Enhanced Verification of the Lightning Jump Algorithm

Elise V. Schultz[1,*], Themis Chronis[1], Kiel L. Ortega[2], Lawrence D. Carey[1], Kristin M. Calhoun[2], Greg Stumpf[2], Christopher J. Schultz[1,3], Geoffrey T. Stano[4], Steven J. Goodman[5]

1. University of Alabama in Huntsville, Huntsville, AL, United States
2. University of Oklahoma/CIMMS and NOAA/NSSL, Norman, OK, United States
3. NASA/MSFC, Huntsville, AL, United States
4. NASA SPoRT/ENSCO Inc., Huntsville, AL, United States
5. NOAA/NESDIS/GOES-R Program Office, Greenbelt, MD, United States

ABSTRACT: Rapid increases in total lightning activity have been shown to be an indicator of severe weather potential within a thunderstorm. The current lightning jump algorithm (LJA) is an objective, statistically based algorithm used to determine when these rapid increases in total lightning are observed within a given storm. This algorithm was constructed using three-dimensional lightning data from lightning mapping arrays in Alabama, Oklahoma, STEPS, and Washington D.C. Offline evaluation of the research algorithm from 2002 – 2011 has yielded a probability of detection (POD) of 65% and a false alarm ratio (FAR) of 46%. Further steps to transition the LJA to a real-time operational algorithm were taken in 2012 and 2013 which resulted in similar POD, larger lead times and notably larger FAR than previous studies. Both of these studies used Storm Data from the National Climatic Data Center (NCDC) for validation. Inconsistencies in the quality and reliability of storm reports in verification have been noted in the literature. One aspect is that not all severe events are reported, leading to the likelihood that the traditional verification methods will result in an elevated FAR due to an incomplete database. A fair assessment of the lightning jump algorithm requires an accurate and precise reporting of severe weather occurrences in both time and space.

The Severe Hazards Analysis and Verification Experiment (SHAVE) is an ongoing project that is part of the NOAA Hazardous Weather Testbed – Experimental Warning Program at National Severe Storm Laboratory to collect high temporal and spatial resolution report data from thunderstorms including hail size, wind damage, and flash flooding. During the 2012 and 2013 real-time Lightning Jump test, SHAVE data was collected on several cases within the Alabama, Oklahoma, and Washington D. C. domains. Because of its widespread availability, good coverage and proven severe storm proxies, radar will also be employed as part of this enhanced verification process. This study will investigate utilizing SHAVE and radar data with case studies from the larger real-time LJA database to explore enhanced verification techniques for the LJA and demonstrate lightning's value to tip the scales in the warning decision framework when combined with operational radar data.

* Contact information: Elise V. Schultz, University of Alabama in Huntsville, Huntsville, AL, USA, Email: elise.schultz@nsstc.uah.edu

INTRODUCTION

Previous work by Williams et al. (1999), Schultz et al. (2009), and Gatlin and Goodman (2010) demonstrate the correlation between rapid increases in total flash rate (i.e., "lightning jumps") and severe weather occurrence. Recent studies (Schultz et al. 2009, Gatlin and Goodman 2010, Schultz et al. 2011) have quantified the lightning jump based on statistical measures. Schultz et al. (2009, 2011) presented strong results linking total lightning rates and the nowcasting of severe and hazardous weather using an objective lightning jump algorithm (LJA) with semi-automated tracking on a large number of storms. Schultz et al. (2009) developed and tested 4 different lightning jump algorithm configurations and found that the 2σ algorithm had the best skill in nowcasting severe weather potential.

However, in Schultz et al. (2011), instances were noted where storm reports were too coarse to be used for verification purposes. For instance, Fig. 1 shows an intense thunderstorm with total flash rate exceeding 100 flashes per minute and 3 objectively identified lightning jumps, but no severe weather was reported. Similar studies (e.g., Williams et al. 1999; Trapp et al. 2006) further document additional caveats and limitations of using severe storm reports to verify forecasting algorithms. Therefore, the goal of this research initiative is to explore the use of Severe Hazards Analysis and Verification Experiment (SHAVE; Ortega et al. 2009) in the assessment of future algorithms like lightning jump and MESH for quantifying storm intensity. Furthermore, a qualitative assessment of the application of total lightning information to the severe weather forecasting paradigm will be performed.

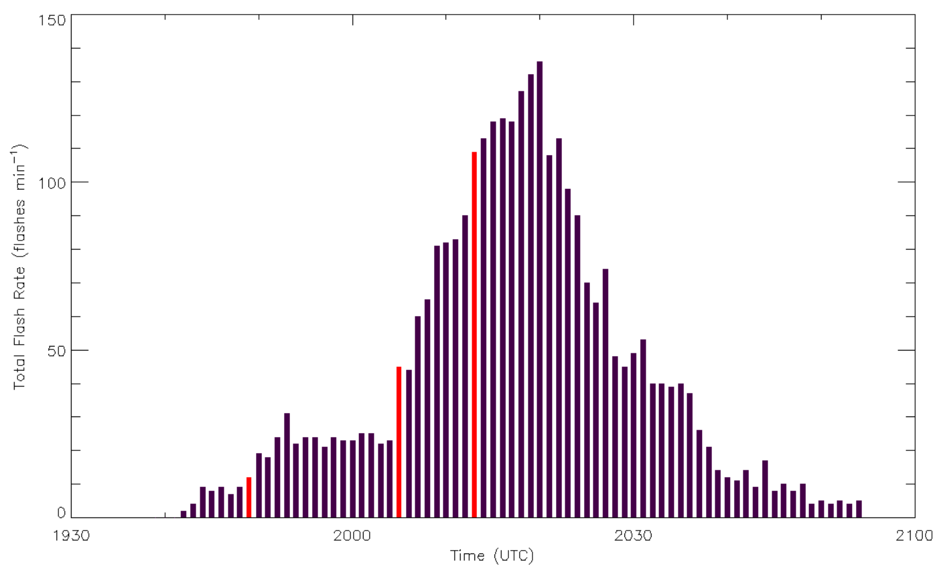

Fig. 1. Time-series of total flash rate (flashes min^{-1}) where red lines indicate objectively identified lightning jumps using the 2σ algorithm. This case shows an example of where severe weather was likely occurring but not reported.

DATA AND METHODOLOGY

The real-time Lightning Jump Test included the Alabama, Oklahoma, and Washington D. C. lightning mapping array (LMA) domains during 2012 and 2013. All radar, cluster tracking, and lightning data were archived. Individual cases studies from this data set were selected based on radar, lightning, and storm report data availability and quality.

Radar

Level II radar data were collected from each Weather Service Radar – 88D (WSR-88D) across the United States. The data were processed using the Warning Decision Support System – Integrated Information (WDSS-II; Lakashmanan et al. 2007) and applied to a common grid. Horizontal reflectivity and the radar derived metric of Maximum Expected Size of Hail (MESH, Witt et al. 1998) were the two radar based metrics primarily used within this study. Horizontal reflectivity was used to track storm clusters at the -10°C level. MESH was compared with the associated hail reports as MESH integrates reflectivity vertically with the largest weights to higher reflectivity aloft. One minute MESH maps are created from the real-time test of the lightning jump within the WDSS-II framework and are mapped on a 1x1 km^2 grid (Fig. 2).

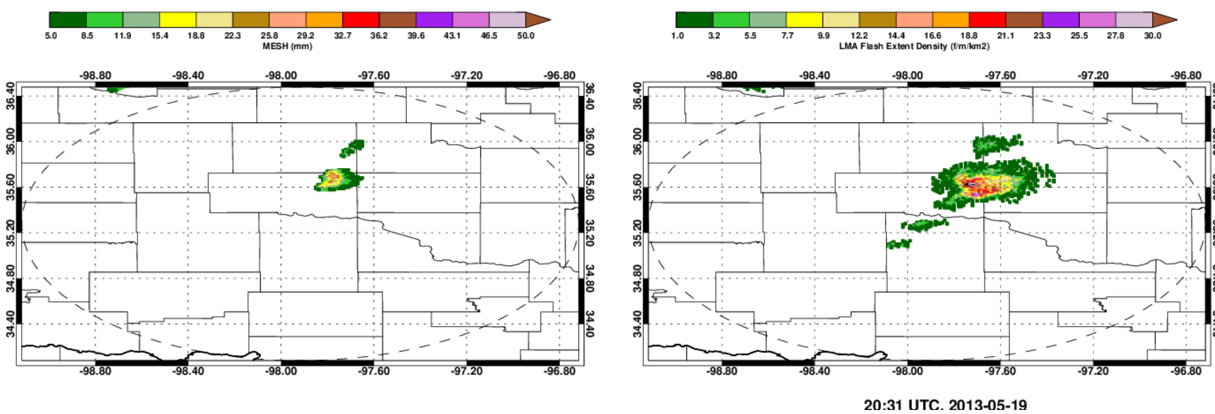

Fig. 2. Gridded MESH (left) and FED (right) on 19 May 2013 at 2031 UTC over central Oklahoma. Images like these were created every minute based on the gridded data processed by the WDSS-II framework.

Lightning

Real-time total lightning data were collected using the very high frequency (VHF) LMA observations (e.g., Rison et al. 1999 , Krehbiel et al. 2000) from three regions of the United States: North Alabama (Koshak et al. 2004), Washington D. C. (Krehbiel 2008), and Central Oklahoma (MacGorman et al. 2008). The VHF source information is combined from multiple stations to build the three dimensional structure of a lightning flash using the total lightning flash algorithm defined in McCaul et al. (2009) with a minimum of 10 sources per flash required. Flash extent density (FED) and flash initiation density (FD) maps are then generated from this data at 1 km resolution at 1 minute temporal intervals (Fig. 2). FED is defined as the number of lightning flash branches that extend through a 1 km^2 grid box during each minute interval (Patrick et al. 2005). FD is defined as the density of the flash origination points in each 1 km^2 grid box. The LJA algorithm is applied to the FD for each WDSS-II tracked cluster (more details on LJA in Schultz et al. 2014; this conference).

SHAVE Data

The Severe Hazards Analysis and Verification Experiment (SHAVE; Ortega et al. 2009) is an ongoing project that is part of the NOAA Hazardous Weather Testbed – Experimental Warning Program at National Severe Storm Laboratory to collect high temporal and spatial resolution report data from thunderstorms including hail size, wind damage, and flash flooding. SHAVE reports are collected via phone calls to verify locations within the vicinity of the thunderstorm immediately following its passage. Report magnitude, time, and location are documented, including phone calls that yield no reports (termed a "null report"). An ideal scenario would be to collect reports depicting a storm's hail swath bounded by null reports or confirmation that no hail fell at a particular location.

During the 2012 and 2013 real-time Lightning Jump test, SHAVE data was collected on several cases within the Alabama, Oklahoma, and Washington D. C. domains. This study will explore utilizing this SHAVE data with case studies from the larger real-time LJA database to explore enhanced verification techniques for the LJA and demonstrate lightning's value to tip the scales in the warning decision framework when combined with operational datasets like radar. For this paper, a supercell on 19 May 2013 was selected as initial case study for this research. This supercell developed on the south end of a line of severe thunderstorms across central Oklahoma during the late afternoon hours. The storm developed after 2100 UTC and went on to produce up to tennis ball sized hail and a tornado producing EF4 damage before merging and becoming a multicell complex of storms around 0100 UTC on 20 May 2013.

RESULTS

Before applying the SHAVE reports, it was necessary to quantify the relationship between the spatial coherence of MESH and FED. FED values ranging from 1 to 20 flashes km^2 (FED_thr) were used as a threshold to define an areal extend of the FED footprint. Next, the ratio between the total number of common points between {MESH = 0 | FED > FED_thr} and {MESH > 0 | FED > 0} were computed. Figure 3 illustrates the grid points satisfying the {MESH > 0 | FED > 0} constraint (gray color) and the {MESH = 0 | FED > FED_thr} constraint (green color) respectively, for each FED_thr value at 2031 UTC 19 May 2013 over central Oklahoma). Gray-colored points indicate the interface between the updraft and downdraft due to the presences of both larger hydrometeors and lightning activity while the green-colored points indicate regions away from the largest particle growth with less robust vertical motions. Increases in FED values precede the initial development of MESH and can serve as first indicators of spatial convective growth. Figures 4 and 5 illustrate this concept. Figure 4 shows the initial development of lightning prior to the development of MESH. This is not surprising because the ice hydrometeors necessary to facilitate electrification can be on the order of 5 mm or less, and thus are not identified by the MESH algorithm. FED values are on the order of 8-10 flashes/km^2. The lightning information provides useful indicators on updraft growth and points toward regions in which MESH values may increase, which highlights a higher potential for hail. Moving forward in time by 12 minutes (Fig. 5), one can observe that the FED has increased in magnitude and spatial coverage with values in excess of 22 flashes/km^2. Meanwhile, MESH indicates particles around 5 to 8 mm in diameter as the storm grows. The spatial scale of these two developing storms is compact and most of the lightning is concentrated near the location of increasing MESH values or near, what is likely, each storms' updraft/downdraft interface. Thirty minutes later, FED has grown considerably and is not confined to regions of larger MESH (Fig. 6). (MESH values are now in excess of 41 mm, while maximum FED is only 12.8 flashes/km^2.) However, maxima in FED are within the proximity of the largest MESH values, highlighting where the interface between the storm's updraft and downdraft while the areal extent of the FED shows areas of the fastest charging rates and accumulation of charge are located in response to vertical motions within the thunderstorm.

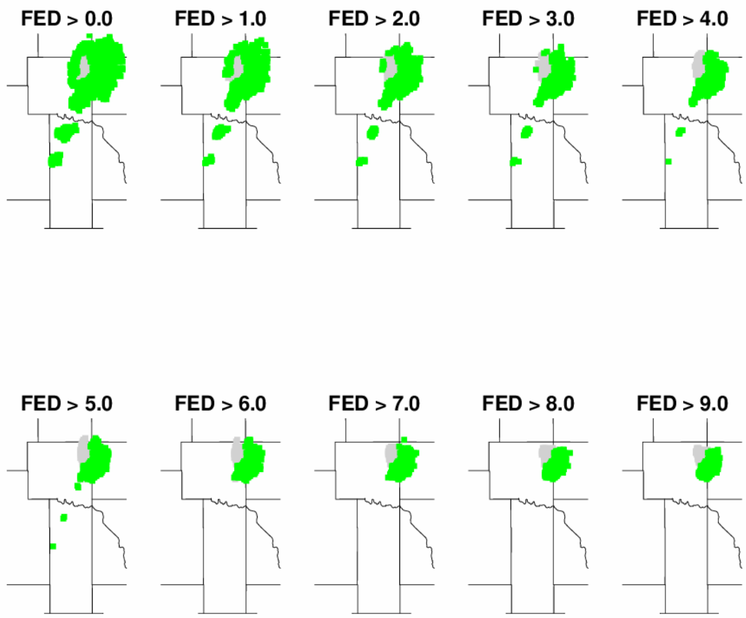

Fig. 3. Graphic showing the effect of different thresholds applied to FED (green) compared to locations with MESH >0 and FED>) (gray).

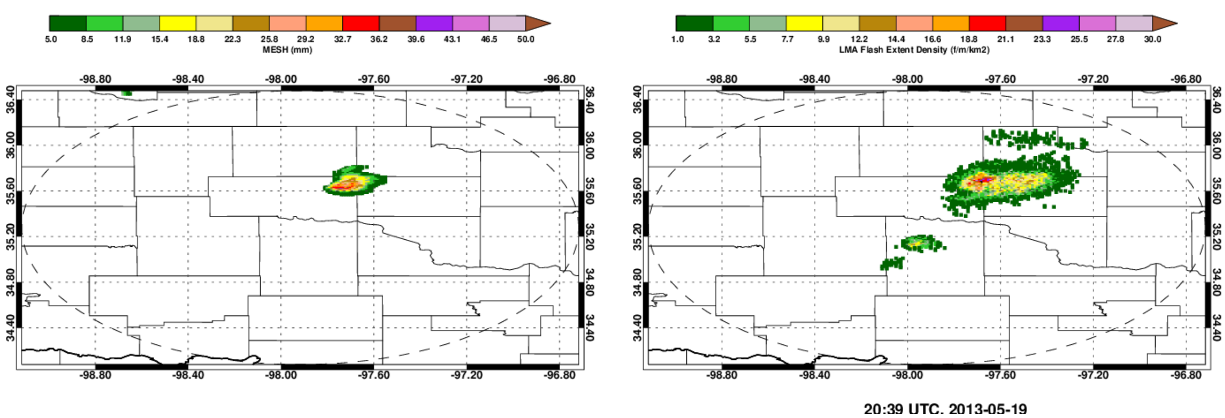

Fig. 4. Gridded MESH (left) and FED (right) on 19 May 2013 at 2039 UTC over central Oklahoma.

Analysis was expanded beyond the results above to include times when SHAVE data was present. A total of 26 hail reports and 1 null report were gathered from the furthest southwest of the three storms in Figure 6. At 2106 UTC the first lightning activity with this storm was observed in FED and a small linear feature can be observed in MESH. At 2121 UTC (Fig. 7), both FED and MESH have increased in magnitude, where the maximum in FED is 7.7 flashes km^2 and maximum MESH is at 30 mm. These two features are collocated and highlight where the updraft of the storm is most likely located. Figures 8-10 depict the storm evolution starting at 2155 UTC when the storm has already formed and beginning to intensify. At 2155 UTC, a lightning jump is noted objectively by the 2σ LJA and this intensification is seen both in FED and MESH. FED values increase from 18 flashes/km^2 to 26 flashes/km^2 and MESH increases from 33 mm to 36 mm (Fig 8). At 2226 UTC (Fig. 9), the MESH coverage increased downwind as the storm continued to grow and move to the east. At this time, the first SHAVE hail report was documented on the northern portions of the storm. Between 2226 UTC and 2322 UTC (Fig. 10), the storm maintained its strength and produced hail up to the size of tennis balls in a number of locations according to the SHAVE dataset. Additional lightning jumps were noted at 2247, 2301, and 2323 UTC using the 2σ lightning jump algorithm. Figure 11 illustrates the temporal relationship between FED, MESH, FD, and SHAVE hail reports, highlighting the utility that lightning provides in a nowcasting framework. The FED (similar to flash rate) peaks approximately 15 to 30 minutes prior to MESH at 2155, 2227, and 2301 UTC with severe sized SHAVE hail reports following at 2226, 2249 and a number of reports after 2312 UTC. While using FED to determine lightning jumps has not been fully tested (like flash initiation), FED does provide spatial context to the storm that is valuable to forecasters, as found in earlier studies (e.g., Patrick et al. 2005, McKinney et al. 2009).

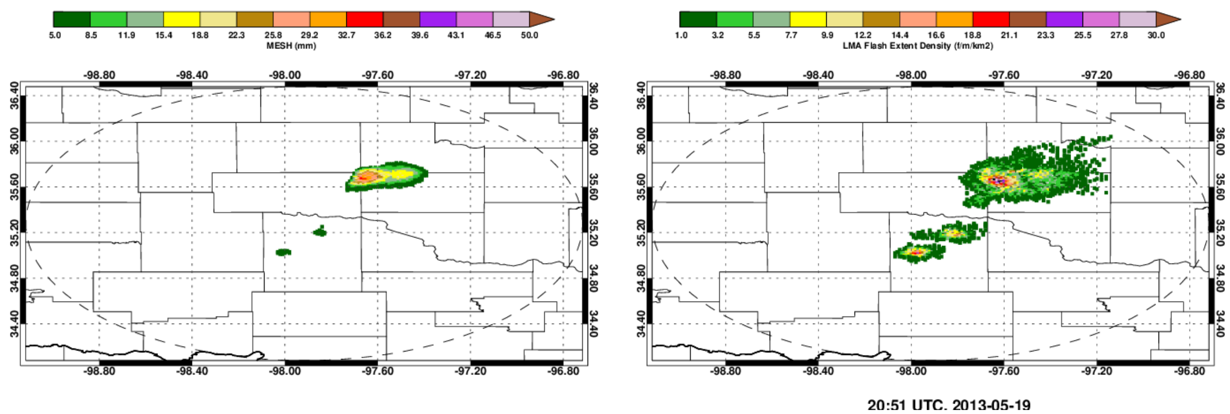

Fig. 5. Gridded MESH (left) and FED (right) on 19 May 2013 at 2051 UTC over central Oklahoma.

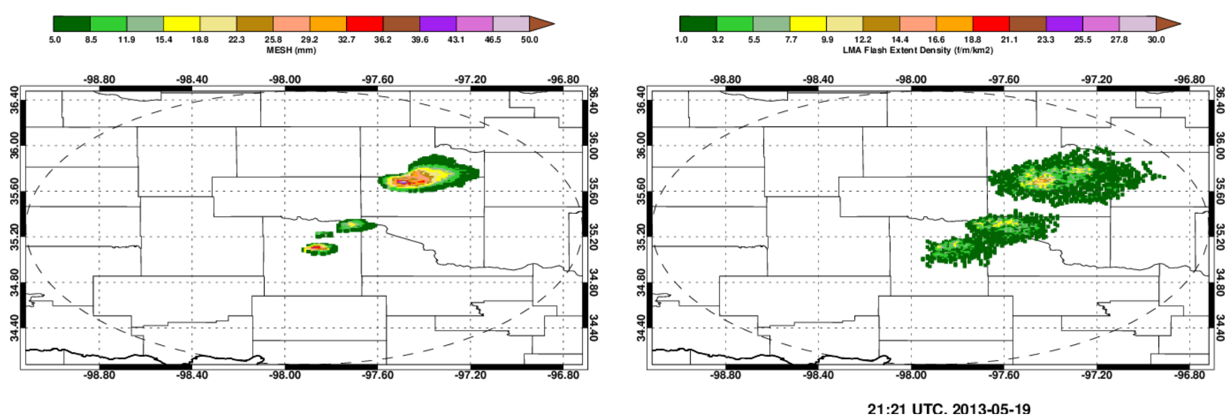

Fig. 6. Gridded MESH (left) and FED (right) on 19 May 2013 at 2121 UTC over central Oklahoma.

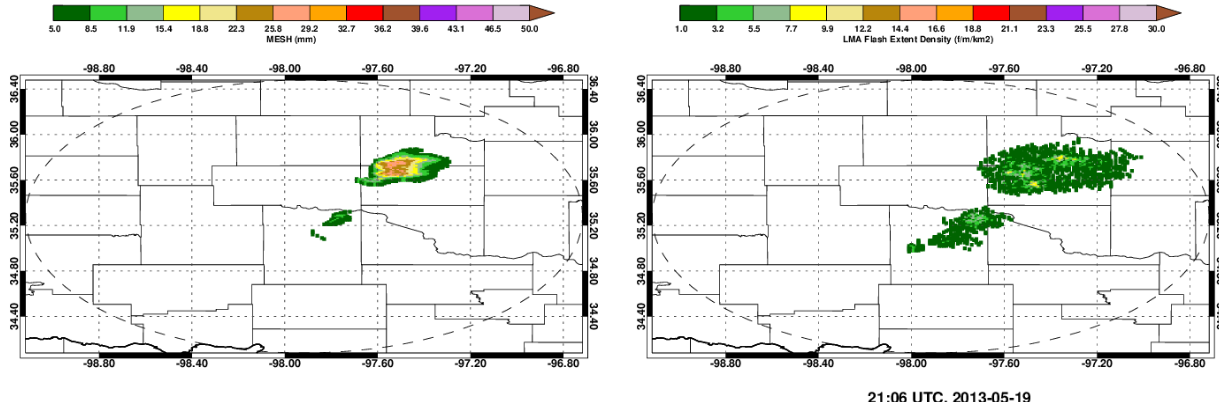

Fig. 7. Gridded MESH (left) and FED (right) on 19 May 2013 at 2106 UTC over central Oklahoma.

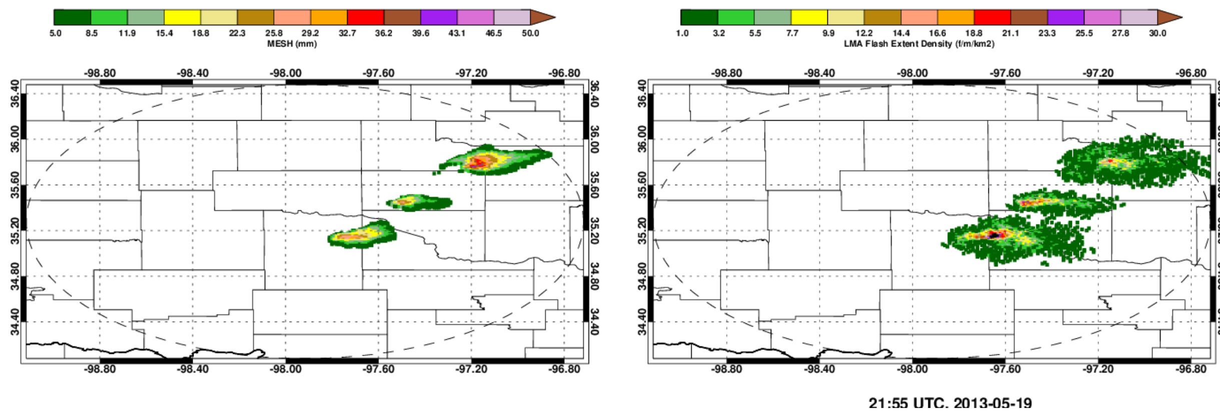

Fig. 8. Gridded MESH (left) and FED (right) on 19 May 2013 at 2155 UTC over central Oklahoma.

SUMMARY

This study investigates the fusion of MESH, lightning FED and flash rate, and SHAVE hail reports to evaluate the utility of merging radar and lightning information to advance nowcasting of storm intensity and, ultimately. severe weather. The event used herein for outlining a technique to merge all three products is a supercell that produced hail and tornadoes in Central Oklahoma on 19 May 2013. Comparisons for FED and MESH suggest that FED identified the intensifying storm 20-50 min in advance of MESH which highlights that these smaller clusters would be candidates for severe hail production (MESH>~20 mm). The approach used also emphasizes the added value of total lightning in terms of relating trends in FED and MESH to the spatial and temporal evolution of the storm. These observations would have real-time application potential in forecasting operations by enhancing the visual information relayed by the LMA/FED and MESH alone. The addition of SHAVE data to MESH and FED analysis shows that a rapid increase in lightning still precedes severe sized hail by 15 to 30 minutes. Additional case studies are currently being analyzed in order to broaden our understanding in terms of spatial and temporal relationships between radar and lightning derived variables. Furthermore, these case studies will potentially aid in understanding the role that enhanced spatial and temporal storm reports from the SHAVE database play in verification of the LJA.

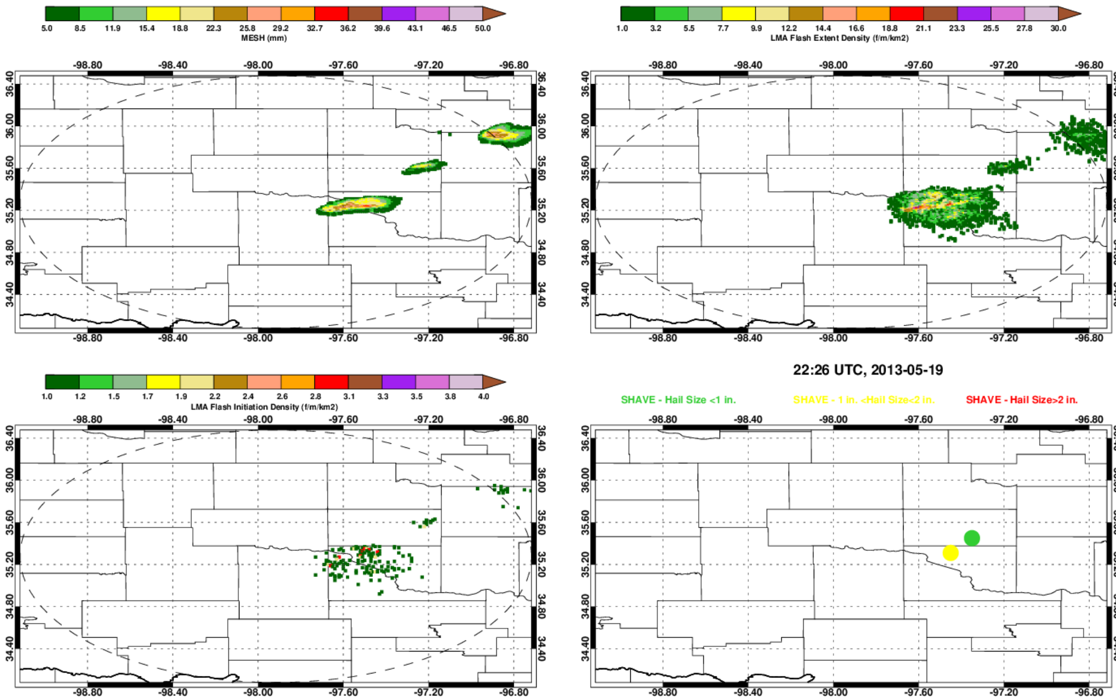

Fig. 9. 19 May 2013 at 2226 UTC. Top left: MESH, Top right: FED, Lower left: Flash initiation points, Lower right: SHAVE reports with size depicted by color.

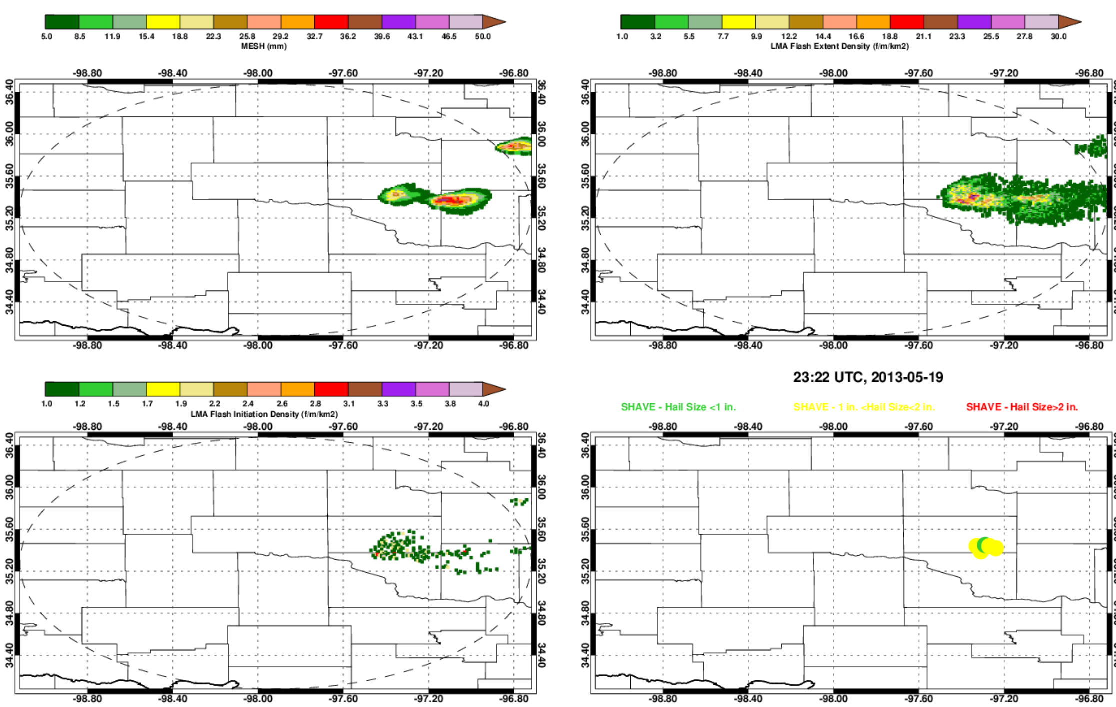

Fig. 10. 19 May 2013 at 2322 UTC. Top left: MESH, Top right: FED, Lower left: Flash initiation points, Lower right: SHAVE reports with size depicted by color.

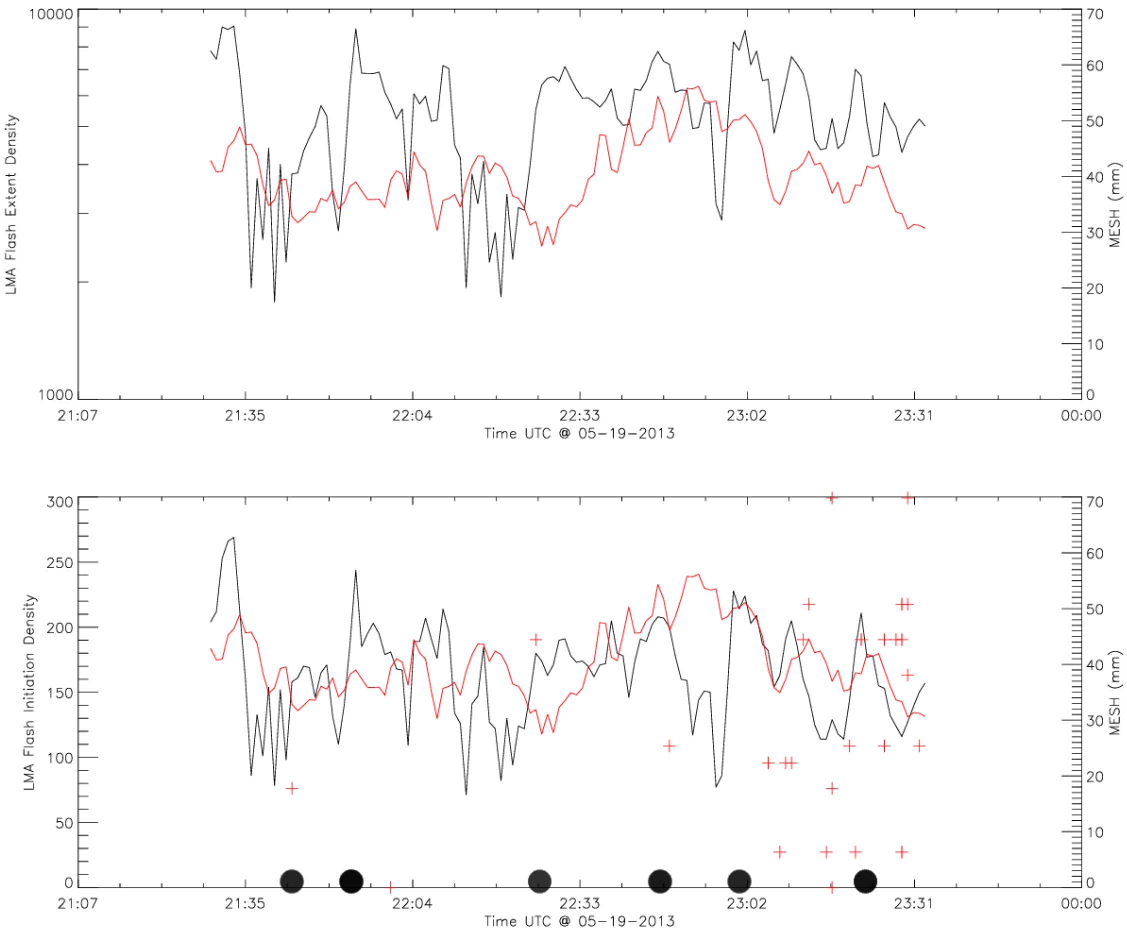

Fig. 11. Top: Time-series of Flash Extent Density (black) and MESH (red) values. Right: Time-series of flash rate based on flash initiation density (black), MESH (red) values, SHAVE reports marked with plus signs indicating hail size (in mm) and time, and black circles along time axis indicating time of 2sigma lightning jumps (2145, 2155, 2227, 2247, 2301, and 2323 UTC).

REFERENCES

Cummins, K. L. and M. J. Murphy, 2009: An overview of lightning location systems: History, techniques, and data uses with an in-depth look at the U.S. NLDN. *IEEE Trans. Electromagn. Compat.*, **51,** 499-518.

Gatlin, P. N. and S. J. Goodman, 2010: A total lightning trending algorithm to identify severe thunderstorms. *J. Atmos. Oceanic Technol.*, **27,** 3-22.

Koshak, W. J. and Coauthors, 2004: North Alabama Lightning Mapping Array (LMA): VHF source retrieval algorithm and error analysis. *J. Atmos. Ocean. Tech.*, **21,** 543-558.

Krehbiel, P. R., 2008: The DC Lightning Mapping Array. *Preprints, 3rd Conf. on Meteorological Applications of Lightning Data*, New Orleans, LA, Amer. Meteor. Soc., 3.2.

Krehbiel, P. R., R. J. Thomas, W. Rison, T. Hamlin, J. Harlin, and M. Davis, 2000: GPS based mapping system retrieval of lightning inside storms. *EOS*, **81,** 21-25.

Lakshmanan, V., T. Smith, G. Stumpf, and K. Hondl, 2007: The Warning Decision Support System – Integrated

Information. *Wea. Forecasting,* **22,** 596-612.

MacGorman, D. R. and Coauthors, 2008: TELEX: The Thunderstorm Electrification and Lightning Experiment. *Bull. Amer. Meteor. Soc.,* **89,** 997-1013.

McCaul, E. W., S. J. Goodman, K. M. LaCasse, and D. J. Cecil, 2009: Forecasting Lightning Threat Using Cloud-Resolving Model Simulations. *Wea. Forecasting*, **24**, 709–729.

McKinney, C. M., L. D. Carey, and G. R. Patrick, 2009: Total lightning observations of supercells over north central Texas. *Electronic J. Severe Storms Meteor.*, **4** (2), 1–25.

Patrick, G. R. and N. W. S. Demetriades, 2006: Using LDAR II total lightning data in an operation setting: Experiences at WFO Fort Worth, TX. *Preprints, 2nd Conf. on Meteorological Applications of Lightning Data*, Atlanta, GA, Amer. Meteor. Soc., 6.7

Ortega, K. L, T. M. Smith, K. L. Manross, K. A. Scharfenberg, A. Witt, A. G. Kolodziej, and J. J. Gourley, 2009: The Severe Hazards Analysis and Verification Experiment. *Bull. Amer. Meteor. Soc.*, **90,** 1519-1530.

Rison, W., R. J. Thomas, P. R. Krehbiel, T. Hamlin, and J. Harlin, 1999: A GPS-based three dimensional lightning mapping system: Initial observations in central New Mexico. *Geophys. Res. Lett.,* **26,** 3573-3576.

Schultz, C. J., W. A. Petersen, and L. D. Carey, 2009: Preliminary development and evaluation of lightning jump algorithms for the real-time detection of severe weather. *J. Appl. Meteor. Climatol.*, **48,** 2543-2563.

Schultz, C. J., W. A. Petersen, and L. D. Carey, 2011: Lightning and severe weather: A comparison between total and cloud-to-ground lightning trends. *Wea. Forecasting,* **26,** 744-755.

Schultz, C. J., L. D. Carey, E. V. Schultz, R. J. Blakeslee, and S. J. Goodman, 2014: Physical and dynamical linkages between lightning jumps and storm conceptual models. *Conference Proceedings 15th Int'l Conf. on Atmospheric Electricity.* Norman, OK.

Trapp, R. J., D. M. Wheatley, N. T. Atkins, R. W. Przybylinski, and R. Wolf, 2006: Buyer beware: Some words of caution on the use of severe wind reports in post event assessment and research. *Wea. Forecasting,* **21,** 408-415.

Williams, E. R., and Coauthors, 1999: The behavior of total lightning activity in severe Florida thunderstorms. *Atmos. Res.,* **51,** 245-265.

Witt, A., M. D. Eilts, G. J. Stumpf, J. T. Johnson, E. D. Mitchell, and K. W. Thomas, 1998: An enhanced hail detection algorithm for the WSR088D. *Wea. Forecasting,* **13,** 286-303.