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# AN OPERATIONAL PERSPECTIVE OF TOTAL LIGHTNING INFORMATION

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**ABSTRACT**

The close and productive collaborations between the NWS Warning and Forecast Office (WFO), the Short Term Prediction and Research Transition Center (SPoRT) at NASA/Marshall Space Flight Center and the University of Alabama in Huntsville (UAH) have provided a unique opportunity for science sharing and technology transfer. One significant technology transfer that has provided immediate benefits to NWS forecast and warning operations is the use of data from the North Alabama Lightning Mapping Array (NALMA). This network consists of ten VHF receivers deployed across northern Alabama with a base station located at the National Space Science and Technology Center (NSSTC).

Preliminary investigations done at WFO Huntsville, along with other similar total lightning networks across the country, have shown distinct correlations between the time rate-of-change of total lightning and trends in intensity/severity of the parent convective cell. Since May 2003, WFO Huntsville has been able to view the total lightning data in the Advanced Weather Interactive Processing System (AWIPS), where it can be plotted in conjunction with other more traditional remotely sensed data (radar, satellite, and surface observations). The additional insight gained from its use has raised the situational awareness of the WFO staff during convective situations. The use of total lightning information, either from current ground based systems or future space borne instrumentation, may substantially contribute to the NWS mission, by enhancing severe weather warning and decision-making processes.

Operational use of the data has been maximized at WFO Huntsville through a process that includes forecaster training, product implementation, and post event analysis and assessments. Since receiving these data, nearly 50 surveys have been completed highlighting the use of total lightning information during significant events across the Tennessee Valley. In addition, 150 specific cases of interest have been archived for collaborative post storm analysis. From these datasets, detailed information on trends from radar and total lightning can be compared to corresponding damage reports. This paper will emphasize the effective use of total lightning information in warning decision making along with best practices for implementation of new technologies into operations.

## 1. INTRODUCTION

The National Weather Service Forecast Office in Huntsville, Alabama is co-located with the University of Alabama in Huntsville and scientists from NASA's Marshall Space Flight Center (MSFC). A small group of earth scientists from NASA have formed the NASA Short-term Prediction Research and Transition (SPoRT) Center. SPoRT seeks to accelerate the infusion of NASA earth science observations, data assimilation and modeling research into NWS forecast operations and decision-making.

The collaboration between NASA atmospheric scientists and NWS meteorologists have provided forecasters several unique datasets to use during forecast and warning operations (Darden et. al., 2002). The NALMA is one such dataset that became operational in November 2001. The NALMA is a principal component within a regional severe weather test bed that utilizes innovative science and technologies in the short-term prediction of severe and hazardous weather (Goodman et. al., 2003). Since 2001, a large number of tornadoes, hailstorms, damaging wind events, non-tornadic supercells, and ordinary non-severe thunderstorms have been observed within the domain of the NALMA network.

The NALMA, developed by NASA scientists and centered in Huntsville, Alabama, has allowed NWS offices across the region the opportunity to employ "total lightning" data in real-time for forecast and warning decision making. The NALMA network detects total lightning activity (both cloud-to-ground and intracloud

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lightning) which can be much greater than the cloud-to-ground activity alone. The NWS currently receives cloud-to-ground lightning from Vaisala's National Lightning Detection Network (NLDN). Though several NWS offices now have access to total lightning data via ground based lightning mapping sensors (Sterling, Nashville, Birmingham, Huntsville, Dallas, Houston, Melbourne, Norman, etc.), the majority of the WFOs across the country still rely on the NLDN network. Access to total lightning data has enhanced situational awareness in the local forecast offices and has added additional confidence to the warning decision making process. This paper provides an overview of NALMA specific products, and discusses preliminary improvements in short-term forecasts for severe convective weather. Future applications of the algorithms and warning decision making tools to the Geostationary Lightning Mapper (GLM) planned for future geostationary satellites GOES-R are also discussed.

## 2. BACKGROUND

The NALMA (Goodman et al, 2005) is based on the Lightning Mapping Array (LMA) developed at New Mexico Tech (e.g. Rison et al., 1999) and consists of 10 VHF receivers deployed across north Alabama (Figure 1). A base station is located at the National Space Science and Technology Center (NSSTC), which is on the campus of the University of Alabama in Huntsville. Each receiver records the time and magnitude of the peak lightning radiation signal received in successive 80 μs intervals and relays this information to the base station. To allow near real-time processing, the data are decimated from 80 μs time intervals to 500 μs. The data are then processed to determine the horizontal, vertical, and temporal location of each source. Several sources (up to many hundreds) can be detected from each lightning flash, allowing one to map the spatial and temporal extent of each flash. The system detects sources from both cloud-to-ground and intra-cloud lightning activity (i.e., total lightning). The detection efficiency decreases with distance from the network center.

A netCDF file of total lightning source density, binned onto a 2 km by 2 km horizontal, 1 km vertical grid is computed every two minutes from the NALMA observations. This 3-D grid (460 km by 460 km by 16 km) is then provided to the NWS offices for ingest into AWIPS. The 2 min time scale is at least half the time of radar volume scan updates, providing more rapid insight into changes in storm intensity. The full suite of gridded data is made available via subscription service on the NASA Local Data Manager (LDM) system. WFO Huntsville, along with neighboring offices in Nashville, Birmingham, and Morristown receive these data in real-time via this feed and ingest into their AWIPS decision support system. The AWIPS workstation is utilized to integrate varied weather data and issue a full suite of forecasts and warnings. Forecasters can interrogate the data on all 17 horizontal levels as well as the cumulative source density from all levels. Forecasters can also readily toggle between NEXRAD and NALMA maps to enhance situational awareness during severe weather episodes. The products auto-update on the forecasters' workstation, with a 30-sec latency from the time of ingest. In this way, the forecaster can optimally evaluate the added value of total lightning data within the forecast and warning decision-making process. Figure 2 shows the NALMA domain (as it appears in AWIPS) that fully encompasses the warning area of the Huntsville WFO and partial coverage of six surrounding forecast offices.

To summarize, key objectives of utilizing total lightning data operationally are to:

- Characterize thunderstorm initiation and boundary interactions.
- Identify intensifying and weakening storms through the time rate-of-change of total source rate.
- Evaluate potential of total source rate trends to improve severe storm probability of detection (POD) and lead time (Williams et al., 1999).
- Provide short term lead time for cloud-to-ground strikes.

## 3. UTILITY IN WARNING AND DECISION MAKING

The National Weather Service maintains its mission to "protect life and property" by providing daily climate, public, aviation, marine, fire weather, air quality, space weather and hydrologic forecasts and warnings. Specifically, storm based warnings and follow-up statements are issued by local forecast offices to alert the public of anticipated or ongoing severe convective weather. These warnings and statements are disseminated through a variety of means including local and national media outlets, NOAA All-Hazards Radio, NOAA Weather Wire Service (NWWS), and other subscription type services.

Across the Tennessee Valley, severe weather is a "year round" occurrence with a primary peak season during the months of March, April, and May. A secondary peak in severe weather takes place in November. The geographical location of the Tennessee Valley just north of the warm Gulf of Mexico waters, and in the primary path of mid-latitude storm tracks, makes the region vulnerable to a host of significant weather events - such as squall lines, discrete supercells, and "pulse" type summertime convection. This variety of weather hazards creates a great forecasting and warning decision making challenge for meteorologists. To assist with this daunting challenge, WFO Huntsville forecasters utilize an array of diagnostic tools including radar, satellite, observations, and ground truth information. The inclusion of real-time total lightning has enhanced the warning decision making process immensely.

Specifically, the forecasters at WFO Huntsville focus on using trends in the total lightning data for short-term prediction of severe weather. Williams et al. (1999) studied 30 severe cases in Florida and found that increases in VHF total lightning mapping activity (termed lightning 'jumps') preceded the severe weather by 5-30 minutes. Since this lightning information is provided as gridded fields of lightning sources, the forecasters use the AWIPS sampling tool to determine the source number at various time intervals to establish a trend (Demetriades et. al. 2007). Thus, the forecasters look for qualitative "lightning jumps" within the data while also analyzing other radar and diagnostic trends to determine the optimal warning decision. Future plans include the implementation of a tool to display real-time lightning trending information in AWIPS. As can been seen in Figure 3, an initial test of such a tool has been ongoing at the NWS Forecast Office in Sterling, Virginia in conjunction with the Meteorological Development Laboratory (MDL).

The feedback from the forecasters utilizing the total lightning information in the warning decision making process has been quite positive. Feedback is collected via post event analysis and reviews, emails, and formal surveys and assessments which will be covered thoroughly in a later section. Some examples of the impromptu feedback include comments like: "*The LMA source densities showed a rapid increase in source rates shortly before the hail was reported*", "*The LMA data helped me in my decision to go ahead and issue a severe thunderstorm warning*", and "*The increasing trends in total lightning activity increased the confidence in the reflectivity signatures which then prompted the warning*."

## 4. SELECTED CASE STUDIES

### a. 6 February 2008

The "Super Tuesday" Outbreak of 2008 resulted in two long tracked supercell thunderstorms moving across north Alabama during the pre-dawn hours. These supercell storms produced a series of tornadoes including two EF-4 tornadoes that resulted in 5 fatalities, numerous injuries, and over 11 million dollars in damage. While tornadoes themselves are not unusual in the Deep South in February, such violent tornadoes are quite rare especially during the overnight hours. An unseasonably warm and moist air mass coupled with extremely strong shear, contributed greatly to this unusual nocturnal outbreak across north Alabama.

The source density data available from the NALMA, coupled with the available output from regional radars and ground truth information, allowed WFO Huntsville forecasters to issue life saving tornado warnings with average lead times in excess of 20 minutes. Feedback from our partners and customers was overwhelmingly positive with comments such as: "*Just wanted to pass along what a great job you guys did on early Wednesday's outbreak; You guy's saved hundreds of lives…*" and "*You all were really on the ball…your warnings were right on the money.*"

For this brief review, we will focus on the EF-4 tornado that tracked across Jackson County in northeast Alabama. This tornado formed from a supercell that initially developed in northeast Mississippi (Figure 4) and tracked approximately 250 miles before dissipating near the Alabama/Georgia border. As can be seen in Figure 4, the storm produced several brief and weak tornado touchdowns earlier in its lifecyle with very minor damage. However, as the storm lifted northeast across the state, warning forecasters noted a sharp increase in the total lightning rates (Figure 5 and Figure 6) in conjunction with a tightening of the low level rotational couplet and intensification of the rear flank downdraft. Based on this evidence, confidence in an imminent tornado touchdown increased and strongly worded tornado warnings were issued for the affected area.

Similar to the previous findings by Williams et. al., the lightning source densities associated with the parent supercell dropped significantly 10 to 12 minutes prior to the tornado touchdown (Figure 7). As can also be seen in the plot in Figure 8, there was a distinct lightning jump and subsequent decline in source rates coincident with the tornado touchdown.

One of the forecasters working the shift commented: "*This is certainly a nice example of how the LMA trends, used in conjunction with the Reflectivity and SRM data can show "added value/detail" to the storm scale structure of a storm. It wasn't too long after the intense lightning jump that the cell climbed Sand Mountain and the tornado vortex made it to the ground.*" Although further studies and research are ongoing concerning the "Super Tuesday Outbreak" of tornadoes, preliminary local findings do indeed suggest that there was a distinct correlation between the trends in total lightning and the development of the tornadoes across the Tennessee Valley.

### b. 2 August 2008

On August 2$^{nd}$ 2008, an unseasonably cool upper level trough combined with a very warm boundary layer and an approaching surface trough set the stage for a significant occurrence of hail producing thunderstorms. The main question mark surrounding this specific event was the amount of available moisture and the extent or areal coverage of convection once initiation was achieved.

It should be noted that although large hail is not rare in the month of August, local climatology studies show that the monthly averages decline steadily as we transition through the latter portion of summer (http://www.srh.noaa.gov/hun/pdf/NAlabamaTornadoClimate.pdf). On this particular day, a total of 24 large hail (≥0.75" in diameter) reports were received at the NWS office in Huntsville. That is not far below the average for the entire month of August.

This case provided a unique forecasting challenge for the WFO Huntsville staff since there were question marks surrounding, as mentioned earlier, the moisture availability and the extent of the convection anticipated. As it turned out, storms began to initiate quite quickly by early afternoon. Due to the extreme level of instability present in the atmosphere on this day, storm tops grew quickly and the storms became electrically active not long after initiation. In this type of environment, the trend of the total lightning data from the NALMA is particularly useful.

One of the first storms to develop in the early afternoon formed along the Madison/Limestone County line (Figure 9) around 2 PM CDT. As can be seen in the 4 panel image, this particular cell is already displaying a fairly healthy reflectivity and total lightning core. By the 1912 UTC scan (Figure 10), roughly 6 minutes later, the total lightning has peaked at over 300 sources per 2 minute period along the county line. Based on this information, radar operators began to monitor this cell closely for the development of large hail. By 1917 UTC, the lightning rates had decreased significantly with this cell and the mid level reflectivity core had started to collapse (Figure 11). It was at about this time (between 1918 and 1921 UTC), that four separate reports of hail up to the size of nickels (0.88" in diameter) were reported in the vicinity of this storm. Based on the lightning jump and trending information, a lead time of 7 minutes would have been provided for the first report of severe sized hail. The total lightning data were also quite useful for the additional cells that developed as the day progressed, and further studies are being done on those for future discussion.

c. 31 May 2004

A vigorous squall line with preceding convection moved through the Huntsville county warning area early on the morning of May 31st 2004. Conditions were very favorable for strong storms with an extremely unstable airmass and high deep layer shear. The majority of the severe weather remained to the north of the Huntsville warning area.

The primary issue that this case illustrates is the ability of NALMA data to highlight locations where cloud-to-ground lightning activity may begin. Figure 12 shows the squall line advancing eastward towards the Muscle Shoals, AL airport in Colbert County. If the WFO Huntsville forecasters only had NLDN data available, the cluster of developing convection preceding the squall line would appear to not be electrically active as no cloud-to-ground strikes are evident in the circled regions. If this were the case, workers at the Muscle Shoals airport would have been informed that the lightning threat would not arrive until the main squall line approached. However, in the lower right panel of Figure 12, the NALMA is observing source densities of 10-20 sources per 4 square kilometers in the two circled regions in Colbert and Lauderdale Counties (Alabama) and Lawrence County (Tennessee). The NALMA observations clearly show the preceding cells are electrically active and that the threat of cloud-to-ground lightning was imminent.

Figure 13 shows the same region five minutes later. Now, where there had only been intra-cloud activity observed by the NALMA previously, the preceding convective cells are now producing several cloud-to-ground strikes. This intra-cloud activity leading the first cloud-to-ground strike is in agreement with MacGorman (1989) and Weins et al. (2005). The advantage of the NALMA observations was giving the WFO Huntsville forecasters additional lead time in knowing when a storm has become electrically active. This technique is useful for updating Terminal Aerodrome Forecasts (TAFs), as was done for Muscle Shoals in this example, or potentially for specific locations where the WFO is performing incident meteorology support.

## 5. FUTURE APPLICATIONS - GLM

The Geostationary Lightning Mapper (GLM) is a baseline instrument on the GEOS-R satellite. The expected field of view from both GOES-E and –W views are shown in Fig. 14. The GOES-R satellite is expected to be launched in 2014. The experience and input from WFOs using the ground-based total lightning products will be invaluable in developing products from the GLM. These products will be made available to all WFOs in real-time within the GLM field of view.

The GLM will continuously measure total lightning activity at a horizontal resolution of about 10 km, varying from about 8 km at nadir to 12 km near the edges of its field of view (Goodman et al., 2007). The predicted detection efficiency will be better than 90% both day and night, with a false alarm rate of 3%.

## 6. PRODUCT ASSESSMENTS

A primary effort of the NASA SPoRT center is to quantify the utility of the products provided to the National Weather Service. With input from WFO Huntsville's Science and Operations Officer, Christopher Darden, a web-based user survey was developed. This process was selected to provide forecasters an expedited method to provide feedback as soon as possible after an event in which the NALMA lightning data were used in the warning decision making process. Since forecasters have many time constraints, the web survey had to gather as much information as possible in a short period of time (1-3 min).

To accelerate the completion of the survey, a "point and click" method was primarily adopted. Questions identify the event type, date, time, and the type and number of warnings that were issued. Two text boxes are used to obtain a brief synopsis of the event and some verification information. A total of 42 assessments have been provided by the offices utilized the NALMA datasets (Table 1). The survey questions focus on the general performance of the NALMA data in the warning decision process. This follows the form of a ranking system where individual products (i.e., radar, NALMA, NLDN, etc.) are ranked on a scale of 1-10 on how useful they were to the warning decisions made during the event. Another question asks the forecaster to estimate the improvement in lead time the total lightning data provided to make an earlier forecast decision. This answer can be negative if the total lightning data made the forecast decision worse. These assessments indicate clear scenarios when the NALMA data are valuable and when the data are not. The assessments cover the period from November 2003 to June 2007.

The assessments covered a wide range of events, from intense supercell thunderstorms producing significant damage to small hail producing storms. Overall, the results indicated that radar reflectivity was the most useful decision making tool with a user rating of 8.8 out of 10. However, the NALMA was rated second, overall, with a 6.9 rating. The forecasters indicated that the NALMA provided, on average 2.5 – 3.2 minutes of estimated additional lead time over traditional warning decision making datasets.

There surveys were next divided into two groups. The first group was for events with one or more tornado warnings issued. This covered 11 surveys and a total of 68 warnings. This subset of surveys showed that radar and near storm environment observations topped NALMA usefulness. The results of the surveys did indicate that the addition of NALMA may have provided between 1.0 – 1.2 minutes of additional lead time over standard warning tools. While the NALMA exhibited lightning jumps with several of the tornadic cells, it added little additional diagnostic information above and beyond the traditional radar observations in some cases. However, recent discussions with NWS forecasters have indicated that lightning jumps have been used for tornado warnings when the radar signature was not as obvious, such as for weak EF-0 and EF-1 tornadoes. Further evaluations indicated that the NALMA was far more useful in marginal severe weather events.

These more marginal severe events were summarized in the second group of surveys. There were 31 surveys associated with 151 severe thunderstorm warnings. Unlike the tornadic cases, the surveys indicated the NALMA data were quite useful and ranked a close second behind radar reflectivity. In these events, the NALMA data provided between 3.0 – 3.8 minutes of additional lead time. In these severe, but non-tornadic events, the NALMA was able to provide information about the strength of a cell's updraft, indicating a strengthening or weakening cell. Additionally, the 2 minute refresh rate of NALMA data was particularly powerful. The rapid update allowed the forecaster to obtain more information between radar volume scans, which can take between 4 and 6 minutes to complete.

The surveys and personal communications with forecasters revealed other uses. The NALMA data have been found to precede the onset of cloud-to-ground lightning by 3–5 minutes, assisting forecasters in updating their Terminal Aerodrome Forecasts (TAF). Additionally, NALMA data have been used to hold back on issuing warnings, point out cells that may produce hail when radar observations are unclear, focus attention on a particular cell when multiple cells are present, and to provide information at extreme ranges from the radar, or a region where radar coverage is poor.

Further work relating total lightning trend relationships to severe weather are ongoing. Gatlin (2007) recently studied 20 springtime thunderstorms (6 tornadic supercells, 1 non-tornadic supercell, 12 non-tornadic non-supercells, and 1 non severe storm). Using a 2-min cell-based moving average total lightning threshold, he found a severe event probability of detection of .985 with a false alarm rate of .446. Further studies are following up on these results, as well as finding a method to provide cell-based trending information in real-time to the forecaster.

## 7. TRAINING INITIATIVES

Another key component of the SPoRT program is to provide training on various products to NWS forecasters. This has enhanced communication between forecasters and the SPoRT program which ultimately leads to better evaluations. These improved evaluations will, in turn, lead to the advancement of products to the forecasters.

This training is provided through many avenues. One of the easiest is with science sharing sessions with WFO Huntsville forecasters who are co-located with the SPoRT center. These sessions, generally 15-30 minutes in length, allow SPoRT researchers and NWS forecasters to interact on a given product and to discuss live data ingested into AWIPS. Attendees assist SPoRT by providing feedback and suggestions to improve the training and collaboration methods. These improvements are then taken into account to provide science sharing sessions with other SPoRT partners via monthly coordination calls. Additionally, this work is also converted into a short web-based training module that NWS forecasters may view at their leisure.

Additionally, SPoRT researchers have been making site visits to every collaborating WFO this year. This effort provides the same face-to-face interaction available with the Huntsville Weather Service office. In these visits, SPoRT personnel raise awareness of SPoRT products, such as the NALMA data as well as provide training on how to use the available datasets. While some partner WFOs do not receive NALMA data, they do have access to total lightning data from other sources making the SPoRT training applicable to their operations. The desired result is to develop advocates within each WFO who will energize local interest for SPoRT developed products. This advocacy leads to products better tailored to the end user and creates an environment more conducive to product integration and implementation. Forecaster input eventually leads to providing better products and services for the National Weather Service.

## 8. SUMMARY

The use of real-time output from the NALMA has proven quite beneficial to NWS forecasting and warning decision making. Beyond the standard analysis of cloud to ground lightning information, the ability to visualize three dimensional total lightning within developing thunderstorms has led to enhanced situational awareness by warning forecasters and furthered knowledge of real-time storm scale processes. This additional piece of information has led to greater confidence in the warning decision making process.

In addition, the lessons learned and training initiatives associated with the NALMA project have aided similar ongoing projects across the country. When the next generation of geostationary satellites are launched (GOES-R and beyond), the GLM sensor will provide real-time total lightning information to the entire CONUS. The work being done utilizing ground based total lightning systems will be invaluable in assisting with algorithm development, product assessments and validation, along with advanced training.

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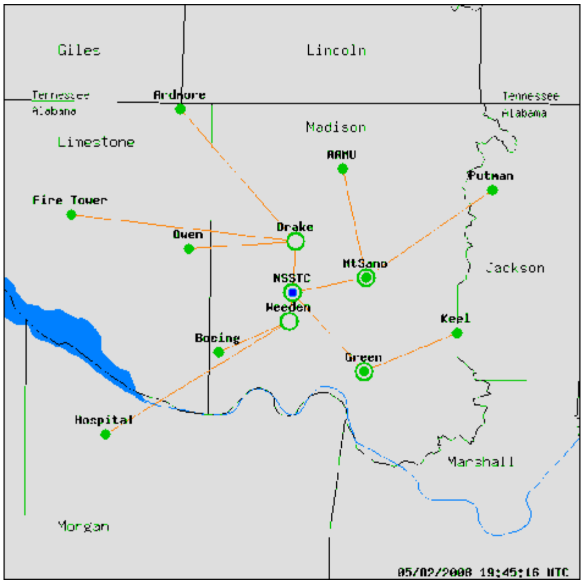


Figure 1. Schematic showing the 10 sensors and receiving station that comprise the NALMA.

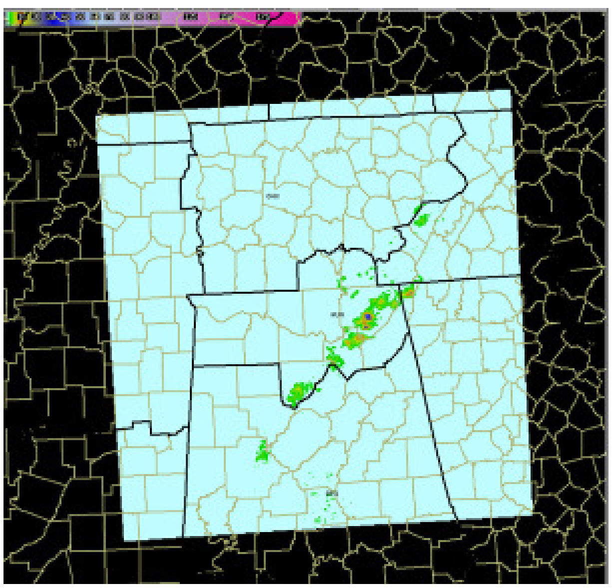

Figure 2. The blue shaded area shows the NALMA domain within AWIPS. WFO County Warning Areas are outlined in black.

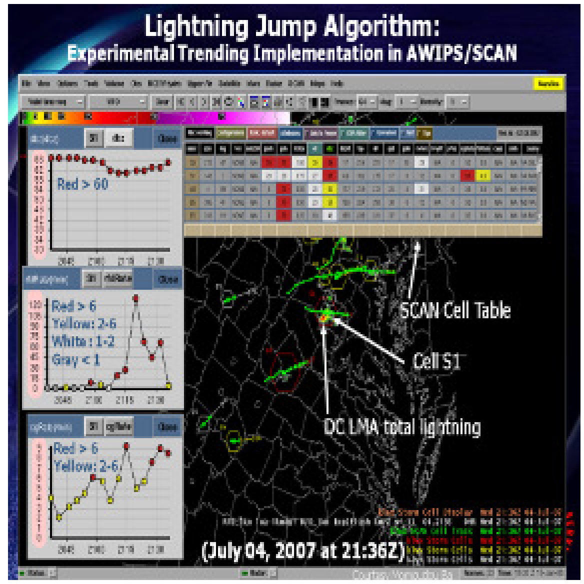


Figure 3. Experimental trending capability for total lightning as displayed at WFO Sterling Virginia.

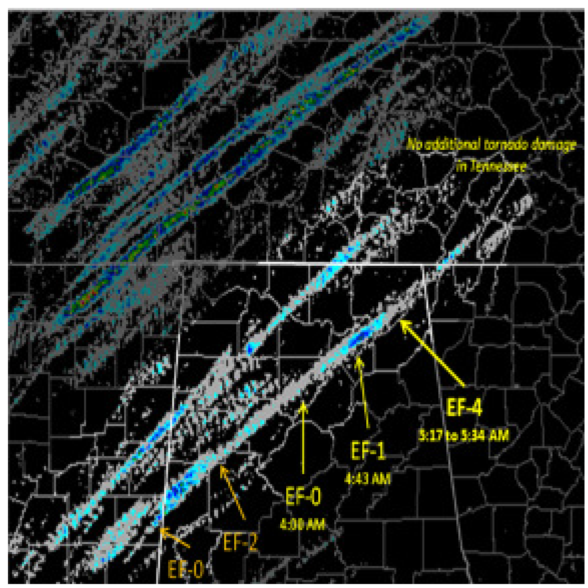


Figure 4. NSSL produced track of the supercell (far right) that produced EF-4 damage in northeast Alabama.

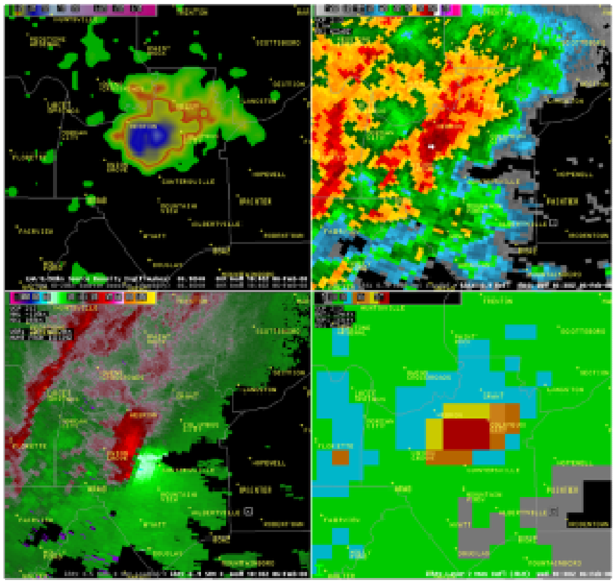

Figure 5. A 4 panel at 1038 UTC from KHTX radar showing clockwise from upper left quadrant: (1) NALMA total source density, (2) 0.5 degree base reflectivity, (3) Mid Level Layer Reflectivity Maximum, and (4) 0.5 degree Storm Relative Motion. At this time a distinct pulse in the lightning source rates was noted.

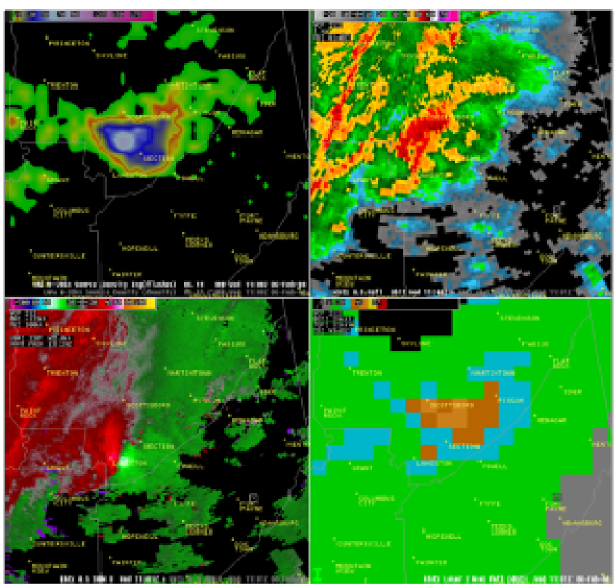

Figure 6. Same four panel image as above for the 1101 UTC volume scan. By this time, the surge in total lightning sources has reached a maximum across southeastern Jackson County coincident with a tightening of the low level couplet.

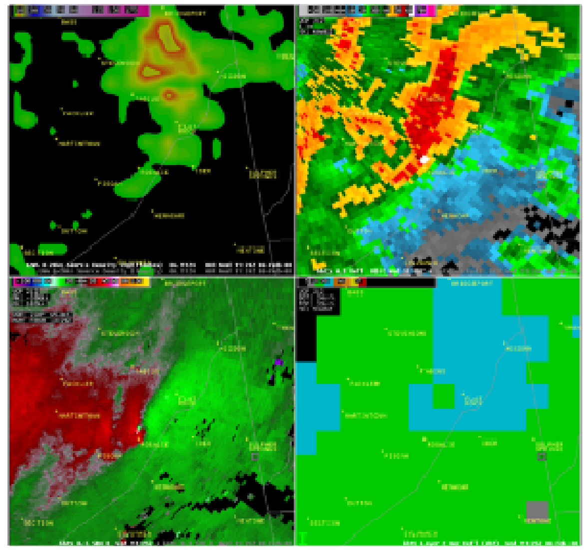

Figure 7. Same four panel image as above for the 1124 UTC volume scan. By this time, the lightning rates have dropped off significantly. The tornado has already touched down and is at its peak EF-4 intensity near Rosalie, Alabama.

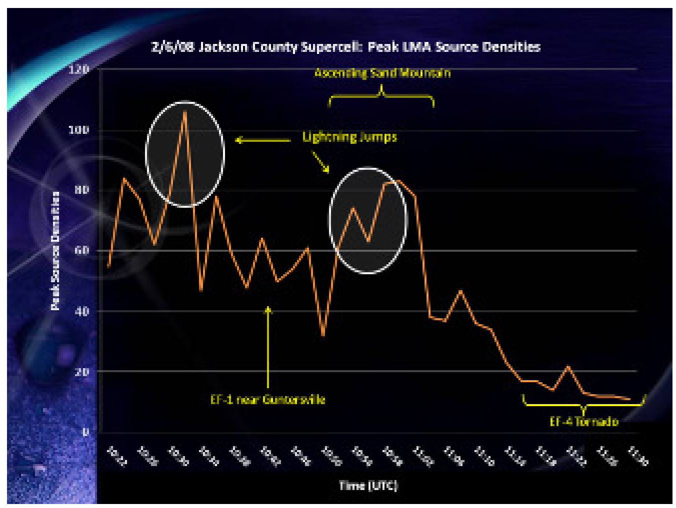


Figure 8. A plot of peak source densities versus time for the supercell that tracked across northeast Alabama. As can be seen in the graph, a distinct lightning jump was evident before both tornado touchdowns (especially the last and most violent occurrence) across the Huntsville County Warning Area. Lightning jumps are annotated by the circled locations.

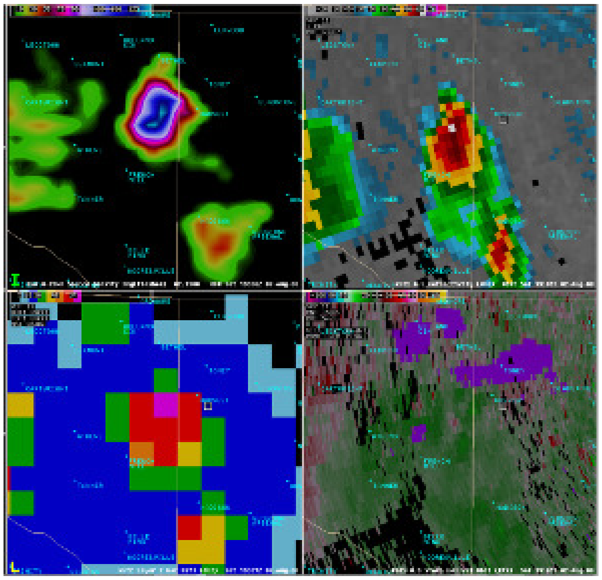

Figure 9. A 4 panel at 1906 UTC from KHTX radar showing clockwise from upper left quadrant: (1) NALMA total source density, (2) 0.5 degree base reflectivity, (3) 0.5 degree Storm Relative Motion, (4) Mid Level Layer Reflectivity Maximum.

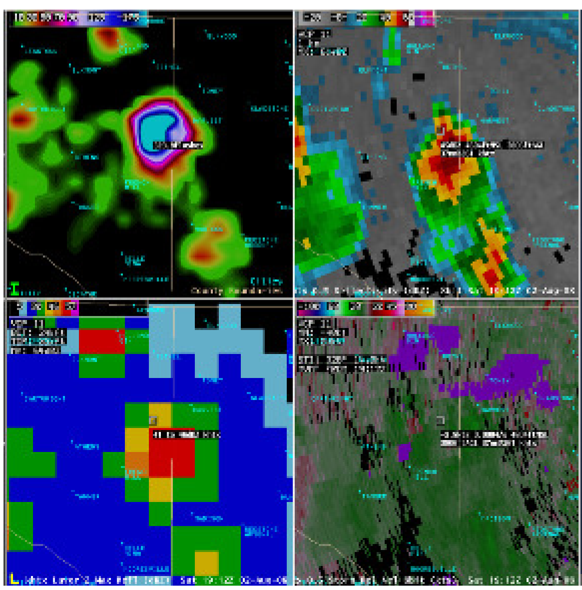

Figure 10. A 4 panel at 1912 UTC from KHTX radar showing clockwise from upper left quadrant: (1) NALMA total source density, (2) 0.5 degree base reflectivity, (3) 0.5 degree Storm Relative Motion, (4) Mid Level Layer Reflectivity Maximum. At this time, the total lightning source rates had reached a maximum of over 300 sources per 2 minute period.

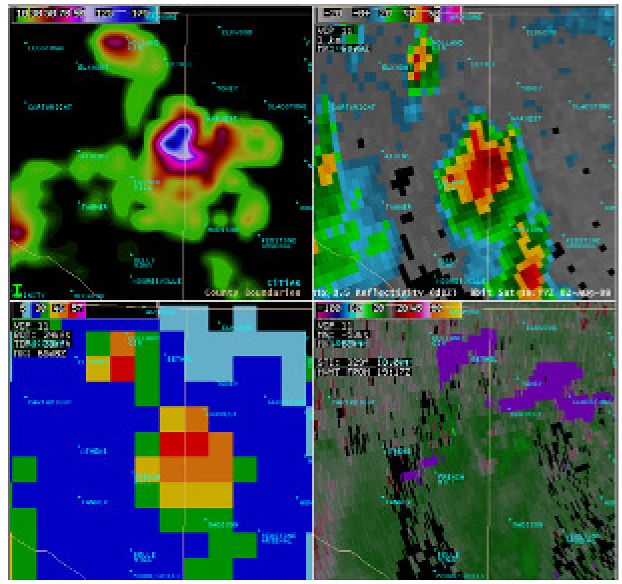

Figure 11. A 4 panel at 1917 UTC from KHTX radar showing clockwise from upper left quadrant: (1) NALMA total source density, (2) 0.5 degree base reflectivity, (3) 0.5 degree Storm Relative Motion, (4) Mid Level Layer Reflectivity Maximum. The total lightning source rates have dropped significantly as the core descends toward the surface. Large hail was reported 2 minutes later.

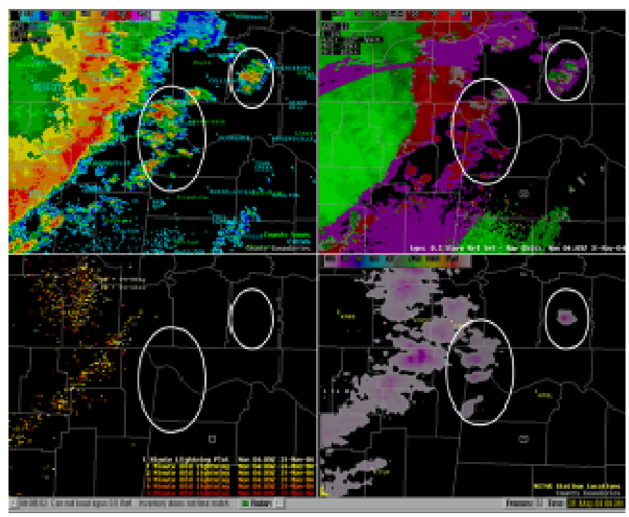

Figure 12. A 4 panel at 0409 UTC from KGWX radar showing clockwise from the upper left quadrant: (1) 0.5 degree base reflectivity, (2) 0.5 degree storm relative motion, (3) NALMA total source density, (4) NLDN cloud-to-ground lightning. The circled regions indicate where the NALMA detect intra-cloud lightning activity in the leading convective storms where the NLDN have no cloud-to-ground observations.

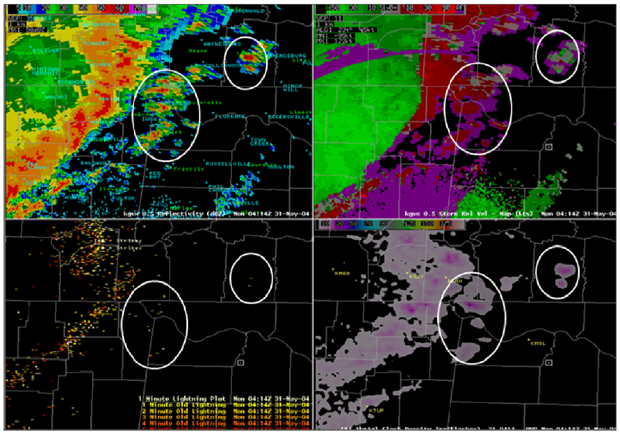

Figure 13. The same as Figure 12, but now five minutes later at 0414 UTC. The key feature now is the occurrence of cloud-to-ground lightning observed by the NLDN in the circled regions, where the NALMA indicated already electrically active storms previously.

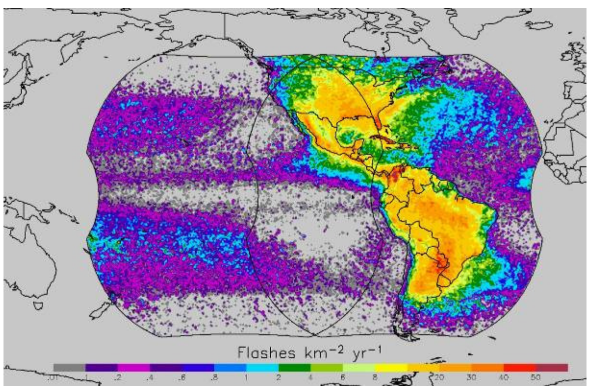


Figure 14. The planned field of view for satellites in the GOES-E (75 W) and GOES-W (137W) positions. Superimposed on the field of view of the two instruments is the annual lightning climatology derived from OTD and LIS observations.

Table 1: Summary of all 42 NALMA assessment surveys showing the ranking of each product available to WFO forecasters overall and the utility in severe storm and tornado warning decision making. The NALMA results are highlighted.

**NALMA Benchmarking: Results**
**Warning Variable Rankings on Scale of 1-10**

| Warning Variable | All Surveys | Severe Storms 151 warnings, 31 surveys | Tornado 68 Warnings, 11 surveys |
|---|---|---|---|
| Reflectivity Signatures | 8.8 | 8.6 (1) | 9.1 (2) |
| NALMA Total Lightning | 6.9 | 7.2 (2) | 5.8 (4) |
| Near storm Environment | 5.6 | 5.4 (3) | 6.3 (3) |
| Strong Rotation | 4.6 | 2.9 (7) | 9.3 (1) |
| Eyewitness Report | 3.8 | 3.2 (5) | 5.5 (5) |
| NLDN CGs | 3.7 | 3.4 (4) | 4.4 (6) |
| Boundaries | 3.5 | 3.2 (5) | 4.3 (7) |
| TVS | 1.7 | 1.2 (8) | 3.0 (9) |
| Previous SVR WX | 0.8 | 0.2 (9) | 3.8 (8) |