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TOTAL LIGHTNING INFORMATION: AN OPERATIONAL PERSPECTIVE

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ABSTRACT

The National Weather Service (NWS) in Huntsville began utilizing total lightning information from the North Alabama Lightning Mapping Array (NALMA) in May 2003. Since the data became available in real-time, forecasters at the Weather Forecast Office (WFO) in Huntsville have integrated the information with other traditional real-time/remote sensing tools (i.e. radar, satellite…etc.) to improve situational awareness during various convective events. Specifically, they have found similar correlations between the time rate-of-change of total lightning and trends in intensity/severity of convective cells that have been noted in previous research. As a result, it is believed that the use of total lightning information, either from current ground-based systems or future spaceborne instrumentation, can substantially contribute to the NWS mission, by enhancing severe weather warning and decision-making processes.

The operational use of total lightning information has been maximized at WFO Huntsville through a collaborative process of forecaster training, implementation of end user products, and post event analysis and assessments. Over 60 surveys have been completed by the forecast staff detailing the use of total lightning during convective events across the Tennessee Valley. In addition, specific cases of interest have been catalogued for further analysis and detailed research purposes. From these events of interest, time trending information from radar and total lightning can be compared to observed damage reports. This presentation will emphasize the effective use of total lightning information in a WFO operational setting, particularly during the warning decision-making process. Best practices for implementation of new technologies into operations also will be highlighted.

1. INTRODUCTION

WFO Huntsville 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 North Alabama Lightning Mapping Array (NALMA) is one such dataset that became operational in November 2001 with real-time access to the data at WFO Huntsville since May 2003. 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 lightning) which is often much larger in magnitude 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, Birmimgham, Huntsville, Dallas, Houston, Melbourne, Norman, etc.), the majority of the WFOs across the country still rely primarily on the NLDN network. Access to total lightning data has enhanced short-term 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 forecasting of severe convective weather via specific case studies. Future applications of the algorithms and warning decision making tools for 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 11 VHF receivers deployed across north Alabama (Figure 1). As of this writing, two additional receivers have also been deployed across north Georgia. The base station for network is located at the National Space Science and Technology Center (NSSTC), which is on the campus of the UAH. 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 minute 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 (Figure 2). 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 also can 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 3 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 NWS 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 Weather 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 significant 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 trend information in AWIPS.

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 was a great help in identifying storms that were producing the largest hail",* "*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. 10 April 2009

A large outbreak of severe weather occurred across the Tennessee Valley during the daylight hours of 10 April 2009. The early morning SPC outlook outlined the Tennessee Valley in an area of moderate risk with the forecast calling for "the development of supercells associated with significant low-level wind shear and instability ahead of an approaching cold front". As the day progressed and conditions worsened SPC upgraded much of the area to a high risk (Figure 4). This event produced a number of large and long lived supercells producing very large hail up to the size of softballs. Most notably two significant tornadoes occurred on this day, an EF-4 Tornado in Murfreesboro, TN and an EF-3 in north Alabama that tracked across Marshall, Jackson, and DeKalb counties. For this brief review, we will focus on the north Alabama tornado.

Thunderstorms began to erupt by mid morning across much of the Deep South on the 10th aided by a very unstable airmass. A proximity sounding (Figure 5) taken at 1700 UTC at Redstone Arsenal, located in Huntsville Alabama, indicated Surface Based

CAPE (SBCAPE) of 2920 J kg^{-1}, a Lifted Index of -10.8 °C and 0-1 km SRH of 233 m^2s^2. The large instability, particularly in the lower levels of the atmosphere, coupled with the strong low level shear, indicated the potential for rotating supercells.

A review of the NALMA source density in conjunction with radar and other remotely sensed data from the North Alabama case reveals some particularly interesting features. This tornado formed from a supercell that developed near Water Valley, Mississippi around 1615 UTC and tracked across northern Alabama before being absorbed into a squall line in north Georgia around 2200 UTC. Strong rotation was noted with this supercell during much of its 6-hour (300 mile) lifecycle prompting the issuance of numerous tornado warnings. However, based on ground truth reports and subsequent follow-up analysis the storm produced only large hail until nearly 4 hours into its lifecycle.

As the storm tracked eastward across the state and began to interact with a smaller convective cell lifting rapidly to the north, a sharp increase in the total lightning rates (Figure 6) was noted. This increase in source rates also correlated with an increase in the overall storm structure and some hints of a developing “hook echo” in the radar reflectivity. It should be noted though that at this time the low level rotational couplet was still fairly broad, though forecasters were alerted to the intensifying trends based in part to the increase in LMA sources.

Similar to the previous findings by Williams et. al., the lightning source densities associated with the parent supercell dropped significantly several minutes prior to the tornado touchdown (Figure 7). In Figure 7, you can also clearly see a tightening and strengthening of the rotational couplet along with a more pronounced “hook echo” type feature. The tornado touched down approximately 5 minutes later south southeast of Grant, Alabama near the Preston Island community.

There has also been previous discussion in the literature about “lightning holes”. These are typically defined as small regions within a storm that are relatively free of “in-cloud” lightning activity. Murphy et. al. (2005) discussed the correlation between lightning holes and severe weather across north central Texas. During the tornado event of 10 April 2009, a “lightning hole” was observed nearly coincident with the time the tornado reached EF-3 intensity near Preston Island, Alabama. In fact, overlaying the total source density image with the WSR-88D storm relative motion data (not shown) reveals very good spatial correlation between the lightning hole and the circulation vortex. The tornado lightning hole was evident in the total source density imagery for approximately 6 minutes before becoming more obscure. As can be seen in Figure 8, there is a distinct lightning “hole” or minima in sources coincident with the intense couplet on both the storm relative motion and base velocity images. At this time, the tornado was producing EF-3 damage as it tracked across the Lake Guntersville area (Figure 9). All totaled, the tornado was on the ground for approximately 28 miles with a maximum width of ½ mile. Fortunately, due to the well advertised nature of the severe weather outbreak and adequate warning lead times only 5 minor injuries and no fatalities were reported.

A review of the 10 April 2009 event revealed a distinct correlation between the trends in total lightning and the development of the tornado in Marshall County. In fact, the lightning jump in association with the intensifying rotational couplet and the subsequent drop-off coincident with the tornado touchdown matches well with previous findings. As can be seen in Figure 10, the peak of the lightning jump occurred nearly 10 minutes before the tornado touched down in northeast Marshall County. This case also revealed a well defined lightning hole which was coincident with the maximum intensity of the tornado occurrence.

b. 21 January 2010

Isolated convection was developing across the Tennessee Valley during the late afternoon hours on 21 January 2010. In fact, conditions were becoming somewhat favorable for rotating thunderstorms and isolated severe weather was becoming a concern for the forecasters on duty. Through much of the afternoon, the most organized severe weather was generally contained across Tennessee and points north but isolated strong to severe convection was beginning to develop in Alabama. In fact, one tornado tracked through downtown Huntsville just before sunset which garnered significant local media attention.

The primary issue that this case illustrates, however, is the ability of NALMA data to highlight locations where cloud-to-ground lightning activity may begin. Figure 11 shows isolated convection developing southwest of both Pryor Field (DCU) in Decatur and the Huntsville International Airport (HSV). WFO Huntsville is required to issue both Terminal Aerodrome Forecasts (TAFs) and Airport Weather Warnings (AWWs) for HSV.

If the WFO Huntsville forecasters only had NLDN data available, the convective storms approaching the 10 nautical mile radius of HSV (as noted by the outer ring in Figures 11-14) would appear to not be electrically active as no cloud-to-ground strikes are evident. If this were the case, workers at the Huntsville airport would have been initially informed that the lightning threat with these cells was minimal. However, in Figure 11, the NALMA source density imagery (overlaid on top of the KHTX base reflectivity image) is observing total lightning activity approaching the 10 nautical mile radius of HSV. The NALMA observations clearly show the preceding cells are electrically active and that the threat of cloud-to-ground lightning was imminent.

Figure 12 shows the same region 20 minutes later. Now, the convective cell is within the 5 nautical mile radii of HSV (as noted by the inner ring in Figures 11-14) and the NALMA sources have increased significantly. At this time, the NLDN network is still not detecting any cloud to ground lightning activity. However, based on the information at hand WFO HUN forecasters have already issued an Airport Weather Warning (AWW) to alert ground crews and personnel to the impending lightning thread. At 2250 UTC (Figure 13), the first CG occurred approximately 4 miles southwest of the Huntsville International Airport (HSV). Utilizing the NALMA data in conjunction with radar information provided more than 10 minutes of lead time for the initial CG within the 5 nautical mile radius of the airport. A few minutes later (Figure 14), additional CG strikes occurred just north of the airport.

The trend in this case of the 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) and providing site specific Airport Weather Warnings (AWW), as was done for Huntsville 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. 15. The GOES-R satellite is expected to be launched in 2016. The experience and input from WFOs using the ground-based total lightning products will be invaluable in developing products for 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. 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. These training modules can be accessed at: http://weather.msfc.nasa.gov/sport/training/.

Additionally, SPoRT researchers have been making an effort to make site visits to collaborating WFO offices. This effort provides the same face-to-face interaction available with WFO Huntsville. 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. In early March 2010, the SPoRT program conducted a 2 day workshop in Huntsville in which all collaborating offices attended and presented a brief overview of their offices use of SPoRT datasets and how they utilize the SPoRT products in the local forecast process. In addition, breakout sessions and planning sessions were held to lay a roadmap for future collaborative activities.

7. 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 the forecasters' 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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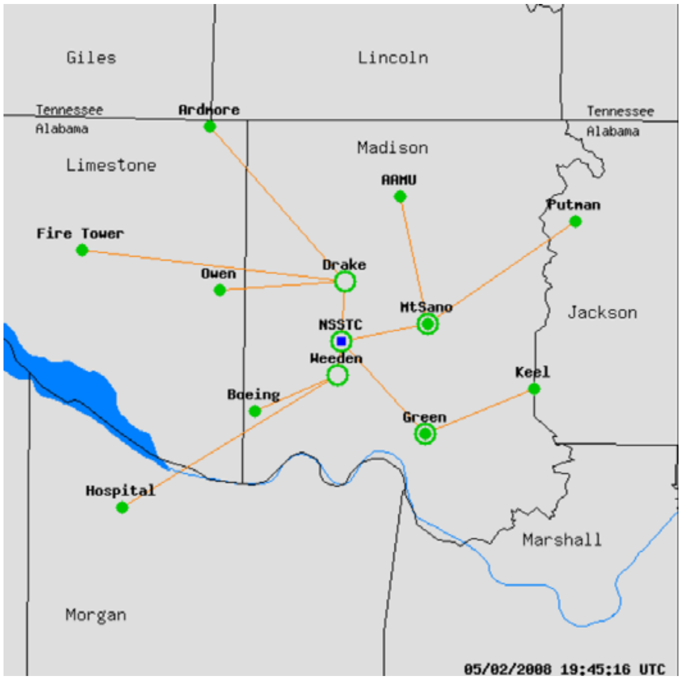

Figure 1. Schematic showing the 11 sensors and receiving station that comprise the NALMA.

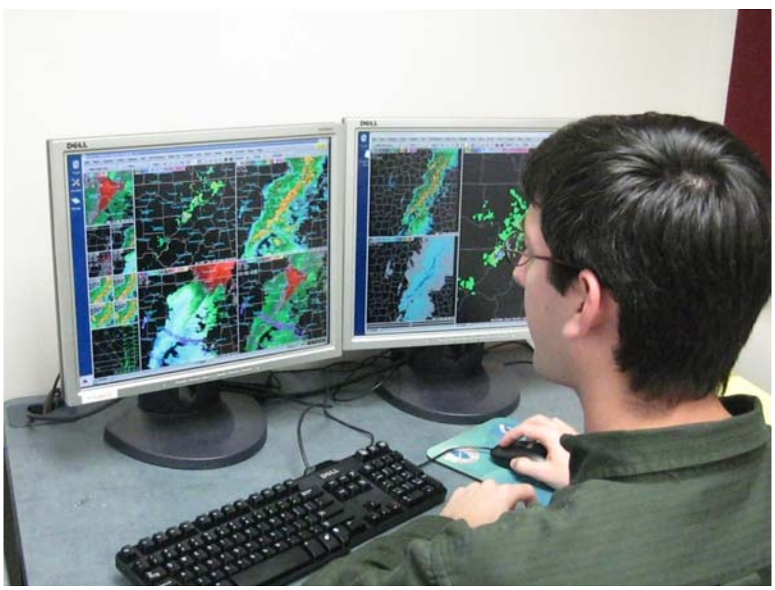

Figure 2. A NASA scientist analyzing the NALMA total lightning data on an AWIPS workstation.

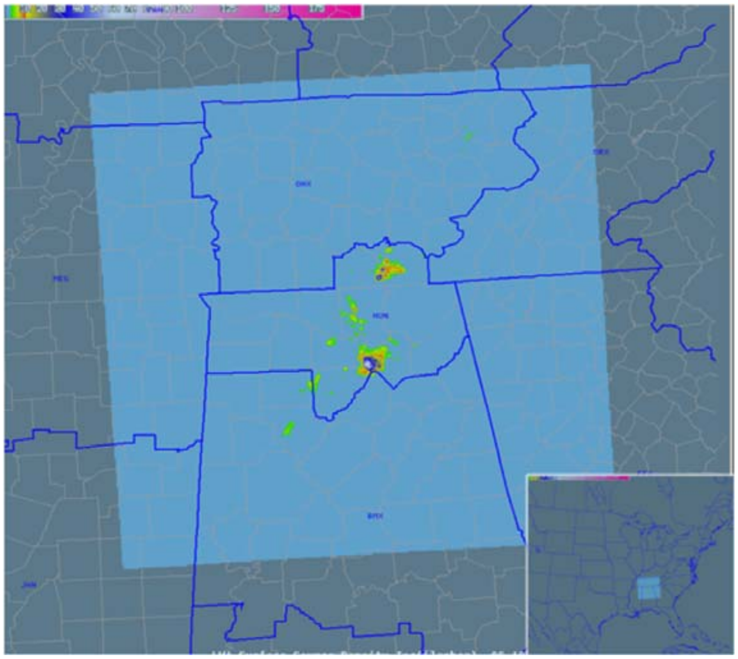

Figure 3. The light blue shaded area shows the NALMA domain within AWIPS. WFO County Warning Areas are outlined in dark blue. The image contained within the NALMA domain is a sample image of the NALMA output for a given thunderstorm day.

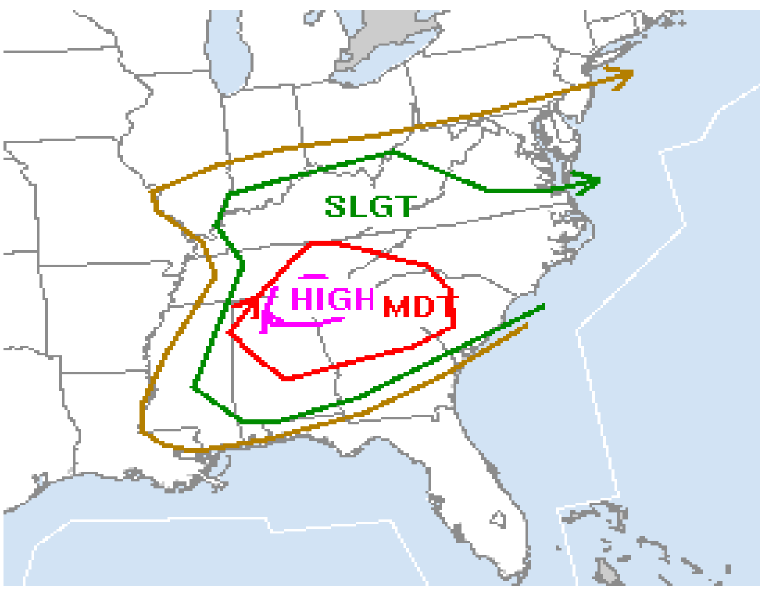

Figure 4. Zoomed image of the SPC Day One Outlook for 10 April 2009 issued at 1844 UTC.

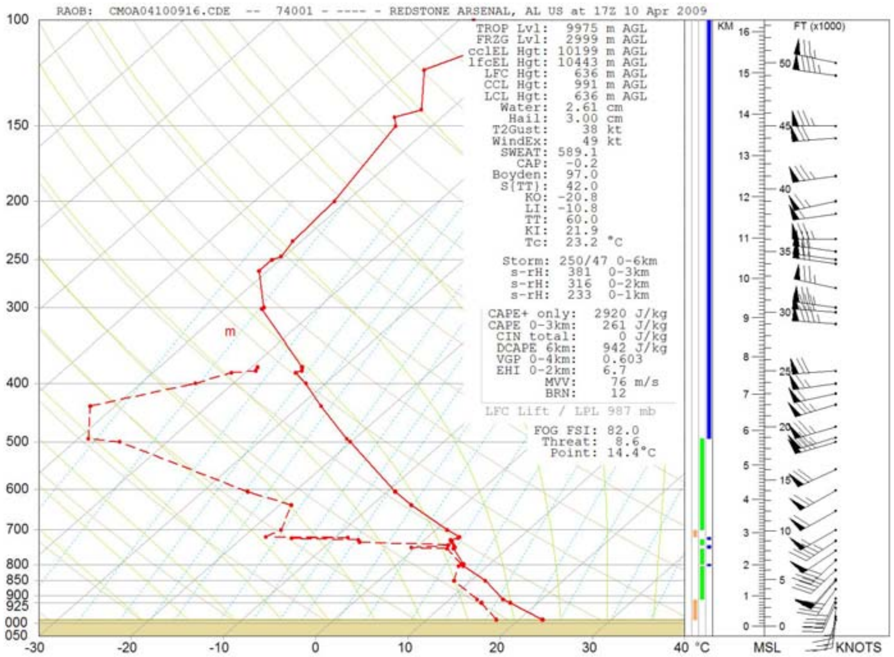

Figure 5. 1700 UTC radiosonde from Redstone Arsenal (RSA) in Huntsville, Alabama

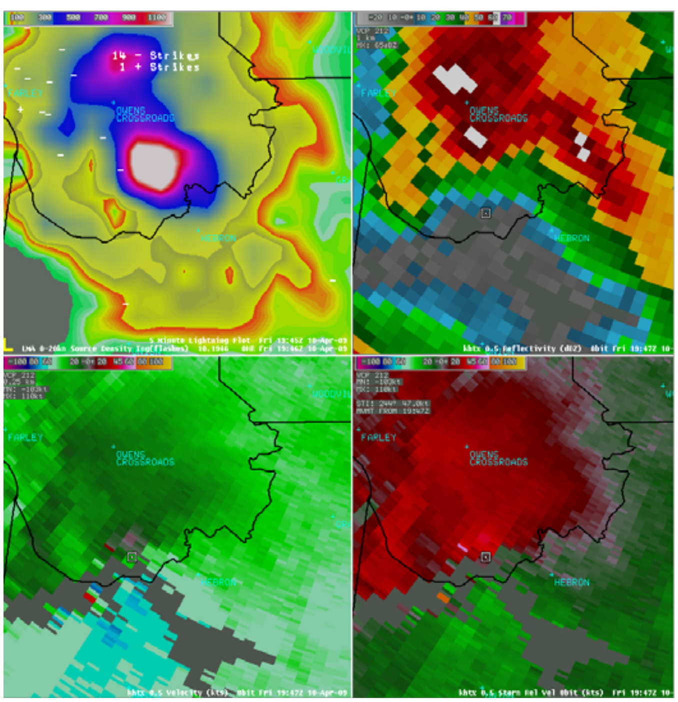

Figure 6. A 4 panel AWIPS image at 1947 UTC showing clockwise from upper left quadrant: (1) NALMA total source density with NLDN overlaid, (2) KHTX 0.5 degree base reflectivity, (3) KHTX 0.5 degree storm relative mean radial velocity, (4) KHTX 0.5

degree base velocity. At this time a distinct pulse in the lightning source rates was noted.

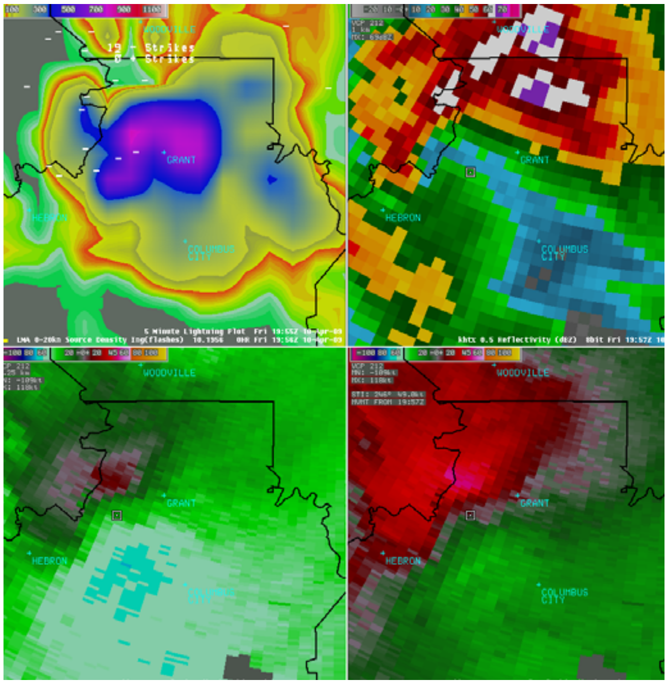

Figure 7. Same four panel image as above for the 1957 UTC volume scan. By this time, the total lighting sources have decreased somewhat and the low level velocity couplet continues to tighten. There is also some indications of a reflectivity notch or “hook echo” in the upper right.

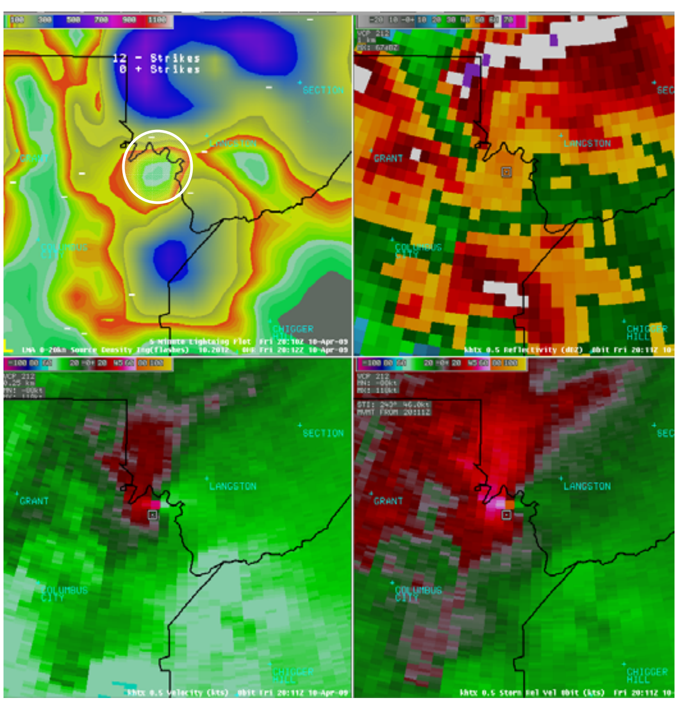

Figure 8. Same four panel image as above for the 2011 UTC volume scan. By this time, the lightning rates have dropped off significantly in the vicinity of the rotational couplet and “hook echo”. The tornado has already touched down and is nearing its peak EF-3 intensity over Lake Guntersville. Note the existence of the apparent lightning hole coincident with the tornado circulation, as highlighted in the upper left quadrant by the white circle.

Figure 9. Photo of the EF-3 tornado as it was crossing Lake Guntersville on the afternoon of 10 April 2009. This image was taken at approximately the same time as the lightning was observed in Figure 8 above. Photo courtesy of Martha Tellefsen.

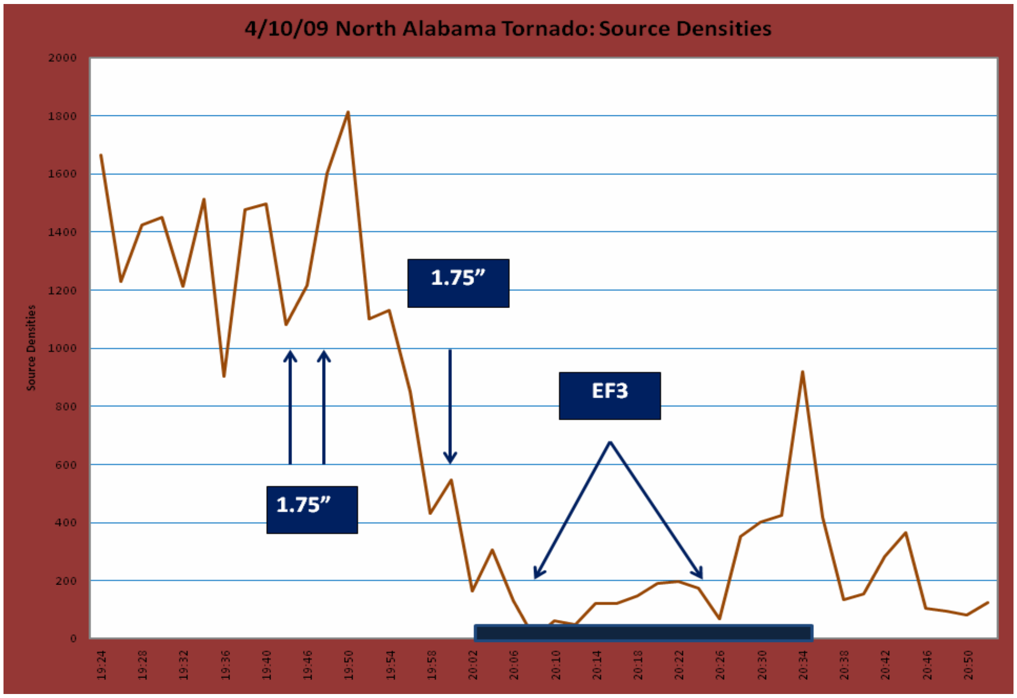

Figure 10. A plot of peak source densities versus time for the supercell that tracked across northeast Alabama. As can be seen in the graph, a distinct lightning jump was evident before the tornado touchdown at 2002 UTC. The time the tornado was on the ground is annotated by the solid blue bar just above the x-axis. The time of the earlier hail reports are also indicated for reference.

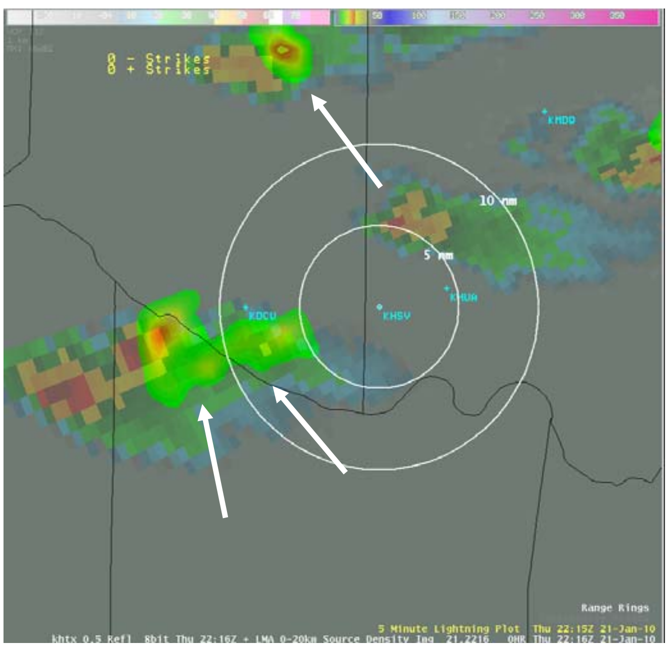

Figure 11. KHTX 0.5 degree base reflectivity overlaid with the NALMA total source density image at 2216 UTC. The two white concentric rings represent the 10 nautical mile and 5 nautical mile radii from the Huntsville International Airport (HSV) respectively. The white arrows depict locations where the NALMA indicates intracloud lighting activity but no CGs have been reported.

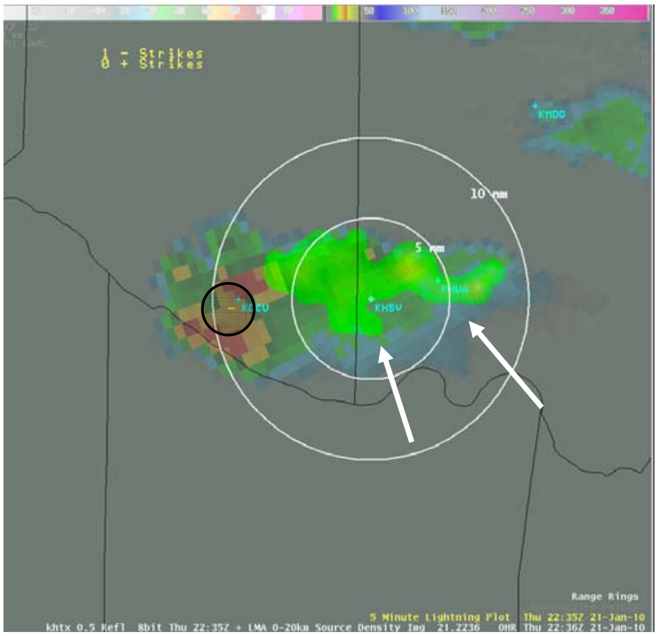

Figure 12. The same as Figure 11, but now 20 minutes later at 2236 UTC. Note that the NALMA data shows a large area of total lightning activity very near HSV. However, only one CG is being reported at this time (highlighted by the dark circle), well to the west near Pryor Field (DCU).

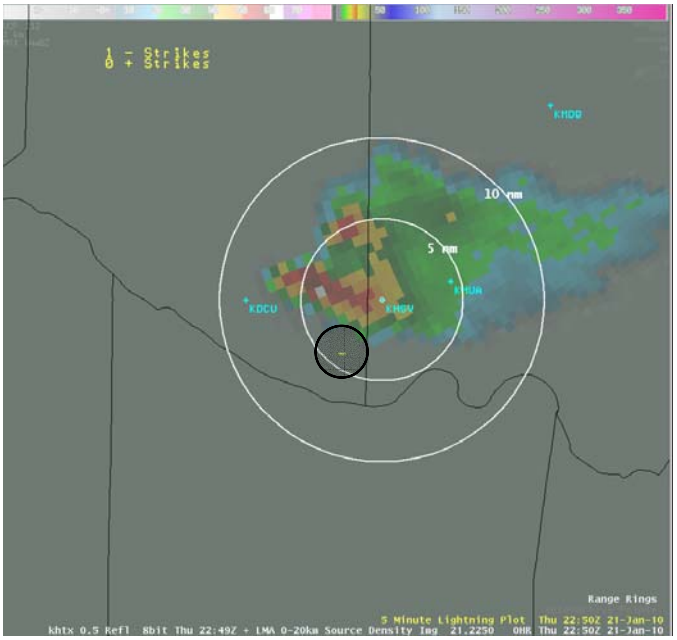

Figure 13. The same image as seen Figures 11 and 12, but now at 2250 UTC. Note the one CG strike highlighted by the dark circle southwest of HSV within the 5 nautical mile ring. This is within the Airport Weather Warning (AWW) zone.

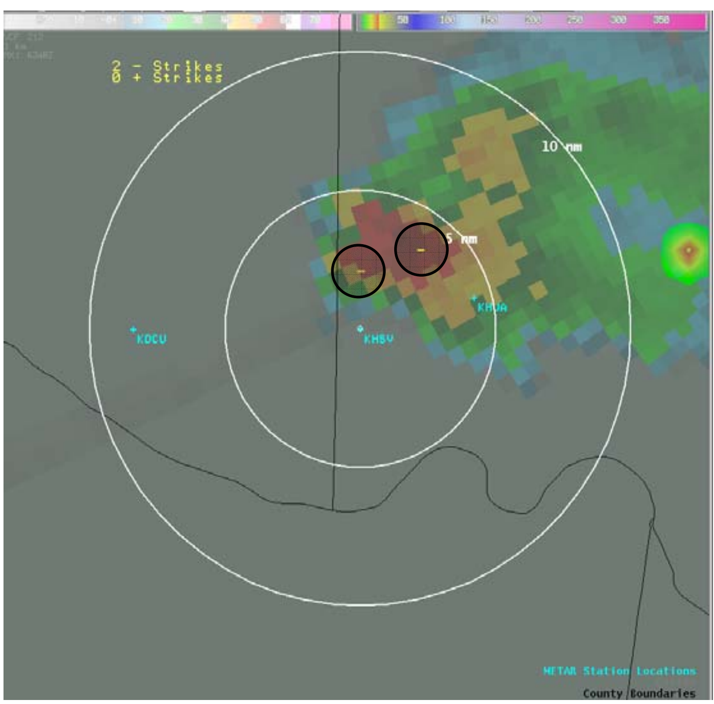

Figure 14. The same image as seen Figures 11-13, but now at 2258 UTC. Note the CG strikes north and northeast of the airport at this time.

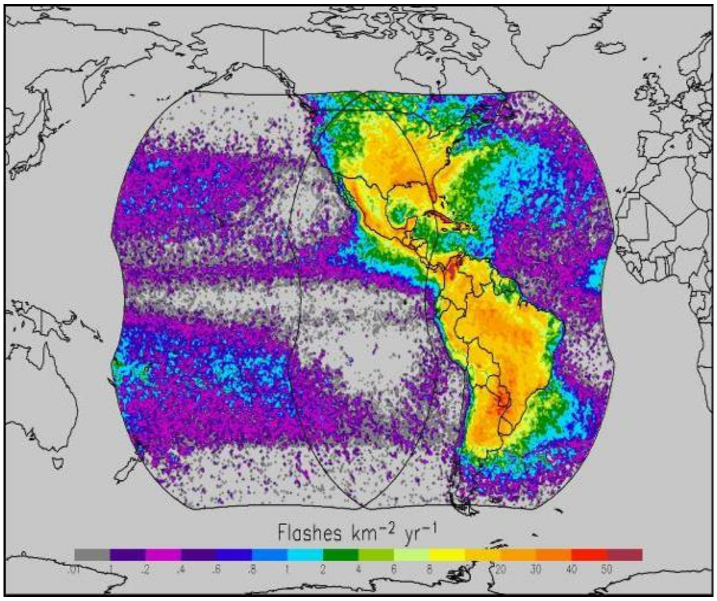

Figure 15. The planned field of view for satellites in the GOES-E (75 W) and GOES-W (137W) positions. Superimposed on the field of view of the two instruments is the annual lightning climatology derived from OTD and LIS observations.