Utilizing Total Lightning Information to Diagnose Convective Trends

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For many years, the operational utility of lightning information in the National Weather Service (NWS) convective warning program has been limited. There are many reasons for this, including the lack of availability of total lightning information on a regional or national scale, limited research on lightning relationships to severe weather, and a cultural legacy of perceiving lightning information as tertiary in importance. However, preliminary investigations performed at the NWS office in Huntsville, Alabama, along with other offices that have access to total lightning information have shown distinct correlations between the time rate of change of total lightning and trends in intensity/severity of the parent convective cell that can be useful to forecasters.

The initial integration of total lightning information within NWS operations during the mid-1990s at Melbourne, Florida, was a landmark achievement. Collaborative access to the Lightning Detection and Ranging (LDAR) system, courtesy of NASA's Kennedy Space Center, offered an early (and real-time) glimpse regarding the electrical character of thunderstorms within strongly baroclinic systems. However, information display remained external to conventional operations platforms, and was therefore difficult to use in tandem with radar or satellite data. Since May 2003, however, forecasters at NWS Huntsville have utilized total lightning data obtained by the North Alabama Lightning Mapping Array (NALMA) within their Advanced Weather Interactive Processing System (AWIPS) workstations, where it can be plotted in conjunction with other remotely sensed data (radar, satellite, etc.). The insight gained from its use has raised the awareness of the NWS Huntsville warning meteorologists during convective situations. The use of total lightning information, either from current ground-based systems or future spaceborne instrumentation, may markedly improve the ability of NWS forecasters to protect life and property by enhancing severe weather warning and decision-making processes.

NWS Huntsville is located at the National Space Science and Technology Center (NSSTC) on the campus of the University of Alabama in Huntsville (UAH). The NSSTC also houses UAH's Earth System Science Center and Atmospheric Science Department, and NASA's Marshall Space Flight Center's (MSFC) Earth Science Office (ESO). In 2001, the Short-term Prediction Research and Transition (SPoRT) Center was created to accelerate the infusion of NASA Earth science observations, data assimilation, and modeling research into NWS forecast operations and decision-making. The collaboration between SPoRT and NWS meteorologists has facilitated the experimental use of several unique datasets for operations. As an example, total lightning observations from NALMA were successfully transferred to HUN operations in May 2003. Since then, numerous tornadoes, hailstorms, damaging wind events, nontornadic supercells, and ordinary nonsevere thunderstorms have been observed within the domain of the NALMA network.

Because of the NALMA's areal coverage, several nearby NWS offices can employ total lightning data in real time for use in the short-term forecast process

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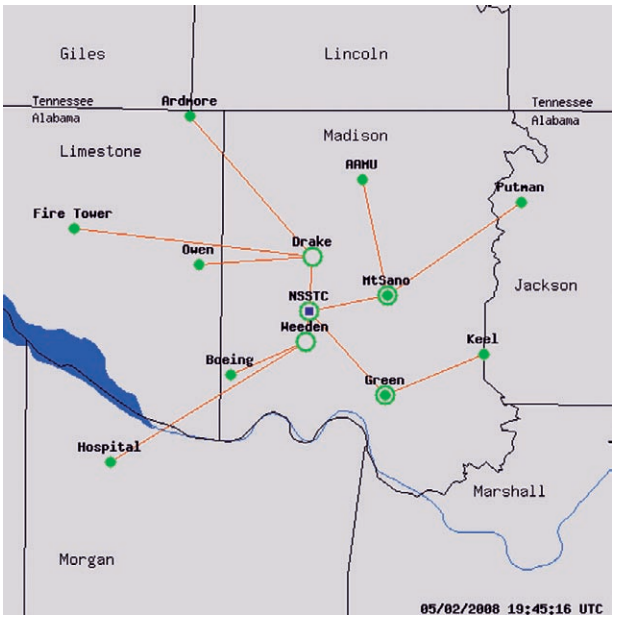

Fig. 1. Schematic showing the 11 sensors and receiving station that comprise the NALMA. The solid green dots indicate sensor locations, the open green circles indicate router locations, and the blue square in the middle is the NSSTC receiving station and collocated sensor site.

and in warning decision-making. The NALMA is a principal component of a regional severe weather testbed that utilizes innovative science and technologies in the short-term prediction of severe and hazardous weather. The NALMA detects total lightning activity (both cloud-to-ground and intracloud lightning), which is often much greater in amount than cloud-to-ground activity alone. CONUS NWS offices currently receive cloud-to-ground lightning data from Vaisala's National Lightning Detection Network (NLDN). Yet only a few have access to total lightning data via ground-based lightning mapping sensors (Nashville, TN; Morristown, TN; Birmingham, AL; Huntsville, AL; Dallas, TX; Houston, TX; Melbourne, FL; Norman, OK; and Sterling, VA). The majority of the NWS offices across the country still rely solely on the NLDN network for assessing a storm's electrical character.

BACKGROUND. The NALMA technology was developed at New Mexico Tech University. The NALMA network, owned and operated by NASA MSFC, consists of 11 VHF receivers deployed across North Alabama (Fig. 1), with the base station located at the NSSTC. 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 locations 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 intracloud lightning activity (i.e., total lightning). The detection efficiency decreases with distance from the network center with an effective three-dimensional network radius of 150 km and two-dimensional radius of 250 km.

A lightning source density product from the NALMA provides coverage over a 460 km × 460 km region centered on the NALMA network. Figure 2 illustrates that this domain (as it appears in AWIPS) fully encompasses both NWS Nashville's and Huntsville's areas of responsibility and provides partial coverage of five other surrounding forecast offices. To produce this product, the number of NALMA sources is obtained every 120 s on a 2 km × 2 km horizontal, 1-km vertical grid (16 vertical levels from 0–16 km). The resulting data array is converted into

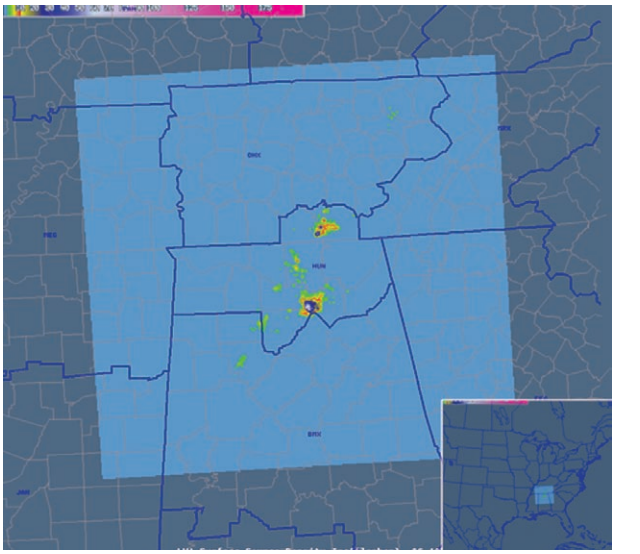

Fig. 2. The large image shows an example of the NALMA source densities plotted within AWIPS D2D. Dark blue lines in the image represent the outline of the WFO county warning areas of responsibility for Huntsville and surrounding offices. The light blue box indicates the effective domain of the NALMA network covering the Huntsville county warning area and several adjacent offices.

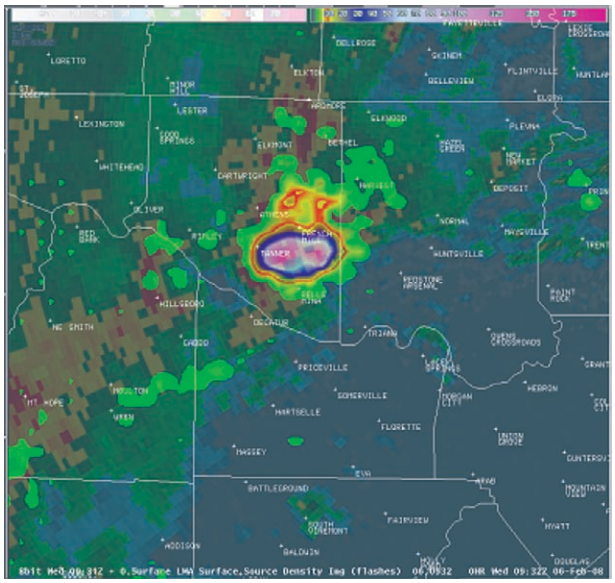

Fig. 3. Combined image of the KHTX (WSR-88D at Hytop, AL) base reflectivity and NALMA source density. Forecasters can readily adjust the opacity of two overlayed images on AWIPS D2D allowing them, in this case, to correlate the lightning core with a specific storm.

a netCDF file for ingest into AWIPS. An additional array in the netCDF file contains the vertically integrated number of sources occurring within each 2 km × 2 km grid box. The 120-s time scale is at least half the time of Weather Surveillance Radar 1998 Doppler (WSR-88D) volume scan updates, providing forecasters with updated information and insight into storm intensity between radar volume scans. NWS Huntsville, along with neighboring offices in Birmingham, Nashville, and Morristown, receive these data in real time via a Local Data Manager (LDM) feed and subsequent ingest into their AWIPS workstation display (often referred to as AWIPS D2D). Forecasters can interrogate the data on any of the 16 individual 1-km vertical levels or view a plot of cumulative source density from all levels. The vertically integrated source density display is favored by forecasters and the following discussions refer to that product. Forecasters can also overlay and toggle between WSR-88D imagery and NALMA images as in Fig. 3. The products are refreshed automatically within workstation displays, with only about 30-s latency from the time of ingest. In this way, the forecaster can quickly evaluate total lightning data within the forecast and warning decision-making process.

OPERATIONAL UTILITY. The Tennessee Valley is located just north of the Gulf of Mexico, a primary moisture source for significant severe weather outbreaks, and in the primary path of midlatitude cyclone tracks. This geographic region is vulnerable to a host of severe convective storm types, including organized squall lines, quasilinear convective systems, discrete supercells, and "pulse"-type summertime microbursts. This diversity often results in forecast and warning challenges for area meteorologists. To meet this daunting challenge, NWS Huntsville forecasters utilize an array of remote-sensing diagnostic tools including radar, satellite, surface and upper-air observations, and ground truth (i.e., spotter) information. Importantly, the addition of real-time total lightning data has immensely enhanced short-term warning decision-making during severe weather operations.

Building upon previous work, the forecasters look for lightning trend signatures in individual storms. In a 1999 *Atmospheric Research* article, Williams et al. studied 30 severe cases in Florida and found that increases in VHF total lightning mapping activity (termed lightning "jumps") preceded severe weather occurrences by 5–30 minutes. The lightning jump signature was found to be a useful proxy for updraft accelerations and intensity, helping forecasters to distinguish between storms acquiring severe potential, and where a particular storm might be in its own life cycle (or within its cyclic process). 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. Currently within AWIPS, there are no algorithms or quantitative means of measuring the time rate of change of lightning sources associated with individual convective cells. Forecasters assess the lightning trends visually and by sampling the moving lightning centroid (associated with a cell of interest). Thus, the forecasters look for qualitative lightning jumps within the data while analyzing other radar and diagnostic trends to make a warning decision. Future plans include the implementation of an AWIPS tool to display real-time lightning trend information. Initial testing of such a tool is ongoing at Sterling, in conjunction with NOAA's Meteorological Development Laboratory (MDL). Algorithms to automatically identify lightning jumps have been better quantified by Gatlin and Goodman (2009) and Schultz et al. (2009), leading toward a practical

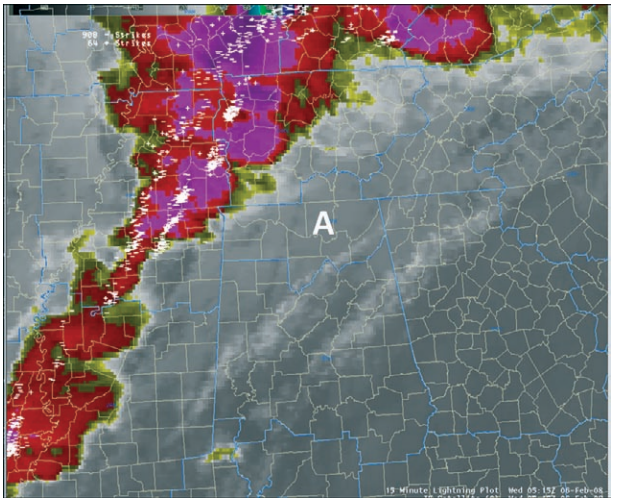

Fig. 4. Infrared satellite image from GOES-East overlaid with NLDN cloud-to-ground lightning (in white) at 0515 UTC on 6 Feb 2008. The NLDN data depict the lightning strikes within the last 15 minutes, and the brighter reds and purples indicate the colder cloud tops associated with convection. The scale at the top represents temperatures in degrees Celsius. For reference, Huntsville is denoted by the white "A."

application and aid in short-term severe weather forecasting.

Much of the operational feedback from forecasters utilizing the total lightning information in the warning decision-making process has been positive. Feedback is collected via post-event analyses and reviews, e-mails, and formal surveys and assessments. One forecaster reported, "The LMA source densities showed a rapid increase in source rates shortly before the hail was reported." Another said, "The LMA data helped me in my decision to go ahead and issue a severe thunderstorm warning." And yet another commented, "The increasing trends in total lightning activity increased the confidence in the reflectivity signatures, which then prompted the warning."

CASE STUDY OF 6 FEBRUARY 2008. The "Super Tuesday" outbreak of 2008 resulted in two long-tracked supercell thunderstorms that moved across North Alabama during the predawn hours. These supercell storms produced a series of tornadoes, including two EF-4 tornadoes that resulted in five fatalities, numerous injuries, and more than $11 million in damage. While February tornadoes themselves are not uncommon in the Deep South, such violent and killer tornadoes are fairly rare, especially during the late night and early morning hours.

Late on the evening of 5 February 2008, an unseasonably warm and moist air mass was already in place across the Tennessee Valley. A significant outbreak of tornadoes and thunderstorms was already underway west and northwest of Huntsville (Fig. 4), and NOAA's Storm Prediction Center (SPC) indicated that the threat for tornadoes would continue overnight.

The 0100 UTC SPC Day One probabilistic tornado outlook (Fig. 5) indicated that the main area of concern would initially be to the west of Huntsville, although the associated text discussion did mention "strong shear will be maintained overnight eastward across the Southern Ohio Valley, Tennessee Valley, and Mississippi/Alabama in advance of surface low and cold front." A tornado

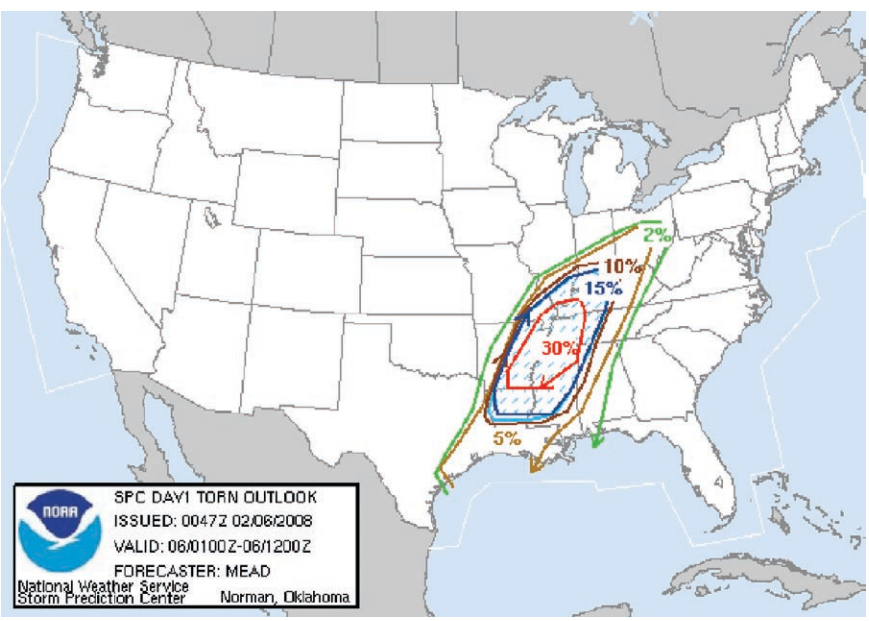

Fig. 5. SPC Day One Probabilistic Tornado Outlook issued at 0047 UTC on 06 Feb 2008 valid for the time period 0100 to 1200 UTC on 06 Feb 2008. For a complete definition of the probabilities see www.spc.ncep.noaa.gov/products/outlook/probinfo.html.

watch was issued for a large portion of Mississippi and Alabama, including the NWS Huntsville area of responsibility from 0400 UTC on 6 February 2008 until 1100 UTC. The watch text specifically referenced "isolated cells ahead of the line continue to pose a risk of hail and isolated tornadoes." At 0841 UTC, SPC issued a mesoscale discussion update mentioning "greatest potential for long-lived/damaging tornadoes accompanying discrete supercells developing ahead of primary convective band." Two such supercells can been seen on the regional radar mosaic at 0900 UTC (Fig. 6).

As these storms strengthened, source density information coupled with the available output from regional radars and ground truth information allowed forecasters to issue life-saving tornado warnings with average lead times in excess of 20 minutes. Comments from NWS partners and customers were overwhelmingly positive, and feedback received during storm surveys and the subsequent service assessment was complimentary of the service provided to the community.

For the remainder of this case study, we will focus on the EF-4 tornado that tracked across Jackson County in Northeast Alabama. This tornado formed from a supercell thunderstorm that initially developed in East Central Mississippi and strengthened as it moved northeast into Alabama (Fig. 6). The supercell tracked approximately 250 miles (402 km) before dissipating near the Alabama/Georgia border. As shown in Fig. 7, the storm produced several brief and weak tornado touchdowns early in its lifecycle, with very minor damage. However, as the storm moved northeast across the state, warning forecasters noted a sharp increase in the total lightning rates (Fig. 8). This increase occurred in conjunction with a tightening of the radar-indicated low-level rotational couplet followed by an apparent intensification of the rear flank downdraft (RFD) based on WSR-88D velocity and reflectivity images (Figs. 9 and 10). Previous studies have shown the importance of the RFD in tornadogenesis (see the 1983 *Journal of the Atmospheric Sciences* article by Klemp). Based on this evidence, confidence in an imminent tornado touchdown became high, and strongly worded tornado warnings were issued for the affected area.

Similar to the previous findings by Williams et al. for Florida storms producing strong to violent tornadoes, the lightning source densities associated with the parent supercell then dropped significantly 10 to

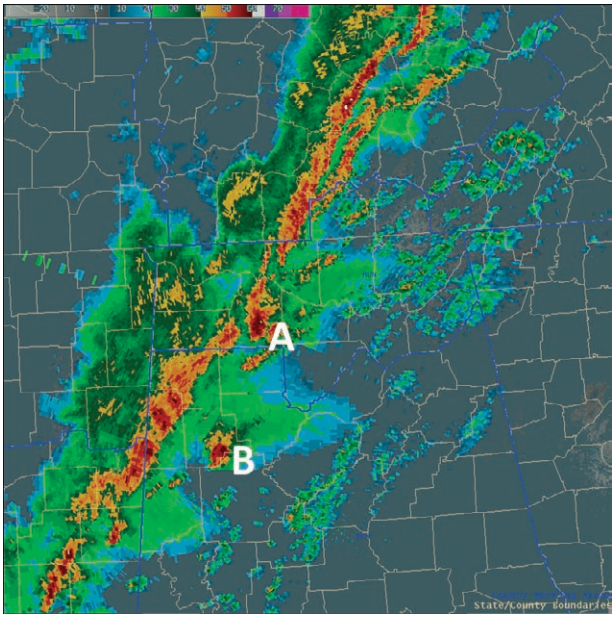

Fig. 6. A mosaic of WSR-88D reflectivity images across the region at 0900 UTC on 6 Feb 2008. The Huntsville CWA is centered in the image, and the two supercells that impacted the area and produced killer tornadoes are denoted by "A" and "B."

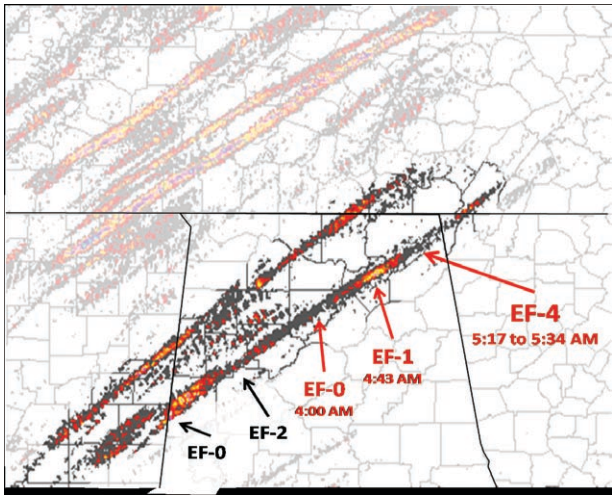

Fig. 7. The mosaic image of the Maximum Expected Hail Size (MESH) shows two distinct storm tracks across northern Alabama (both are highlighted for effect). The track on the far right depicts the supercell storm that eventually produced EF-4 damage in Northeast Alabama. The EF-scale annotations and times on the image indicate individual tornado touchdowns, with the black annotations occurring in the Birmingham (BMX) CWA and the red in the Huntsville (HUN) CWA. MESH mosaic image provided by NOAA's National Severe Storms Laboratory at http://ondemand.nssl.noaa.gov.

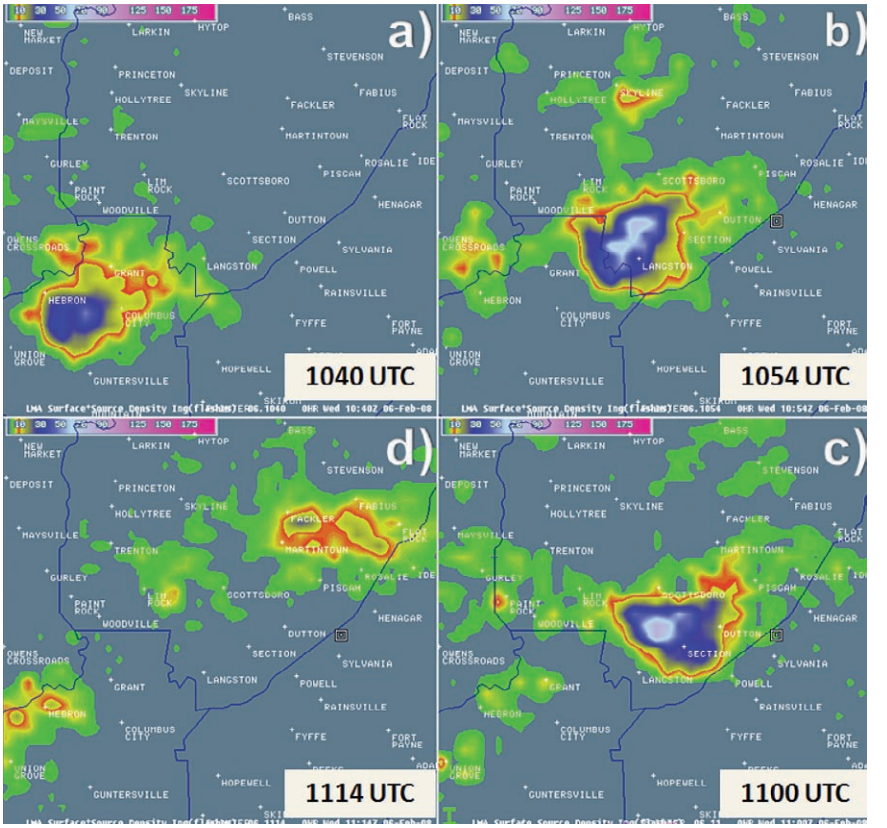

Fig. 8. A 4-panel image of the NALMA at (a) 1040; (b) 1054; (c) 1100; and (d) 1114 UTC, respectively. Note the sharp increase in source rates at both 1054 and 1100 UTC, followed by a sharp drop-off at 1114 UTC. This is what is typically referred to as a lightning "jump." An EF-4 tornado touched down near Pisgah at 1117 UTC.

12 minutes prior to the tornado touchdown (Fig. 8). As shown in Fig. 11, there was a distinct lightning jump and subsequent decline in source rates coincident with the tornado touchdown.

Several of the forecasters working the event noted that they recognized a significant jump in the total lightning rates, which provided them with additional warning confidence. In post-event reviews they also noted that the rates dropped off significantly at the time that the tornado vortex made it to the ground. Previous findings have postulated that the sharp decline in total lightning source rates is likely due to the collapse of the primary updraft and associated BWER (bounded weak echo region) as angular momentum once suspended aloft now descends (Sharp 2005).

Although further studies and research are ongoing concerning the "Super Tuesday" tornado outbreak, preliminary local findings suggest that there was a distinct correlation between the trends in total lightning and the development of the tornadoes across the Tennessee Valley. It should also be noted that the lightning jump preceded the tornado touchdown by approximately 22 minutes. Given the rapid refresh rate of the NALMA data along with the added value of the information, it is anticipated that the total lightning information can add valuable lead time to short-term warnings.

FUTURE APPLICATIONS—GLM. The Geostationary Lightning Mapper (GLM) is a baseline instrument on the *GOES-R* next generation satellite that is expected to be launched in 2015. The GLM is based on previous low Earth-orbiting optical lightning detection instruments. The experience and input from NWS forecasters using the ground-based total lightning products will be valuable in developing products using GLM data. These products will be sent to all NWS offices in real-time within the GLM field of view. Currently, SPoRT and NWS Huntsville are participants in the *GOES-R* Proving Ground project, which engages the NWS forecast and warning community in preoperational demonstrations of GLM and other *GOES-R* instrument capabilities.

The GLM will continuously measure total lightning activity at a horizontal resolution of about 10 km across the CONUS, varying from about 8 km at nadir to 12 km near the edges of its field of view. The predicted detection efficiency will be better than 90% both day and night, with a false-alarm rate of less than 5%. Although the GLM will not have the horizontal resolution or vertical sampling capability that a ground-based measurement system has, it will provide forecasters with a greater picture of the total electrification within a thunderstorm or convective complex. The horizontal resolution will be sufficient

to sample individual storms with high temporal resolution, enabling detection of total lightning trends for warning decision-making.

SUMMARY AND CONCLUSIONS. The use of real-time output from the NALMA has proven 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 thunderstorms has provided forecasters with greater knowledge of storm-scale processes and enhanced warning operations. This has led to greater confidence when issuing severe thunderstorm and tornado warnings.

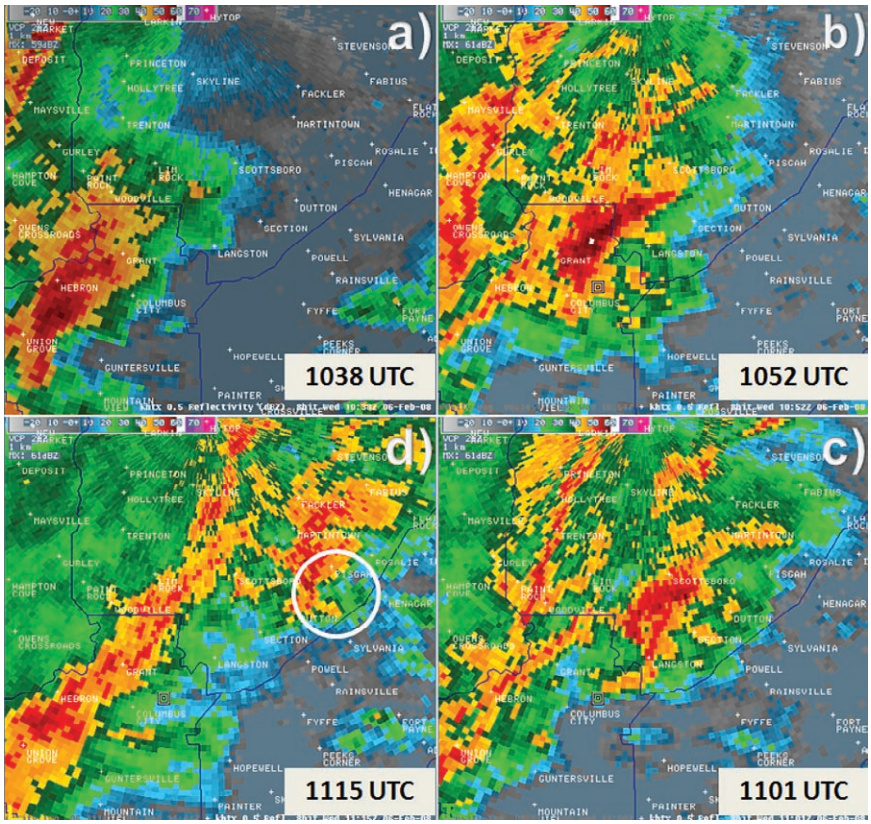

Fig. 9. A 4-panel image of WSR-88D 0.5-degree base reflectivity from KHTX at (a) 1038; (b) 1052; (c) 1101; and (d) 1115 UTC, respectively. The KHTX radar is located approximately 45 miles north of the storm at 1038 UTC. As the storm moved northeast, a well-defined reflectivity notch and eventually a hook echo were noted on radar (as outlined by the white circle on the 1115 UTC image). The tornado touched down approximately 2 minutes later at 1117 UTC.

Preliminary studies and forecaster surveys suggest that the inclusion of total lightning information provides a unique insight into storm-scale structures that may be crucial to increasing warning lead times and severe storm discernment, especially in situations where radar and other observational datasets provide conflicting signals or partial information. However, further research is certainly needed to develop a more quantifiable measure of the "added value" of total lightning information. To date, over 150 specific cases have been archived for collaborative post-storm analyses, training, and research purposes. A further emphasis should also be placed on null cases (e.g., when lightning jumps are observed with no associated reports of severe weather) to gain a better understanding of the false-alarm potential of perceived lightning jumps. Likewise, greater emphasis should be placed on the detection efficiency of ground-based networks so forecasters can recognize when artificial trends in lightning data are strictly related to efficiency or range issues.

Building upon the knowledge and lessons learned from the NWS Huntsville and NASA/SpoRT experience in transferring total lightning observations into operations, other offices with nearby total lightning networks have been able to utilize total lightning products in their forecast operations. One outgrowth of this collaboration is Southern Thunder, which brings together total lightning data and product producers and decision-making consumers for periodic workshops to advance the scientific understanding of thunderstorm processes and help develop nowcasting and warning decision-making applications that use total lightning in an operational environment. Presentations from the July 2009 Southern Thunder Workshop can be found at http://weather.msfc.nasa.gov/sport/southern-thunder/presentations.html.

Finally, related training and operational experience associated with the NALMA project have aided similar initiatives across the country. Moreover, when the next generation of geostationary satellites are launched

(GOES-R and beyond), the GLM sensor will provide real-time total lightning information across the entire CONUS for all NWS offices. Current ongoing projects involving ground-based total lightning systems, including NALMA, will be valuable in the development, validation, and assessment of future spaceborne instrumentation. An example of a NALMA lightning tutorial module developed by SPoRT and NWS Huntsville can be found at http://weather.msfc.nasa.gov/sport/training.

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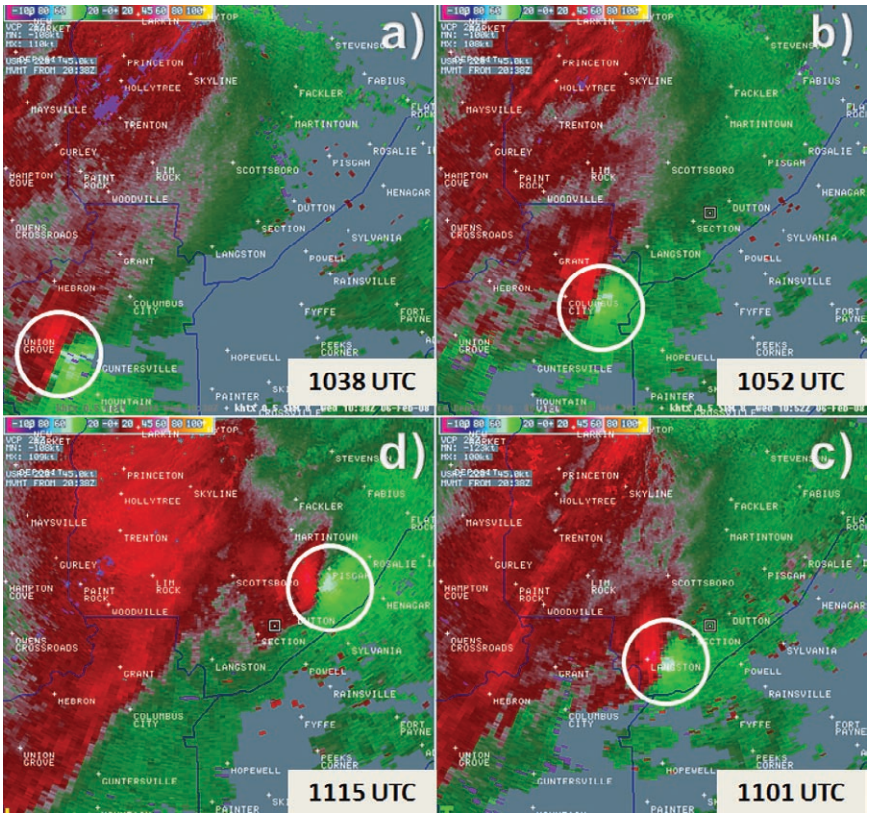

Fig. 10. A 4-panel image of WSR-88D 0.5-degree storm-relative mean radial velocity (SRM) from KHTX at (a) 1038; (b) 1052; (c) 1101; and (d) 1115 UTC, respectively. The velocity couplet tightened substantially as the storm lifted northeast toward the higher terrain of Jackson County in the 1052 and 1101 UTC volume scans.

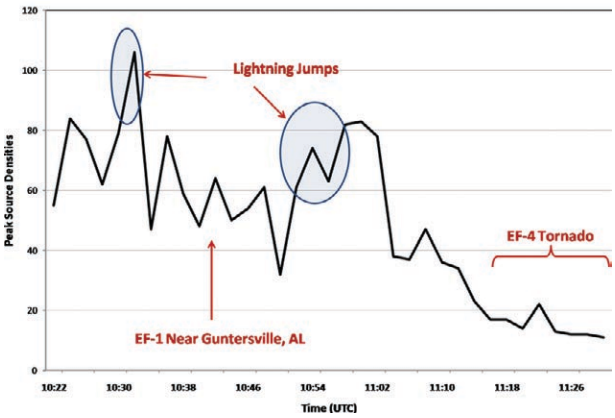

Fig. 11. A time series of peak source densities for the 6 Feb 2008 supercell that tracked across Jackson County, in northeastern Alabama. The times of tornado occurrences, along with the assigned EF-scale rating, are shown with red text and associated red arrows. Distinct lightning jumps, highlighted with filled blue ovals, were evident before both tornado touchdowns across the Huntsville County Warning Area.

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