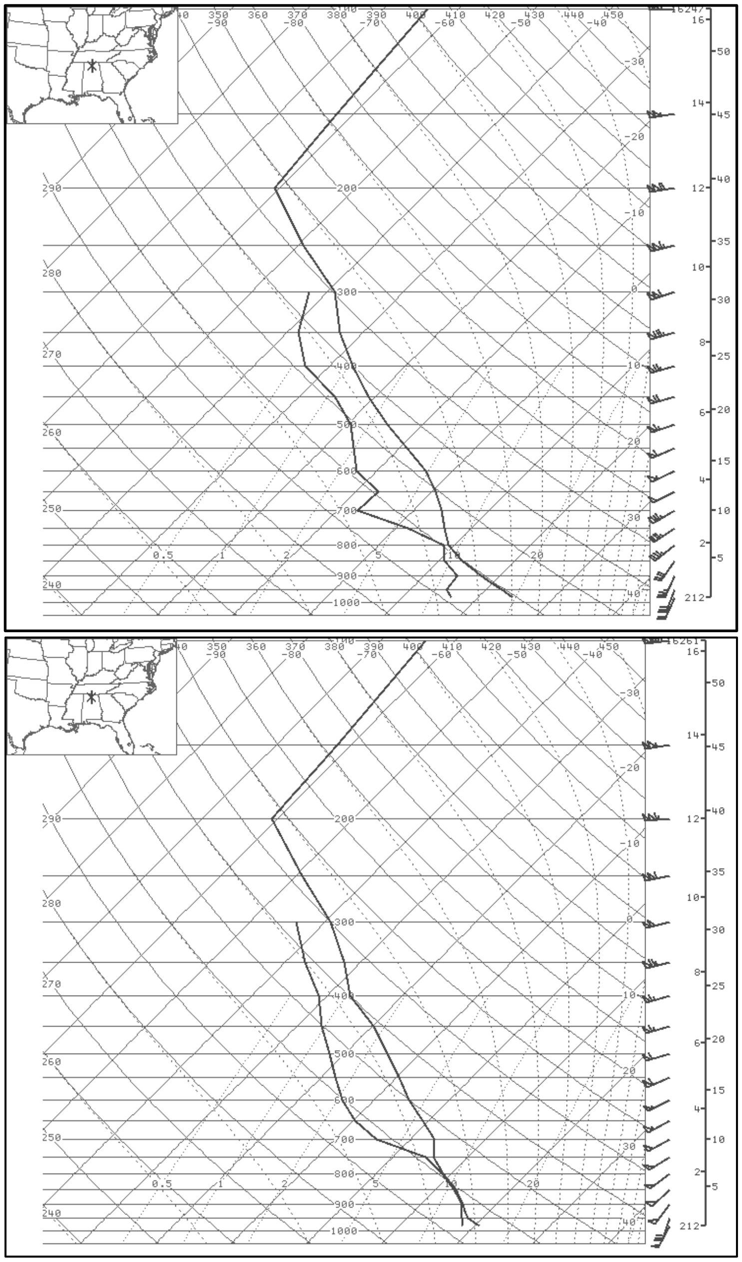


Figure 2a (top) and 2b (bottom): Proximity soundings from the 12-km Rapid Update Cycle (RUC) centered at Huntsville, AL (KHSV) for 1600 UTC (a) and 2000 UTC (b) on 2 March 2012.

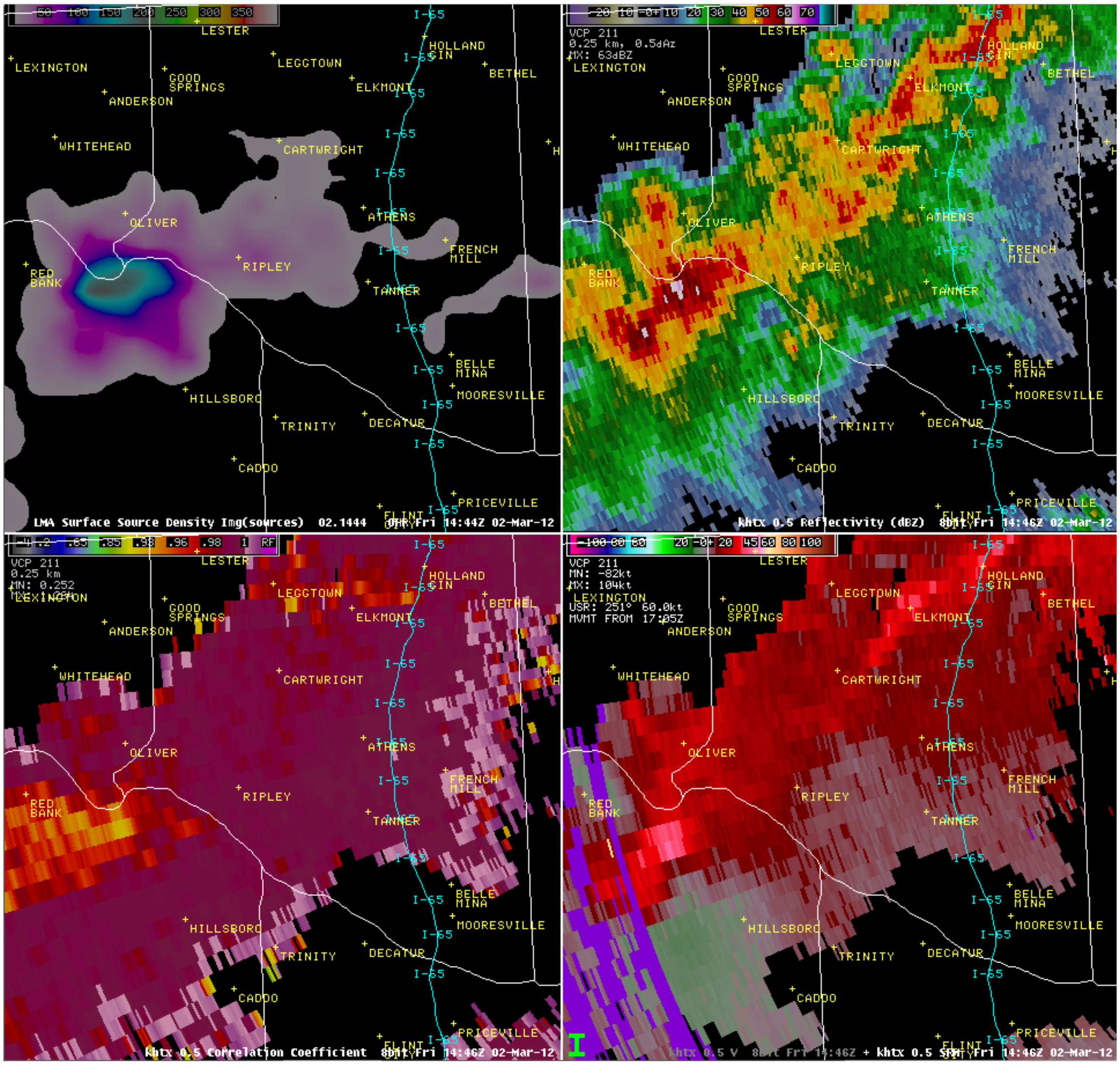

Figure 3. Four-panel AWIPS display on March 2, 2012 of portions of northern Alabama clockwise starting from the upper left: NALMA vertically integrated source density at 1444 UTC, and 0.5 KHTX reflectivity (dBZ), 0.5 SRM (kts) and 0.5 Correlation Coefficient (ρhv) at 1446 UTC. County borders are in white, cities in yellow and Interstate 65 is in light blue.

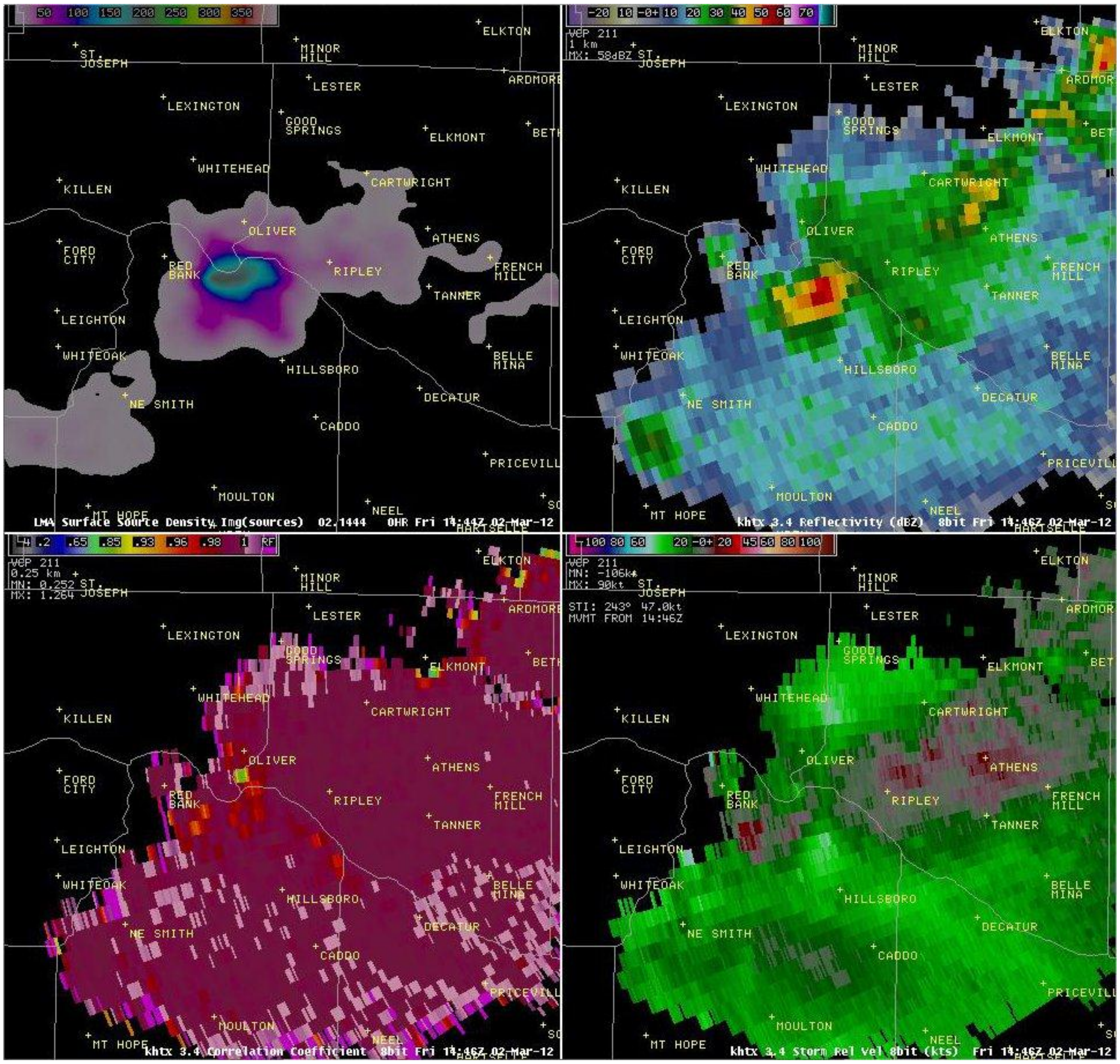


Figure 4. Four-panel AWIPS display on March 2, 2012 of portions of northern Alabama clockwise starting from the upper left: NALMA vertically integrated source density at 1444 UTC, and 3.4 KHTX reflectivity (dBZ), 3.4 SRM (kts) and 3.4 Correlation Coefficient (ρhv) at 1446 UTC.

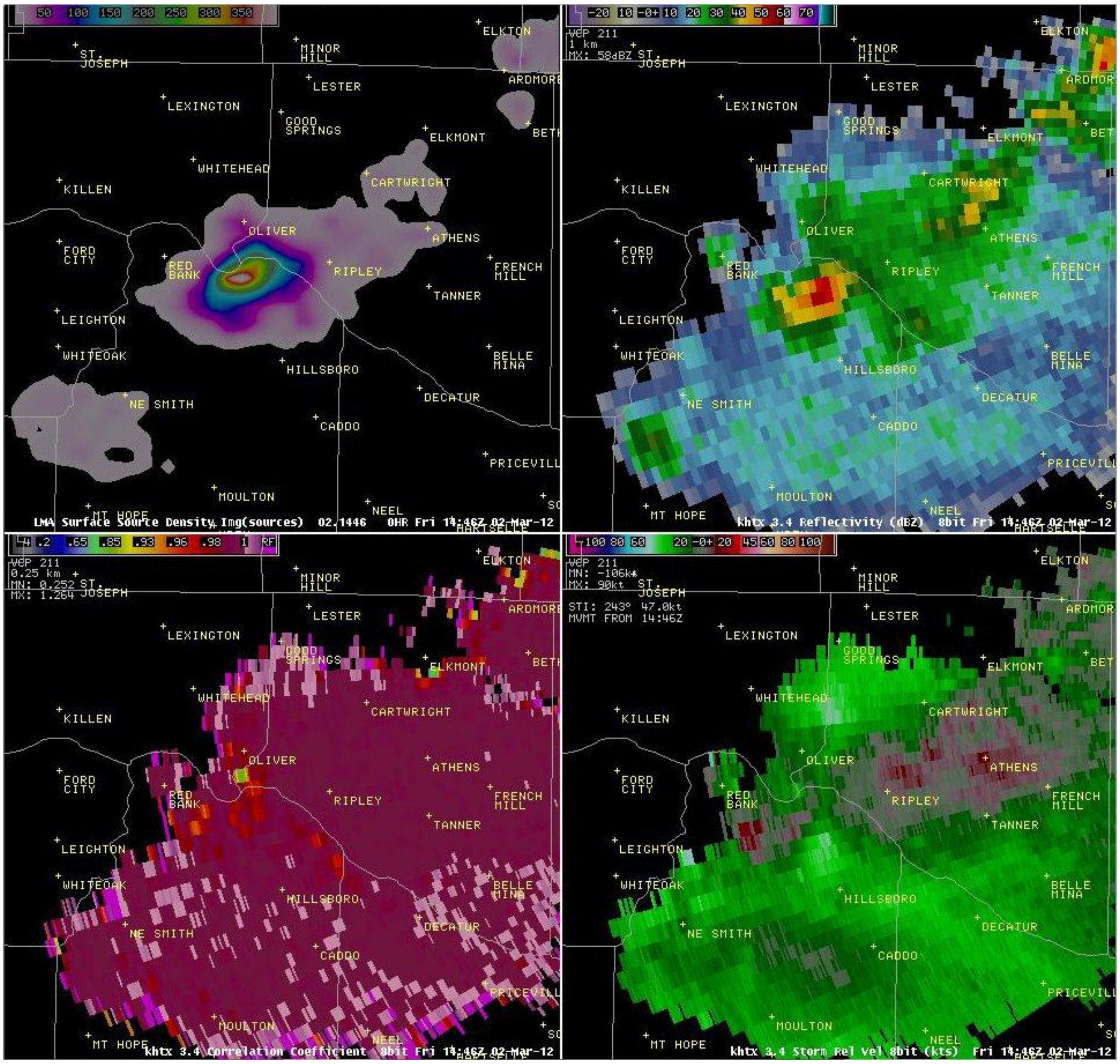


Figure 5. Four-panel AWIPS display at 1446 UTC March 2, 2012 of portions of northern Alabama clockwise starting from the upper left: NALMA vertically integrated source density, 3.4 KHTX reflectivity (dBZ), 3.4 SRM (kts) and 3.4 Correlation Coefficient (ρhv).

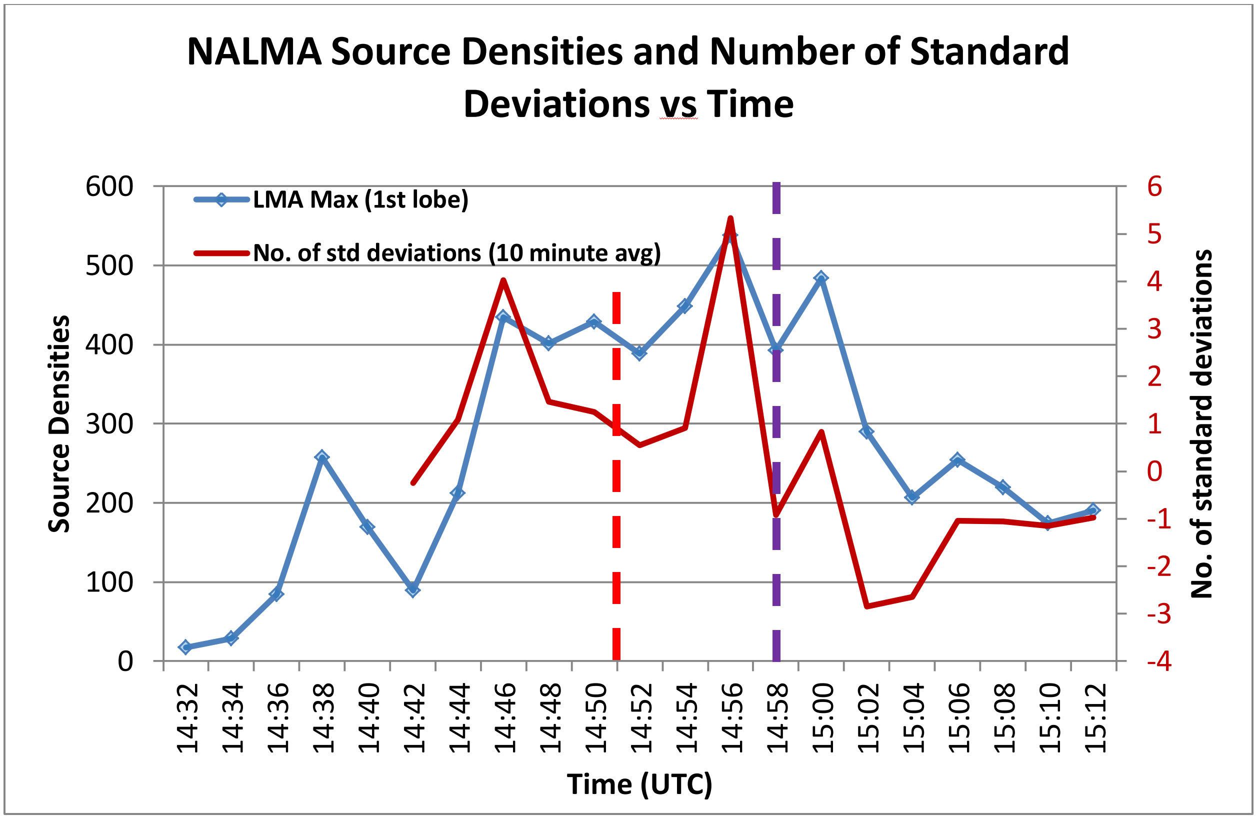


Figure 6. NALMA source density and number of standard deviations versus time for the initial severe thunderstorm. Blue line shows source densities while the magenta line shows a 10 minute preceding average of number of standard deviations. The vertical red hashed line indicates the severe thunderstorm warning issuance, the purple hashed line indicates the receipt of the first severe weather report, and the black hashed line indicates the report of 1.75 inch hail and 70 mph winds.

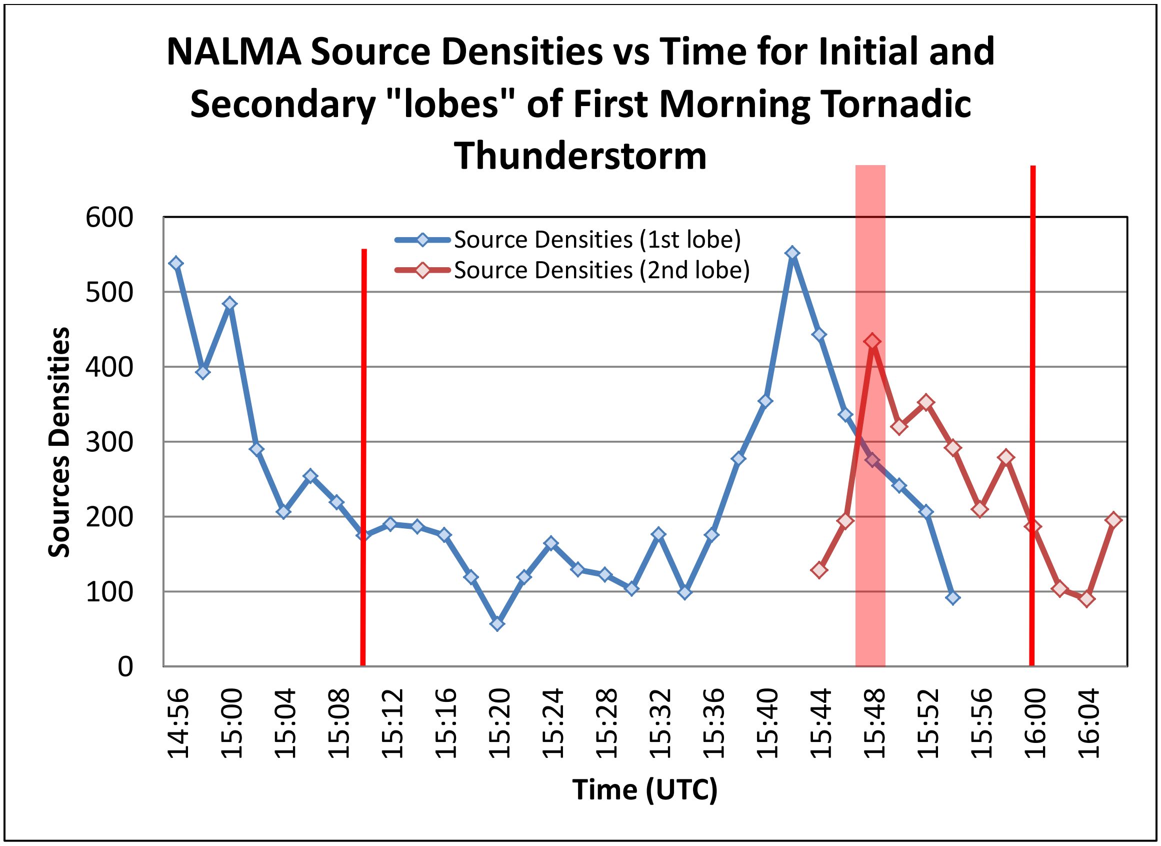


Figure 7. NALMA source density versus time for the first morning tornadic thunderstorm (EF-3). Vertical red lines indicate (1) the start time (1510 UTC), (2) peak intensity (approx. 1548 UTC), and (3) end time of the tornado (1600 UTC), respectively.

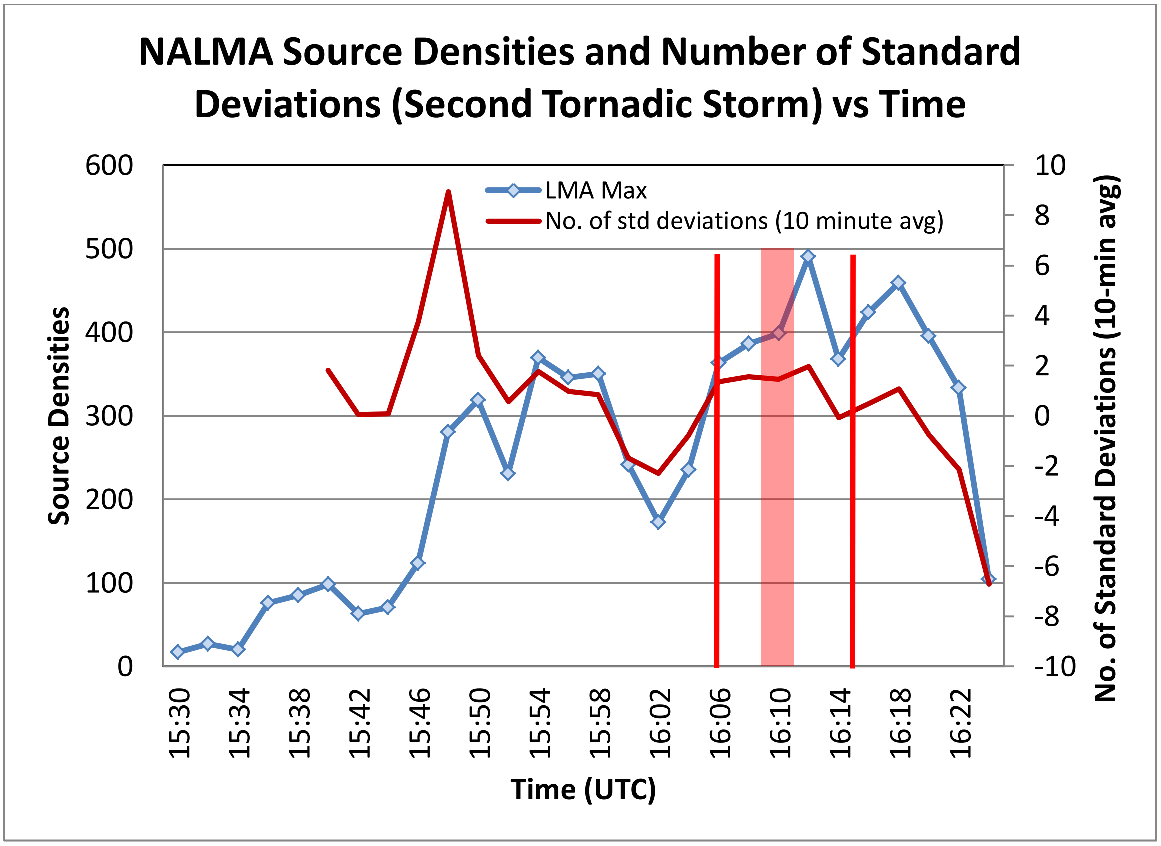


Figure 8. NALMA source density and number of standard deviations versus time for the second severe thunderstorm. Blue line shows source densities while the magenta line shows a 10 minute preceding average of number of standard deviations. Vertical red lines indicate (1) the start time (1606 UTC), (2) peak intensity (approx. 1610 UTC), and (3) end time of the tornado (1615 UTC), respectively.

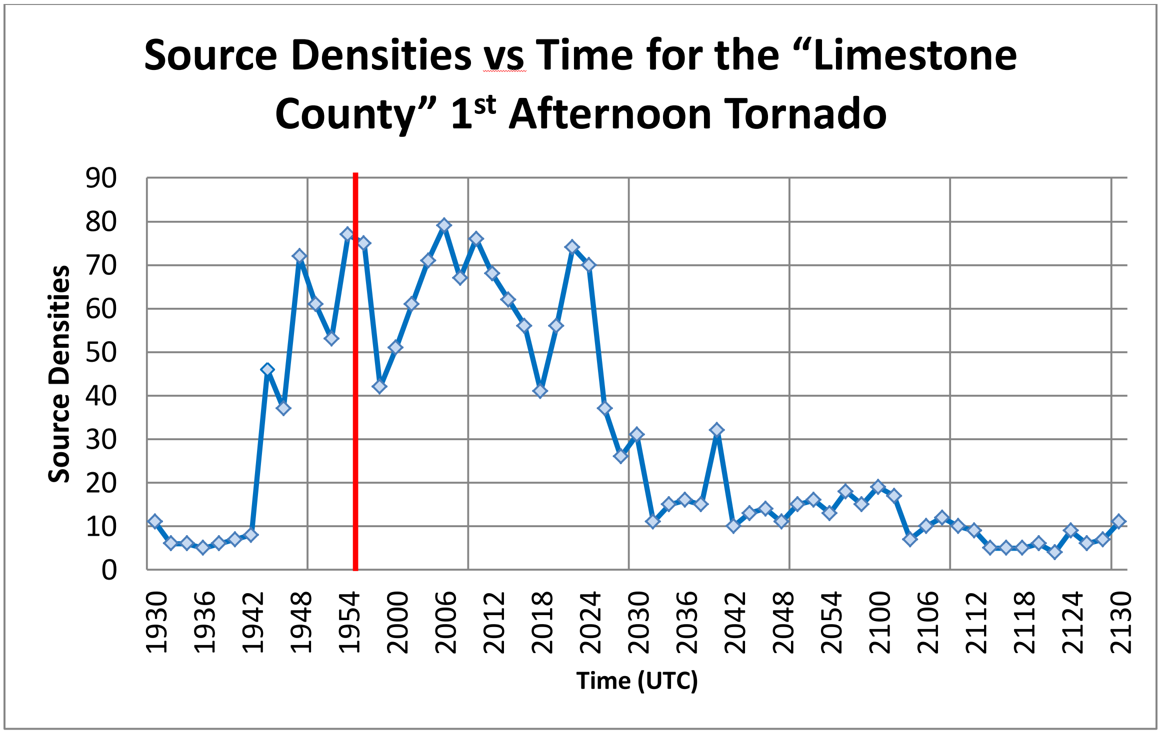


Figure 9. NALMA source density versus time for the first afternoon tornadic thunderstorm. Blue line shows source densities. Vertical red line indicates the start time (1955 UTC) of the tornado. This tornado was only on the ground for about three minutes.

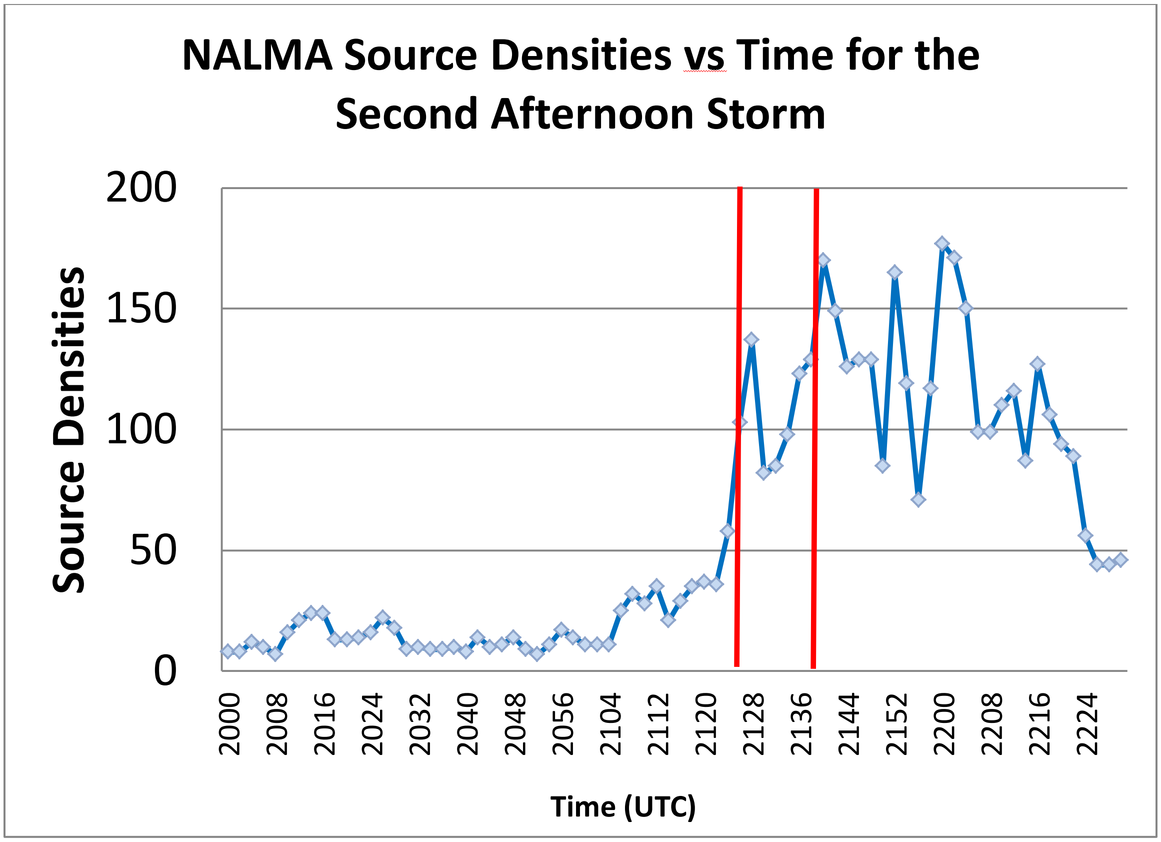


Figure 10. NALMA source density versus time for the second afternoon tornadic thunderstorm. Blue line shows source densities. Red lines indicate touch downs of two separate tornadoes in northeastern Limestone County. The first tornado was on the ground for approximately 5 minutes, while the second tornado was on the ground for approximately 7 minutes.

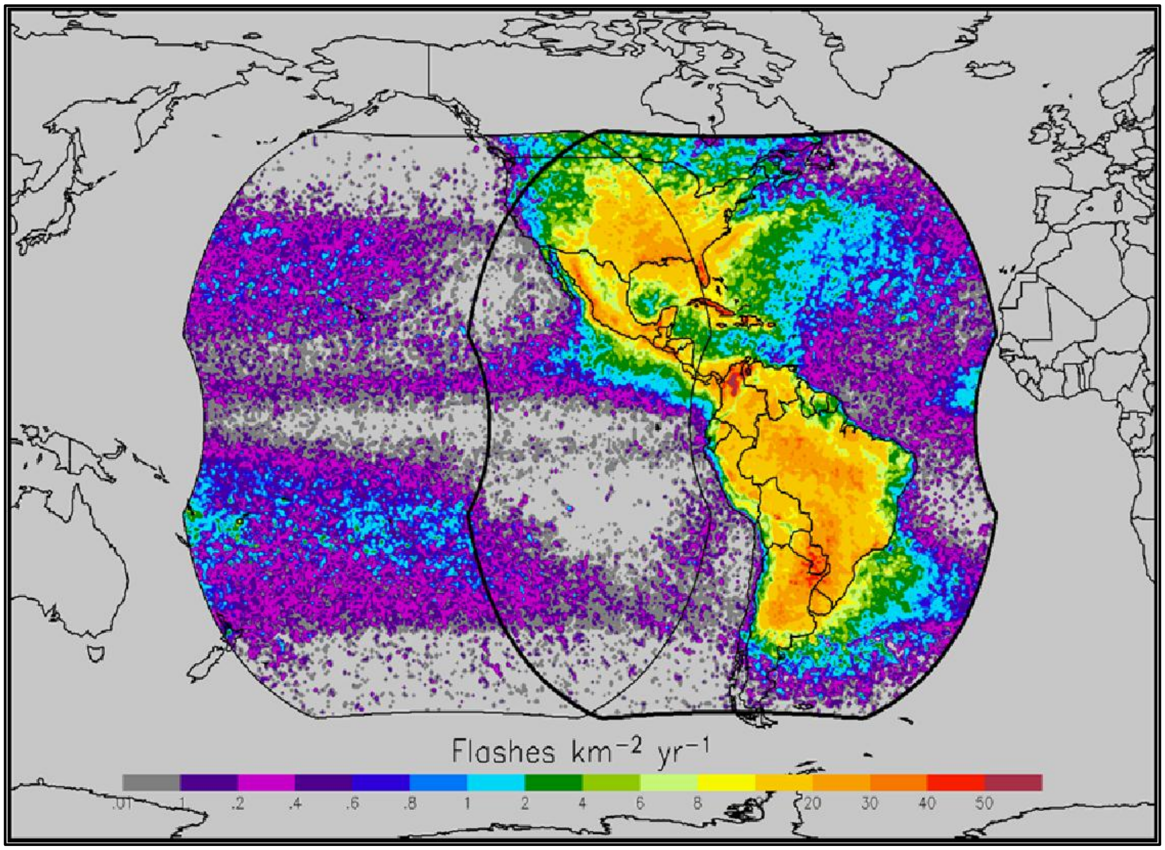


Figure 11: Anticipated domains of the Geostationary Lightning Mapper from the GOES-East and GOES-WEST positions, outlined in black. The background image reflects a lightning climatology derived from the Lightning Imaging Sensor and Optical Transient Detector.

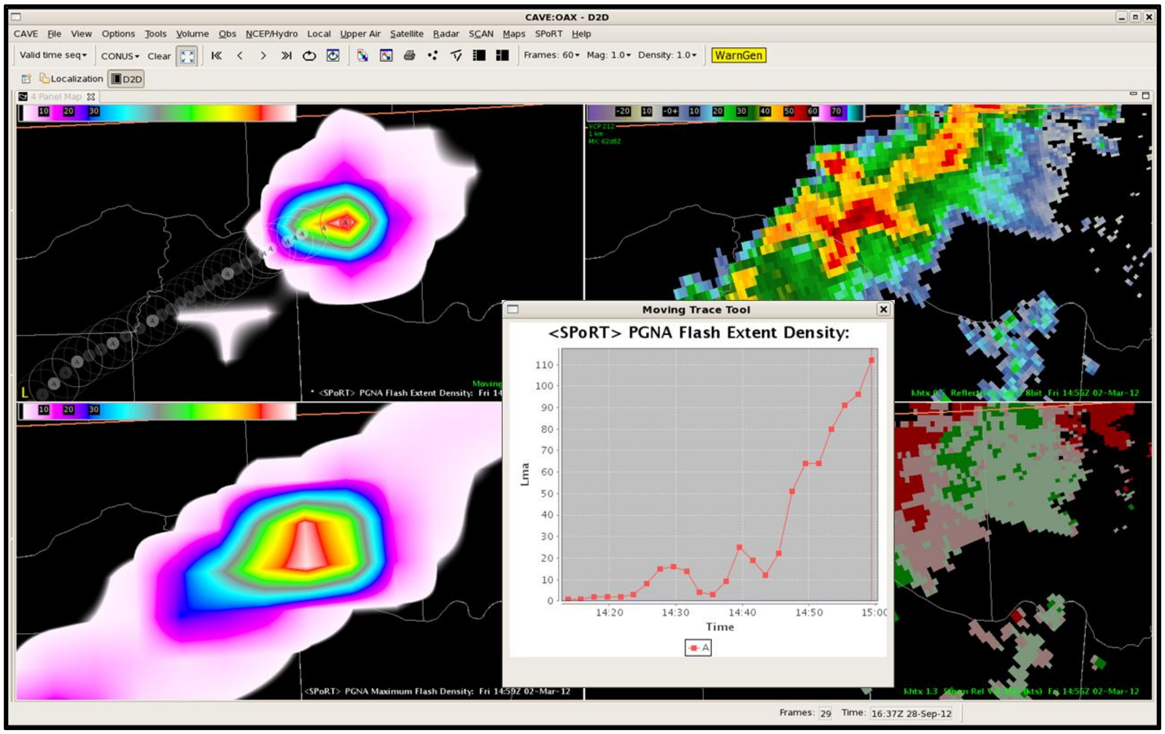

Figure 12: An AWIPS (Advanced Weather Interactive Processing System) 2 “CAVE” (Common AWIPS Visualization Environment) window illustrating total lightning information from the NALMA and the storm-tracking centroid (top-left), KHTX 0.5-degree reflectivity (top-right), KHTX 0.5-degree Storm Relative Velocity (bottom-right), and maximum flash density over 30 minutes (bottom-left).  The line graph near center illustrates output from the moving trace tool.