

8.2 TOTAL LIGHTNING OBSERVATIONS OF SUPERCELLS IN THE WARNING DECISION PROCESS OVER NORTH CENTRAL TEXAS

Christopher M. McKinney^{1*}, Lawrence D. Carey^{1,2}, Gregory R. Patrick³
¹Department of Atmospheric Sciences, Texas A&M University, College Station, TX
²ESSC/NSSTC, University of Alabama at Huntsville, Huntsville, AL
³Fort Worth/Dallas NOAA National Weather Service Forecast Office

1. INTRODUCTION

Total lightning detection arrays, or those that measure both intracloud (IC) and cloud to ground (CG) lightning, detect very high frequency (VHF) sources associated with lightning breakdown processes. The information from these networks may be useful to National Weather Service (NWS) offices for diagnosis of the potential for severe weather associated with a particular convective cell. Currently, NWS forecast offices receive information from the National Lightning Detection Network (NLDN), a network of over 100 sensors that record the position and polarity (positive or negative) of CG lightning in the continental United States. Total lightning detection networks provide information in three dimensions about all lightning types within a thunderstorm, and cover a limited geographic area when compared to the national coverage of the NLDN. A nine-sensor* Lightning Detection and Ranging (LDAR) II network owned by Vaisala, Inc., is currently in operation in the Dallas/Fort Worth (D/FW) metropolitan area. Data from this network are sent in real time to NWS Southern Region Headquarters, and then passed to the Fort Worth/Dallas Weather Forecast Office (WFO FWD). Meteorologists at WFO FWD can display the data using the Display 2-Dimension (D2D) application that is part of the Advanced Weather Interactive Processing System (AWIPS) (Patrick and Demetriades 2005).

Past studies of total lightning in the warning decision process have focused on the use of flash rates as an indicator of severe weather from a convective cell (Williams et al 1999, Goodman et al. 2005). Large jumps in the flash rate have preceded tornado reports at the surface by up to 20 minutes (Bridenstine et al 2005). In addition, a decrease in the height of the 95th percentile of the total lightning sources precedes tornadogenesis in some supercells (Steiger et al. 2007a). Plots of VHF source density and flash extent density (FED) in supercell thunderstorms show features such as lightning holes or lightning hook echoes (Demetriades et al. 2002, Lang et al. 2004, Murphy and Demetriades 2005) that appear to correspond to bounded weak echo regions (BWERs) and updrafts within the thunderstorm (Krehbiel et al. 2000, MacGorman et al. 2005). The evolution and location of these features may prove useful in corroborating severe

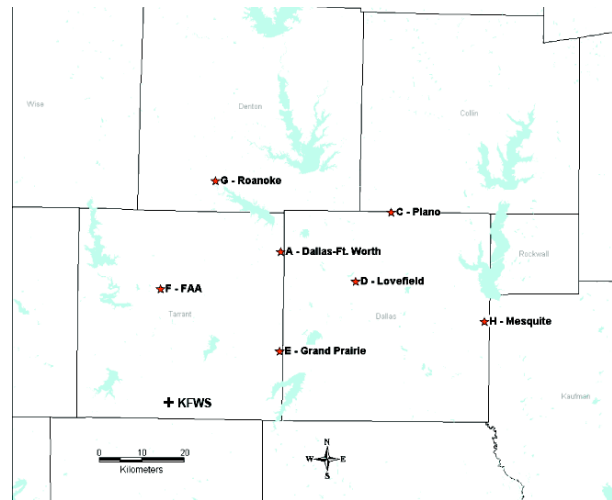


Figure 1. Locations of the KFWWS WSR-88D site and the D/FW LDAR network sensors that were active on the dates in this study. The center of the LDAR network is at D/FW International Airport (sensor site “A”). Adapted from Patrick and Demetriades (2005).

storm signatures obtained from the Weather Surveillance Radar - 1988 Doppler (WSR-88D) (Krehbiel et al. 2000, MacGorman et al. 2005).

Three severe weather days over North Texas will be examined in this analysis. In the first case, from 25 April 2005, a dryline located to the west of the D/FW metroplex served to initiate numerous showers and thunderstorms during the afternoon, including two tornadic supercells that moved across portions of Tarrant, Dallas, Johnson and Ellis counties. Earlier that same month, on 5 April 2005, a broken line of thunderstorms developed in the afternoon hours across sections of Collin, Dallas, and Ellis counties. Within this line, a supercell with left deviant motion moved across Dallas County and produced several reports of severe weather. The final case is from 13 April 2007, when a linear mesoscale convective system (MCS) moved across the D/FW metroplex, including an embedded supercell crossing across northern sections of Tarrant and Dallas counties. This cell was responsible for several reports of tornadoes and large hail across the network domain. In order to investigate the use of total lightning observations in the warning decision process over North Central Texas, data from the LDAR network

* Corresponding Author Address: Christopher M. McKinney, Texas A&M Univ., Dept. of Atmospheric Sciences, College Station, TX 77843-3150; email: cmckinney06@tamu.edu

* On the dates included in this study, only 7 LDAR II sensors were installed and in operation

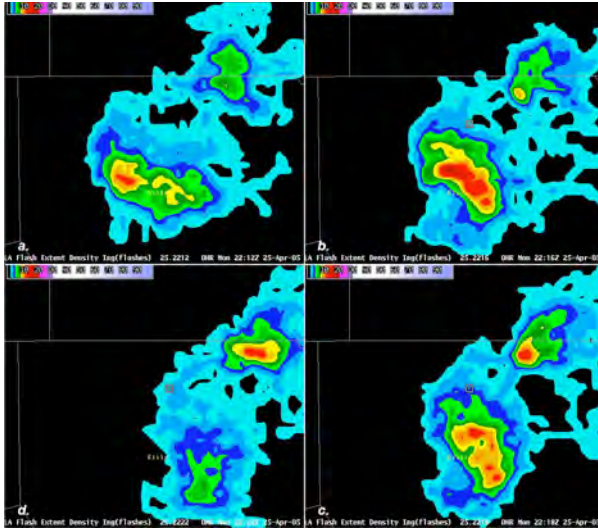


Figure 2. Right hand shift in FED track for cell two on 25 April 2005. Times are: (a) 2212 UTC, (b) 2216 UTC, (c) 2218 UTC, (d) 2222 UTC.

will be combined with radar reflectivity and velocity images from the KFWS WSR-88D and storm reports from official Storm Data publications produced by the National Climatic Data Center (NCDC).

2. METHODOLOGY

For this study, the D/FW LDAR II network was comprised of 7 sensors with baselines between 20 and 30 km. These sensors detect VHF radiation sources from lightning breakdown processes, which are then plotted in three dimensions by calculating their time of arrival at multiple sensor sites. The flash detection efficiency of the network is believed to be greater than 95% within the interior of the network, with a flash detection efficiency of 90% or greater out to a range of 120 km. The location accuracy of the sources is believed to be 200 m when the source is within a 30 km radius of the network center at D/FW International Airport. The position error is expected to be less than 2 km out to range of 150 km from the center of the network (Demetriades et al. 2002, Carey et al. 2005).

The data from the LDAR network is sent in real time to WFO FWD through the NWS Southern Region Headquarters. The data is ingested into AWIPS via the Local Data Acquisition and Dissemination (LDAD) system at WFO FWD. For the purposes of this study, only the LDAR data products available to forecasters at WFO FWD were used to analyze the total lightning activity during the severe weather event. There are currently two data sets available for display within D2D, Gridded Source Density (GSD) and FED. GSD plots the total number of sources per square kilometer (Murphy and Demetriades 2005). FED is a measure of the total number of flashes that pass through one square kilometer (Lojou and Cummins 2005). Each product displays data from a two-minute period, with images updated every two minutes. This information is produced after the VHF sources are grouped into

individual lightning flashes using a clustering algorithm. The data for both products are color coded and displayed in a manner similar to that of radar reflectivity. The color scheme in use was custom designed for the D/FW network by one of the co-authors (Greg Patrick, the Science and Operations Officer (SOO) at WFO FWD), and Nick Demetriades of Vaisala, Inc. GSD images are available in vertical slices through the Volume Browser menu in D2D. Available vertical ranges are 0-20 km, 0-3 km, 3-6 km, 6-9 km, 9-12 km, 12-15 km, and 15-18 km. Currently, FED is the preferred product for most situations, as it is vertically integrated, and is less susceptible to range effects than simple source density plots, which suffer from a decrease in VHF source detection efficiency with increasing range (Carey et al. 2005).

Data on storm structure and evolution was obtained from the KFWS WSR-88D radar site, which is located about 44 km to the southwest of the center of the LDAR network (Fig. 1). During the severe weather events the radar was operating in severe mode using Volume Coverage Pattern (VCP) 11. VCP 11 provides both reflectivity and velocity images from 14 elevation angles, or "tilts" between 0.5 degrees and 19.5 degrees. Due to the number of samples taken, the update time between images is approximately 5 minutes (NOAA FMH-11). This update time means that there are roughly two LDAR images produced for each radar scan update.

Reports of severe weather were taken from preliminary Storm Data reports available from WFO FWD and the official Storm Data published by NCDC. While these reports are generally in good agreement with the timing and location of convective cells from the KFWS data, the times listed on these reports may be up to 5 or 10 minutes off of the correct time due to the nature of the reporting method.

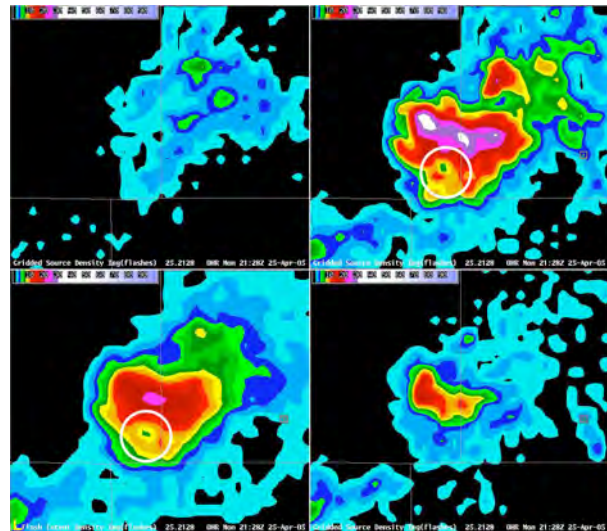


Figure 3. FED and GSD images of cell one lightning hole at 2128 UTC on 25 April 2005. Images are: (a) 6-9 km GSD, (b) 9-12 km GSD, (c) 12-15 km GSD, (d) FED.

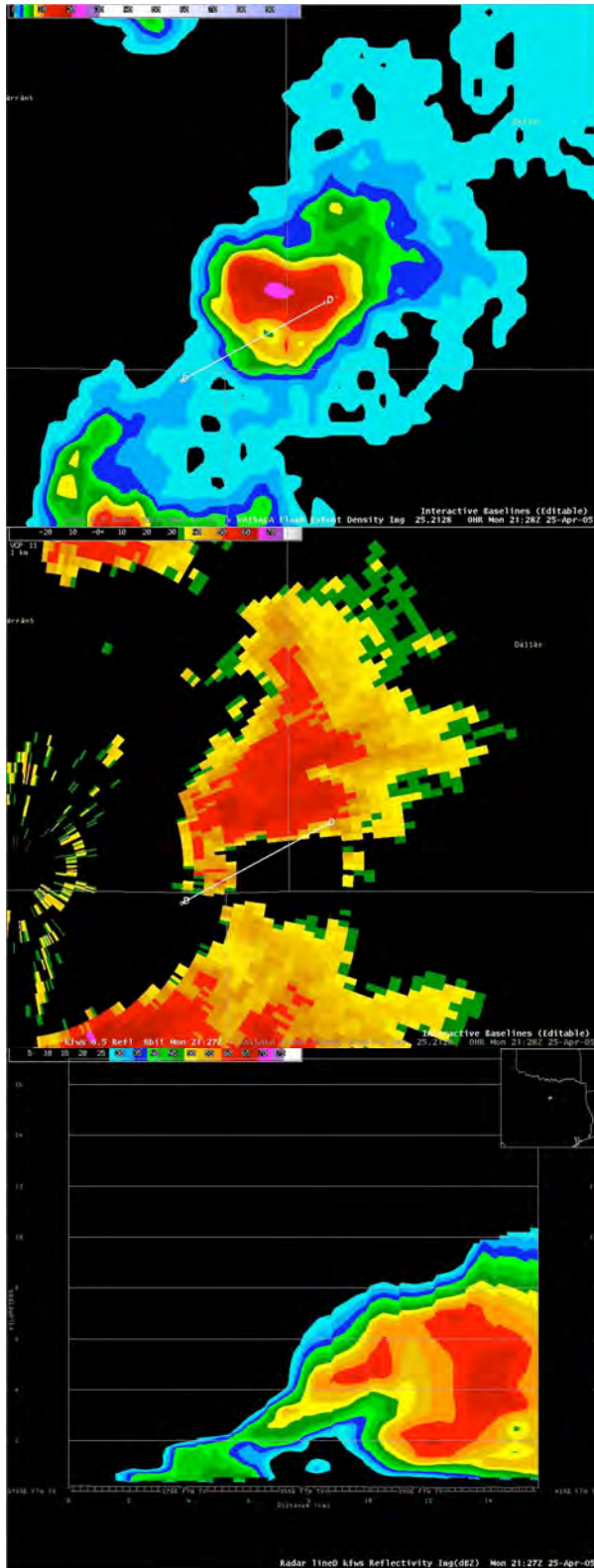


Figure 4. FED and radar reflectivity/cross section (line “D”) images of cell one lightning hole at 2128 UTC on 25 April 2005. Note the weak echo region that extends upward 2-3 km in the lightning hole. Radar images are from 2127 UTC.

3. RESULTS

3.1 25 April 2005

On this date, an advancing dryline was moving eastward and was located just to the west of the D/FW metroplex by mid afternoon. Several cells fired along this boundary, including the two supercells that were the main focus from this date. At 2100 UTC, these two cells were located in eastern Tarrant and central Johnson County, and moved southeastward into Dallas and Ellis counties during the analysis period. By 2300 UTC, the northern cell (cell one) had begun to dissipate, and cell two had moved into northeastern Navarro County.

The FED of cell one, the northern (Tarrant county) storm, exhibited a rightward shift in direction between 2112 and 2118 UTC. This FED shift to the right of the previous storm track corresponded to a similar shift in radar reflectivity data, and is discussed in detail in Patrick and Demetriades (2005). The FED maxima of cell two, the southern (Johnson county) storm, also turned to the right, later in the study period, between 2210 and 2222 UTC (Fig. 2). However, this shift in FED maxima lagged behind the shift in radar reflectivity, which began around 2200 UTC (not shown).

Cell one displayed a minimum in FED and GSD in southeastern Tarrant county at 2128 UTC (Fig. 3). This lightning hole was just to the east of a well-pronounced hook echo at low levels in the KFWS radar reflectivity data. A north-south cross section of radar data through this FED minima shows that it corresponds to an area of relatively low radar reflectivity values up to an altitude of 2 to 3 km (Fig. 4). Another similar area of minimum FED values occurred at 2234 UTC, corresponding to an area where no sources were present in the GSD data (Fig. 5). This region also corresponded to an area of weak reflectivity (25.5 - 27.5 dBZ) on the KFWS radar data at the 5.3 and 6.0 degree elevation angles, at altitudes of 7.2 km (23.7 kft) and 8.3 km (27.4 kft) above ground level (AGL) (not shown). However, this lightning minimum corresponds to relatively high values of radar reflectivity (~55 dBZ) on the 0.5 and 1.5 degree elevation scans, at altitudes of approximately 1.1 km (3.7 kft) and 2.6 km (8.5 kft) AGL (not shown). Each minimum in lightning activity was observed on only one two-minute image of either FED or GSD. However each minimum was followed by a notch in the FED and GSD data that persisted for several images, corresponding to the updraft region of the cell as shown on the KFWS data.

Another interesting observation was the presence of appendages on cell one that appeared in displays of both FED and GSD at several points in the evolution of the storm. They were present at 2116 UTC (Fig. 7c in Patrick and Demetriades 2005), and again between 2132 and 2144 UTC (Fig. 6). No similar features were observed in the FED or GSD images of the second cell. At 2158 UTC, another appendage was observed to form on the southern edge of the FED maxima from cell one (Fig. 7). This appendage evolved over the next five FED images into a separate area of relatively high FED values separate from cell one. During this time, the

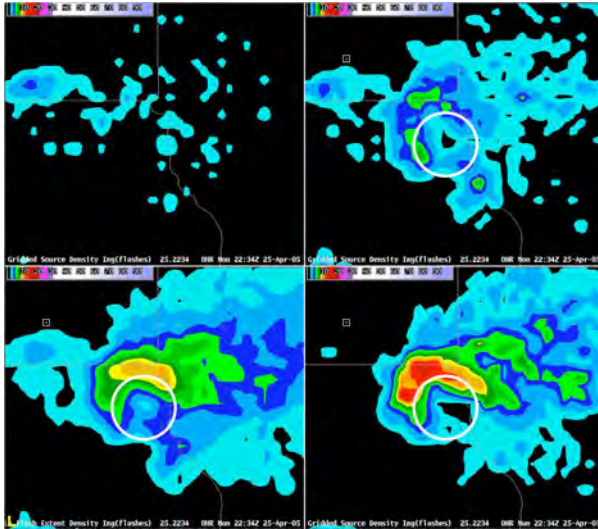


Figure 5. GSD and FED images of second cell one lightning hole at 2234 UTC, 25 April 2005. Images are: (a) 6-9 km GSD, (b) 9-12 km GSD, (c) 12-15 km GSD, (d) FED.

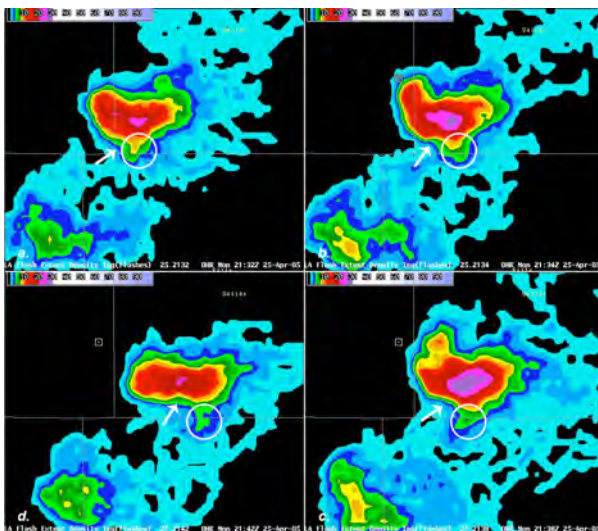


Figure 6. FED time series of cell one leading appendage (circled) from 25 April 2005. Times are: (a) 2132 UTC, (b) 2134 UTC, (c) 2138 UTC, (d) 2142 UTC. Updraft notches are marked with arrows.

maximum FED value observed with this new feature was 16.8 flashes $\text{min}^{-1}\text{km}^{-2}$. Cell one displayed a decrease in both the value and extent of the FED maxima during this ten-minute period. At 2210 UTC, the two FED maxima merged on the D2D display into one feature. FED values associated with the merged feature began to increase at 2216 UTC on the southwest side of the cell, with FED values approaching 9 flashes $\text{min}^{-1}\text{km}^{-2}$. This intensification continued until a maximum of over 17 flashes $\text{min}^{-1}\text{km}^{-2}$ was observed at 2226 UTC. Trends in GSD for this event were similar to those displayed by the FED (Fig. 8), however an area of relatively high GSD was apparent at 2154 UTC, four minutes prior to being a prominent feature in the FED

display. The two GSD maxima remained distinct until 2216 UTC when they were observed to merge. GSD values reached a maximum of 30.4 sources $\text{min}^{-1}\text{km}^{-2}$ at 2226 UTC, corresponding to the time of highest FED values.

Past research has shown that sharp peaks in lightning flash rate often precede reports of severe weather. Williams et al (1999) found that these peaks occurred between 1 and 15 minutes before the severe weather, with flash rates increasing at a rate between 20 and 100 flashes per minute per minute. Bridenstine et al (2005) found similar results from the North Alabama Lightning Mapping Array (LMA), with peaks in flash rate occurring between 3 and 20 minutes prior to tornado touchdowns. FED values for both cells were variable throughout the study period, however several large changes in maximum FED values were readily observed. Cell one displayed increasing FED values between 2124 and 2140 UTC, reaching values in excess of 30 flashes $\text{min}^{-1}\text{km}^{-2}$ (Fig. 9). A drop in FED values then followed at 2142 UTC, where the maximum value was just over 21 flashes $\text{min}^{-1}\text{km}^{-2}$. FED values quickly increased after this drop, with maximum values again above 30 flashes $\text{min}^{-1}\text{km}^{-2}$ by 2146 UTC (not shown). Storm reports indicate that a tornado was spotted on the ground at 2135 UTC in Cedar Hill (NCDC 2005). Another “jump” in FED for cell one occurred just after 2200 UTC. FED values increased between 2200 and 2204 UTC, reaching a maximum value of 21.6 flashes $\text{min}^{-1}\text{km}^{-2}$ (not shown). The maximum FED value dropped below 10 flashes $\text{min}^{-1}\text{km}^{-2}$ at 2206, and continued to drop as a second FED maxima (discussed previously) approached from the southwest, but no severe weather was reported. The FED increased again between 2220 and 2226 UTC after the apparent merger of these two features. Maximum values reached just over 17 flashes $\text{min}^{-1}\text{km}^{-2}$ before dropping to below 11 flashes $\text{min}^{-1}\text{km}^{-2}$ by 2230 UTC. A report of 2.50 cm

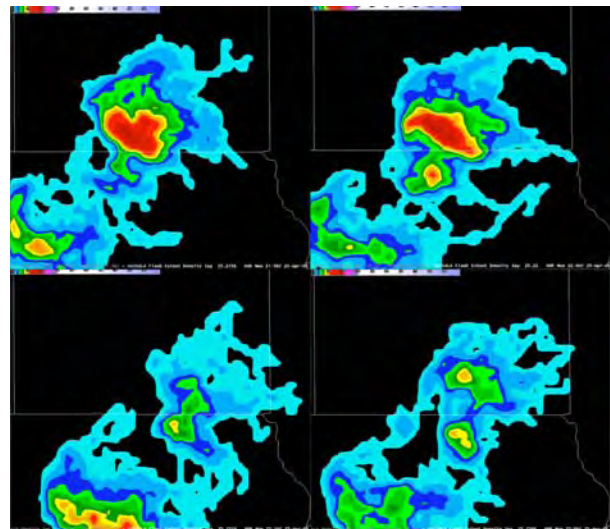


Figure 7. New FED maxima developing to the south of cell one and then merging with cell one. Times are: (a) 2158 UTC, (b) 2200 UTC, (c) 2206 UTC, and (d) 2210 UTC on 25 April 2005.

(1.00 in) hail was reported in Ferris in far northern Ellis County at 2221 UTC, corresponding roughly to a slight decrease in FED values as these two features merged. (NCDC 2005). Cell two exhibited similar features in the time evolution of its FED values. At 2128 UTC, maximum FED values with cell two reached a maximum of 14.7 flashes $\text{min}^{-1}\text{km}^{-2}$ just to the east of Alvarado. At 2130 the maximum FED value dropped to 5.51 flashes $\text{min}^{-1}\text{km}^{-2}$ before increasing again at 2132 UTC (not shown). A tornado was reported 1 mile west of Alvarado at 21:25, and 2.50 cm (1.00 in) hail was reported in Alvarado at 2130 UTC (NCDC 2005). Another strong increase in FED occurred with this cell in western Ellis County between 2142 and 2148 UTC with values reaching a maximum value of 15.5 flashes $\text{min}^{-1}\text{km}^{-2}$ at 2148 UTC (Fig. 10). On the 2150 UTC image, FED values were observed to drop significantly, with a maximum of only 6.85 flashes $\text{min}^{-1}\text{km}^{-2}$ (Fig. 10). A tornado was reported near the community of Maypearl at 2156 UTC (NCDC 2005).

3.2 05 April 2005

LDAR data from this date was examined beginning at 2200 UTC. At that time, a solid line of convection extended from southern Oklahoma down through Collin County. This line extended further south and west as a broken line of cells from Collin to Bosque County. The primary cell of interest on this date forms at approximately 2254 UTC on the tri-county border between Tarrant, Dallas and Ellis counties. This cell undergoes a split beginning at 2309 UTC on the KFWS imagery, and the left moving cell rapidly moves northeast across Dallas county before merging with another cell in far eastern Collin county at approximately 2348 UTC (Fig. 11).

This left moving cell exhibits similar updraft signatures in FED and GSD images to the northern supercell from 25 April. Several "FED notches" were noted with this cell, corresponding to tight reflectivity gradients on the northwestern side of this cell (Figs. 12-13). FED values with this cell were much lower than those from the 25 April northern supercell, but two distinct peaks in FED activity were noted. The first peak occurred at 2314 UTC with a maximum FED value of 10.3 flashes $\text{min}^{-1}\text{km}^{-2}$ (Fig. 12). FED values peaked with this cell again at 2326 UTC, with a maximum value of 10.1 flashes $\text{min}^{-1}\text{km}^{-2}$ over northeastern Dallas County (Fig. 13). At 2322 UTC 2.50 cm (1.00 in) hail was reported 5 miles northeast of Dallas, and 3.75 cm (1.50 in) hail was reported two miles north of Garland (northeast of Dallas) at 2336 UTC. A report of 2.50 cm (1.00 in) hail was reported in Blue Ridge, in eastern Collin County at 2350 UTC, immediately after the merger of the left moving cell with another cell in the line. While there was some increase in FED values associated with this new cell prior to this severe weather event, an apparent loss of FED data at 2338 UTC (manifested as a significant drop in FED values across all cells for one image) makes it difficult to make an accurate statement on the lightning activity leading to this severe report. A third, smaller cell began to develop

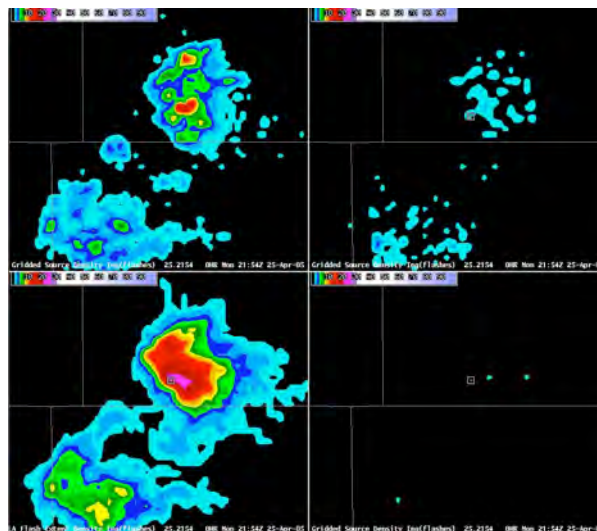


Figure 8. Comparison of GSD and FED at 2154 UTC on 25 April 2005. Images are: (a) 6-9 km GSD, (b) 9-12 km GSD, (c) 12-15 km GSD, (d) FED. Note highlighted region in (a), this feature evolved into the second maxima of FED displayed in Fig. 7, although it was not a distinct feature in FED until 2158 UTC, four minutes after appearing on the GSD display.

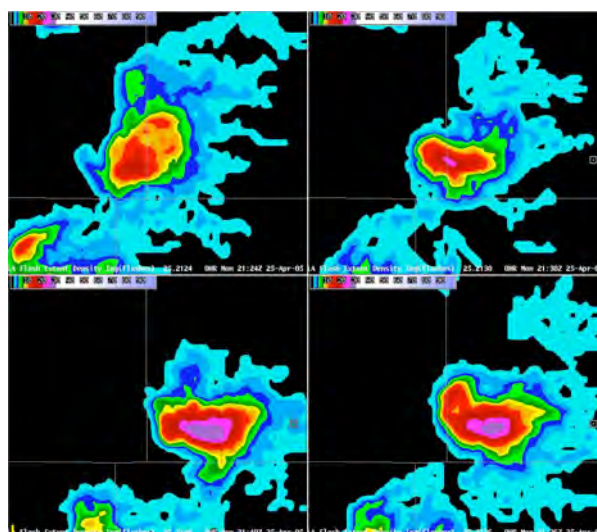


Figure 9. Increasing values of FED associated with cell one at (a) 2124 UTC, (b) 2130 UTC, (c) 2136 UTC, and (d) 2140 UTC on 25 April 2005.

northeast of Desoto in Dallas County at approximately 2334 UTC. This cell had a peak in FED of 14.4 flashes $\text{min}^{-1}\text{km}^{-2}$ just to the west of the town of Mesquite at 2340 UTC, but no severe weather was reported at the time. Again, data from this cell is also hampered by the apparent data loss mentioned previously, but after dropping off from 2340 UTC, FED values on the northeast side of this cell begin to rise again at 2358 UTC in northeastern Rockwall County. This activity peaked at a value of 15.5 flashes $\text{min}^{-1}\text{km}^{-2}$ (the highest seen on this date) at 0002 UTC (not shown). FED values began to decline on the 0004 UTC image, which

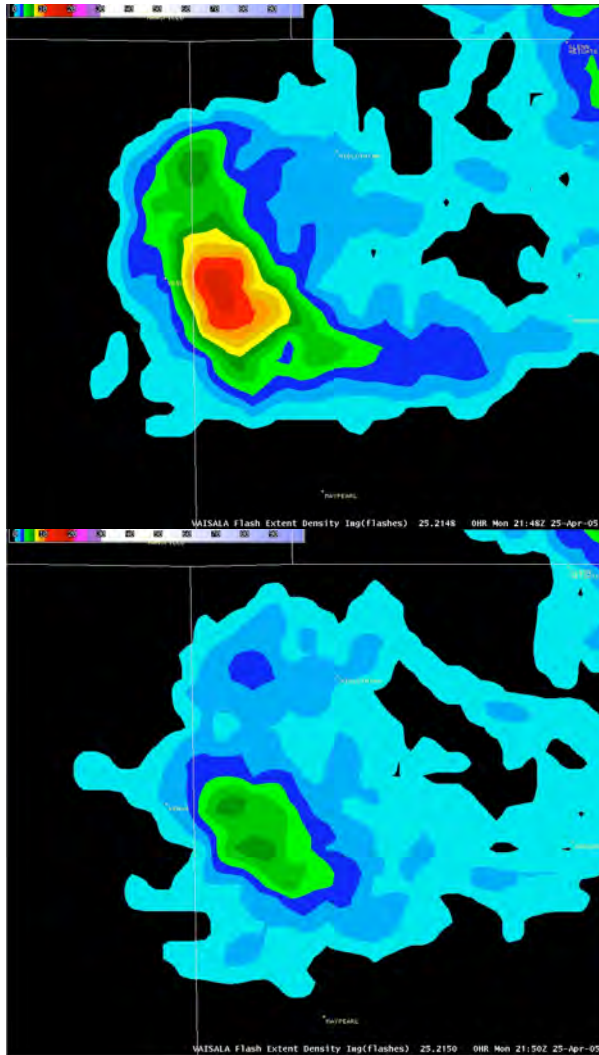


Figure 10. FED from cell two on 25 April 2005 from 2148 and 2150 UTC. Note the dramatic decrease in FED between the two images.

was the last image of FED data available for this study. Although this cell showed higher values of FED than the supercell in this case, no severe weather was reported with this cell.

The left moving supercell in this case displayed lightning appendages on the left flank of the cell similar to those seen on the right flank of the northern cell from April 25. The first appendage developed at 2314 UTC and became more pronounced on the 23:16 UTC image (Fig.12). The radar reflectivity image from 2319 UTC showed that the cell had shifted to the left of its track from the previous 6 volume scans (not shown). A second appendage and an associated FED notch develop at 2328 UTC (Fig. 13). After each of these appendages developed, the FED values appear to turn towards them, and the higher values of FED shift farther to the left. The composite reflectivity data from KFWS showed what appears to be another, smaller, deflection to the north of the previous cell track beginning at 2334 UTC (not shown).

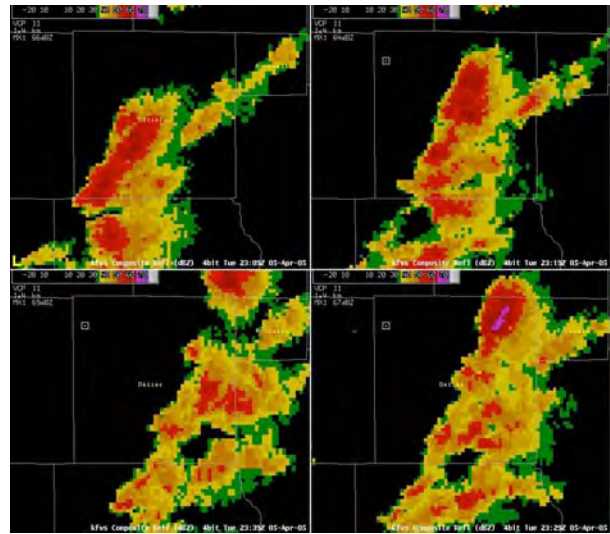


Figure 11. Evolution of left moving supercell from 05 April 2005 from KFWS composite reflectivity. Position of this cell is displayed at (a) 2309 UTC, (b) 2319 UTC, (c) 2329 UTC, and (d) 2339 UTC.

3.3 13 April 2007

On this date, a dryline across North Central Texas served as a triggering mechanism for the formation of a broken line of isolated cells to the west of the Dallas/Fort Worth metroplex that soon formed into a solid linear MCS. At the center of this line, an embedded supercell developed and moved across Tarrant and Dallas counties, producing several reports of tornadoes and hail up to 7.50 cm (3.00 in). Due to concerns with network communications, only data after 2300 UTC were considered in this study. Additionally, at 2336 UTC, values of FED began to decrease for all cells, until all VHF data across the network were lost at 23:43 UTC (not shown). After this image, FED values began to slowly climb through the 2354 UTC image where values returned to their magnitudes before this data loss. This loss in data occurred as areas of strong convection crossed several of the sensor sites.

The first feature of interest from this date occurs at 2316 UTC in southern Denton County. A large “hook” appendage developed on the southern edge of a large FED maxima (Fig. 14). When compared to radar data, the FED minimum encircled by this appendage was located in an area with reflectivity values between 40 and 45 dBZ (Fig. 15). An area of cyclonic rotation and a radar hook echo develop on the southern end of this storm by 2332 UTC (Figs. 16 & 17). This feature quickly dissipates within the next two radar volume scans as the activity to the south of this cell rapidly moves eastward.

At 2324 UTC, a notch begins to develop on the west side of the FED maxima located in Denton County (Fig. 18). This feature persists into the network data loss period between 2336 and 2352 UTC. After this data loss, the feature becomes most pronounced on the 2354 UTC FED image as a sharp notch of low FED values extending into the large FED maxima that had

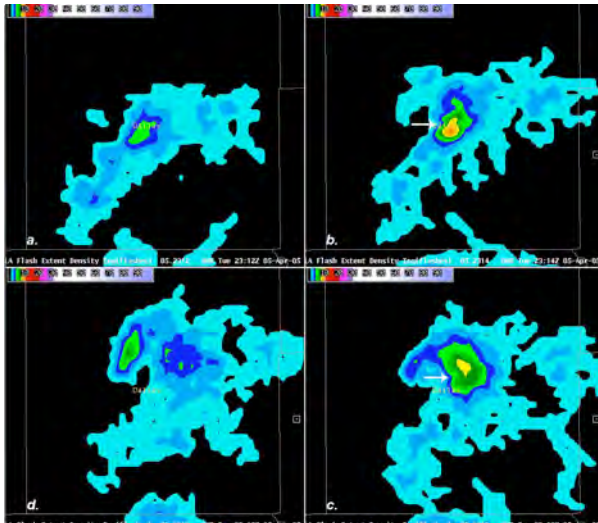


Figure 12. Development of leading appendage on the left moving supercell and subsequent shift of FED maximum at (a) 2312 UTC, (b) 2314 UTC, (c) 2316 UTC, and (c) 2318 UTC on 13 April 2007. Updraft notches are marked with arrows.

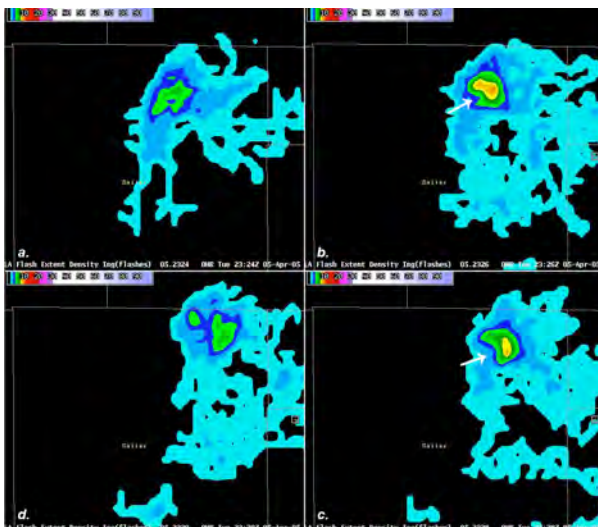


Figure 13. Development of second leading appendage associated with the left moving supercell from the 05 April 2005 case. Times are: (a) 2124 UTC, (b) 2126 UTC, (c) 2128 UTC, and (d) 2130 UTC. Updraft notches are marked with arrows.

crossed into Collin County (Fig. 19). At 2347 UTC, velocity data from the KFWS radar showed outbound velocities of over 80 knots in southeastern Denton County at approximately 3.9 km (13.0 kft) and 3.0 km (10.0 kft) were 77 and 54 knots, respectively. The 4.3 and 3.4-degree tilts at this time also show a slight bow in reflectivity in this area. At 0001 UTC, the bowing reflectivity was observed on the 2.4 and 1.5-degree tilts, and outbound velocities from the 2.4-degree tilt had increased from 54 knots at 2347 UTC to greater than 64 knots. Outbound velocities in this area on the 1.5-

degree scan were greater than 51 knots, at an altitude of approximately 2.1 km (7.1 kft) AGL (Fig. 20). A wind gust of 50 knots was reported 0.9 miles northeast of Allen in south central Collin County at 0015 UTC (NCDC 2007).

Another minimum of FED appears in Dallas County at 2354 UTC, associated with the supercell embedded within the convective line (Fig. 21). This feature is located in an area of relatively low radar reflectivity values to the south of a tight radar reflectivity gradient and to the east of a radar hook echo that develops on the 2356 UTC 0.5-degree radar tilt (Fig. 22). A strong area of cyclonic rotation persists in this area for several volume scans, as shown on the 2356 UTC velocity image (Fig.23). At 0000 UTC on 06 April, a tornado was reported 4 miles to the east-northeast of Dallas (NCDC 2007).

4. DISCUSSION AND CONCLUSIONS

Displays of FED and GSD have shown the ability of total lightning data to highlight key characteristics of supercell structure on the dates examined in this study. FED and GSD imagery successfully highlight the updraft regions of the cells, as shown by the lightning holes present at two separate times with the northern cell on April 25. The radar reflectivity cross section through the first lightning hole on April 25th clearly shows the vaulted shape corresponding to the updraft region of the parent thunderstorm. Although each of these lightning holes themselves were only apparent on one image of either FED or GSD, both holes evolved into a persistent notch in the lightning data at the same location in the cell as the radar reflectivity hook echo or updraft notch, similar to the lightning notch described in Demetriades et al. (2002). It is also worth noting that each lightning hole was far more evident in GSD rather than FED, as the method by which FED is calculated tends to fill in bounded areas without VHF sources. This advantage of GSD over FED is good reason for forecasters to check

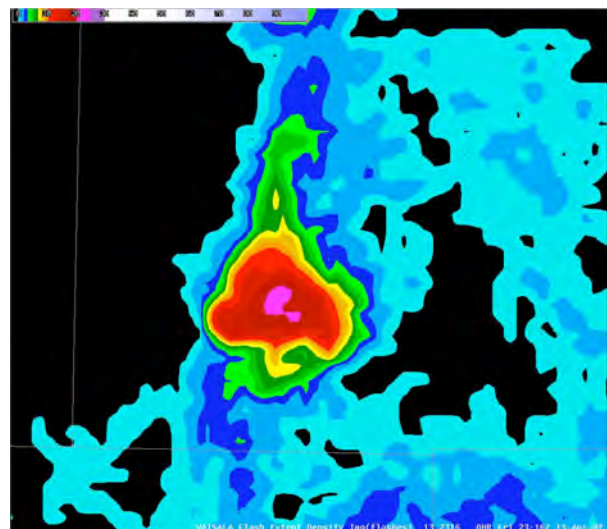


Figure 14. Hook shaped FED appendage in Denton County at 2316 UTC on 13 April 2007.

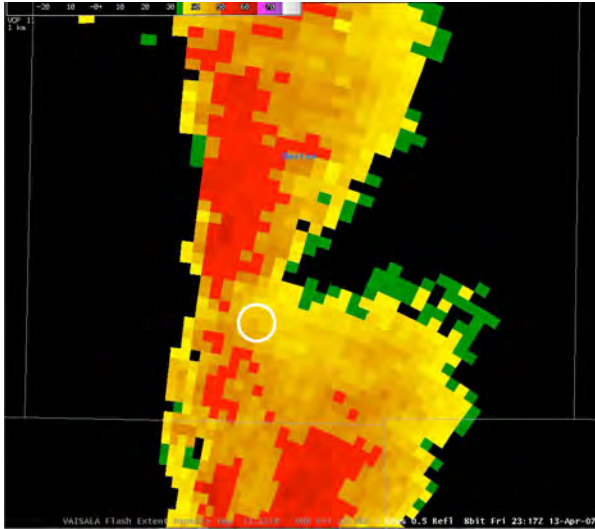


Figure 15. KFWs 0.5 degree reflectivity image from 2317 UTC on 13 April 2007. Highlighted area is the area encircled by the FED hook appendage in Fig. 14.

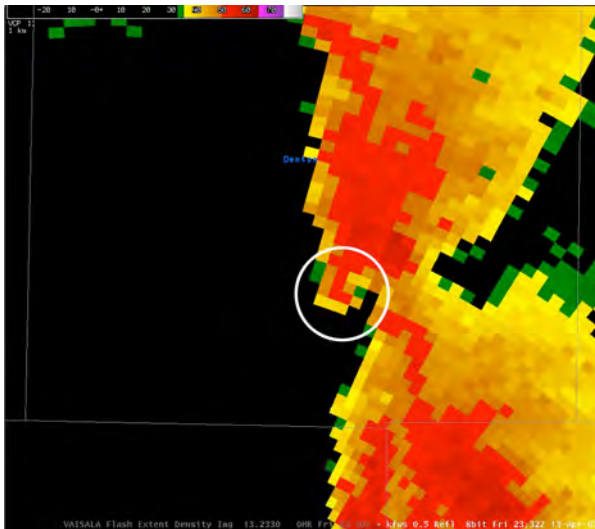


Figure 16. 0.5 degree reflectivity image from KFWs radar at 2332 UTC on 13 April 2007 showing a radar hook echo that developed in southern Denton County.

both products, at least at ranges close enough that GSD isn't degraded by decreasing detection efficiency

On April 5th, similar updraft notches were present in FED imagery of the left moving supercell that crossed Dallas County. In this case, the FED provides even greater benefit, as this cell tended not to have a well-defined radar hook echo around the updraft region. The presence of the updraft notch in FED in addition to the tight radar reflectivity gradient on the northwest side of this cell served to highlight it as a left moving supercell, despite the lack of the "classic" supercell shape.

The embedded supercell from April 13th also showed a minimum in FED at 2354 UTC that was clearly associated with the updraft region of this cell. Although this minimum appears to be visually similar to the lightning hole seen with the northern supercell on 25

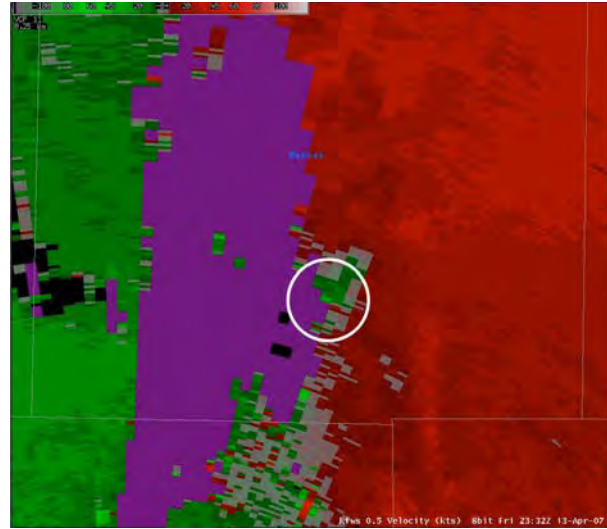


Figure 17. KFWs 0.5 degree velocity image from 2332 UTC on 13 April 2007. Highlighted location is the same as that in figure 16. Note the velocity couplet co-located with the hook echo shown in Fig. 16.

April, this may be a consequence of its location between the FED maximums associated with the convective core of the supercell and the flanking line to the south. Regardless of whether this feature is a true lightning hole, it does bring the forecaster's attention to the updraft region associated with the main cell.

Additionally, the lightning "hook echo" and associated FED minima that developed along the convective line in Denton County at 2316 UTC appears to have preceded the development of a mesocyclone north of the main supercell. Although this hook feature only persisted for two LDAR update images, a small hook echo in radar reflectivity did develop by 2332 UTC, and an associated area of low-level rotation was observed in the velocity data. Again, this was short lived, most likely due to the rapid speed of advance of the reflectivity line segment immediately to the south of this rotation, cutting off the inflow to the updraft in a similar manner to the death of the main supercell shortly after 0000 UTC. It is interesting that in this particular case the development of the lightning "hook" and associated notch occurred roughly 15 minutes before it was observed in the radar data.

As a consequence of these results and those of other studies it appears that *forecasters can use lightning data in D2D as a secondary indication of the presence of a strong updraft associated with a particular cell, as regions within the cell with little intracloud lightning have shown a strong correlation with the updraft region of the thunderstorm* (Krehbiel et al. 2000, Goodman et al. 2005, Murphy and Demetriades 2005).

In a similar fashion, the rear notch in FED associated with the cell moving across southern Denton and Collin counties on 13 April 2007 appears to highlight an apparent rear inflow jet in this part of the convective line similar to the results of Steiger et al. (2007b). This notch, which first formed at 2124 UTC, became most pronounced on the 2354 UTC FED

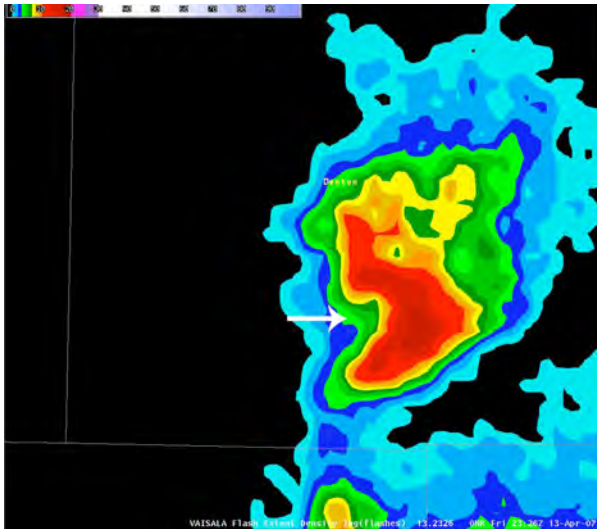


Figure 18. FED notch developing at 2326 UTC on 13 April 2007 on the back side of the cell in Denton County.

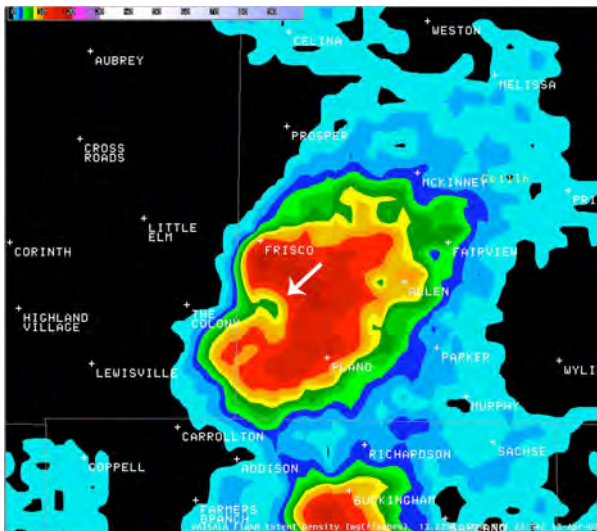


Figure 19. FED notch from the same cell as figure 18 at 2354 UTC on 13 April 2007. A severe wind report was recorded just north of the town of Allen (located on the east side of the cell) at 0015 UTC.

image. The development of this feature preceded the descent of strong outbound radar velocities to low levels in the KFWS volume scans. No rear inflow notches were readily apparent in radar reflectivity data during this time period with this line. The occurrence of a severe wind gust near Allen in southern Collin County at 0015 UTC suggests that *this rear notch may be an FED signature of the potential for severe straight line wind gusts associated with a linear MCS* as in Steiger et al. (2007b). This feature is not to be confused with the “updraft” notches also described in the text. The rear notch in FED from 13 April is a much larger and more pronounced feature than the updraft notches, and not located in an area of the cell that would suggest an updraft. More cases involving linear systems with severe straight-line winds need to be investigated to

determine whether this is an isolated feature or a reliable indication of severe weather potential.

Another very interesting result from this study is the occurrence of FED appendages that appear to signal a tendency for deviant motion with a supercell. On 25 April, the northern supercell develops two appendages during its lifetime that appear to be just to the east of the updraft region of the cell. These appendages develop at 2116 and between 2132 and 2144 UTC. During both of these times the cell was in the process of shifting to the right of its previous track. Right moving supercells were favored on this day as shown by the 1900 UTC sounding from WFO FWD (not shown). Additionally, two similar appendages were observed to develop with the left moving supercell from April 5th. Again, each of these appendages developed at approximately the same time as the cell motion became more deviant, this time to the left. After the development of each of these appendages, the highest values of FED appeared to “roll” towards these appendages, placing the highest FED values above the strongest reflectivity gradient with the cell. This tendency appears to follow the observation from Steiger (2007) that the highest values of FED are found with the strongest gradients in reflectivity. These observations appear to show that FED not only indicates updraft regions of a supercell but may also indicate when a new updraft is developing on the preferred side, leading to a shift in cell track. *This ability to highlight updraft development and propagation on a timescale faster than the update time of the WSR-88D makes the LDAR data an important resource for forecasters to maintain situational awareness during warning operations.*

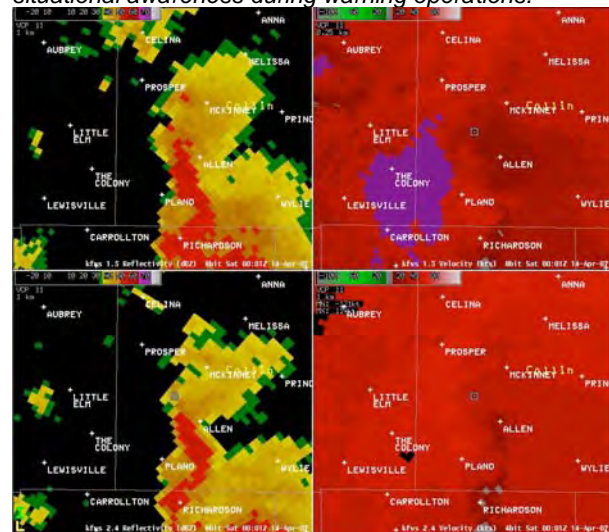


Figure 10. KFWS radar reflectivity and velocity images from 0001 UTC 14 April 2007, showing bowing reflectivity and strong straight line winds just to the west of the town of Allen. Images are 0.5 degree: (a) reflectivity and (b) velocity, and 2.4 degree: (c) reflectivity and (d) velocity.

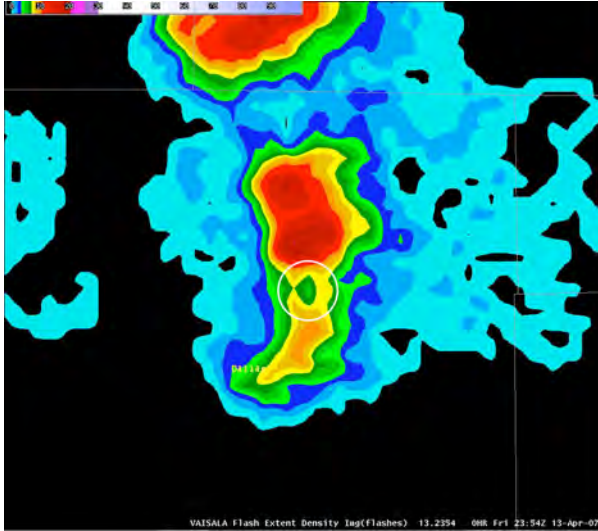


Figure 11. FED minimum associated with the embedded supercell in Dallas County at 2354 UTC on 13 April 2007.

The results in this study also appear to support the hypothesis that trends in FED intensity show promise in indicating the potential for severe weather from a cell. Several efforts have been made to correlate changes in total lightning flash rates with the occurrence of severe weather at the surface (Williams et al 1999, Goodman et al 2005, Bridenstine et al. 2005, Steiger et al. 2007a,b), with some interesting results in regard to spikes in total flash rate and changes in altitude of lightning activity. Although FED values cannot be considered interchangeable with flash rates, as they are a derived product, they do appear to show a similar trend with respect to severe weather reports. Spikes in FED values on April 25th were visible in D2D before two reported tornadoes with the Johnson County cell, as well as large hail reports for each of the two cells. The left moving supercell from April 5th also showed two distinct spikes in lightning activity prior to reports of severe hail in Dallas County. While this is encouraging evidence that the lightning data can aid in the warning decision process, the FED values with each cell varied substantially throughout the entire study period. In the case of April 5, the cell with the highest FED values showed FED spikes without producing any severe weather, indicating that there are possibly other considerations beyond the maximum flash rate or FED value. More research is needed to quantify what rates of change of FED or GSD are significant in order to reduce the false alarm potential associated with jumps in the lightning data.

The usefulness of the LDAR network also appears to be highly dependent upon the distance of the cell from the network and the performance ability of the network on a given day. On April 25th, the southern cell consistently displayed much lower values of FED and GSD than the northern cell, despite having higher values of radar reflectivity and more severe weather reports. It is unclear whether this is due to the detection ability of the network in the region transited by this cell,

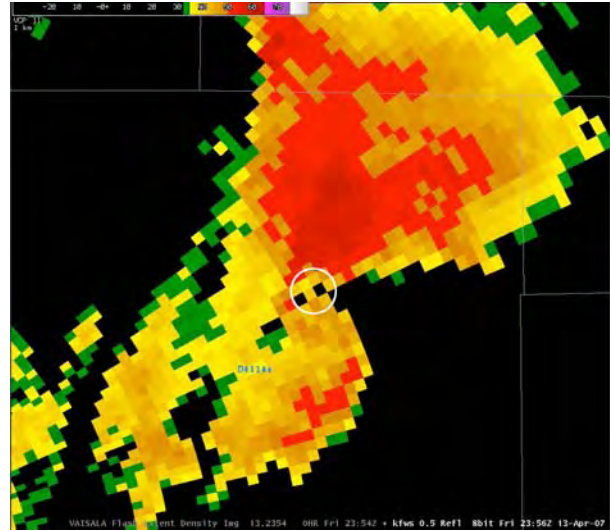


Figure 22. KFWs 0.5 degree reflectivity image from 2356 UTC on 13 April 2007. Highlighted location is the position of the FED minimum shown in Fig. 21, just to the east of a radar hook echo.

or if perhaps the presence of another highly active cell closer in to the network acts to mask the farther storm, similar to the attenuation of radar energy passing through areas of strong convection. While the installation of two more LDAR sensors on the southern side of the network should work to mitigate situations such as this, forecasters at WFO FWD must be educated on both the strengths and weaknesses of the LDAR data if they are to be able to accurately apply the lightning data into the warning decision process in real time. Additionally, issues such as precipitation induced phase distortion, which can disrupt telecommunication paths and result in the loss of real time data, must also be understood by forecasters if they are to correctly interpret the lightning products. A good example of such a situation occurs in the April 13th case, as detected values of both FED and GSD drop off and return with all cells between 2336 and 2354 UTC. While sharp decreases in FED values for one particular cell should signal a forecaster that a severe weather event may be imminent, a similar decrease with all cells is more likely a network detection issue, and not the harbinger of widespread severe weather. As detection ability can vary day to day given the status of the network sensors, forecasters should be kept aware of any situations (maintenance, communication problems, etc.) that would affect the data being sent to the WFO, so that artificial signals are not treated as indicative of the actual convective or severe activity within a given cell.

Although the lightning images often exhibit trends that are quite similar to Doppler radar images in D2D, the LDAR network does present one clear advantage over the WSR-88D, which is the ability to rapidly update images during an event. The total lightning data can be updated on any time step required, whether two minutes or every 30 seconds, as opposed to the radar, which currently updates each scan every four to six minutes.

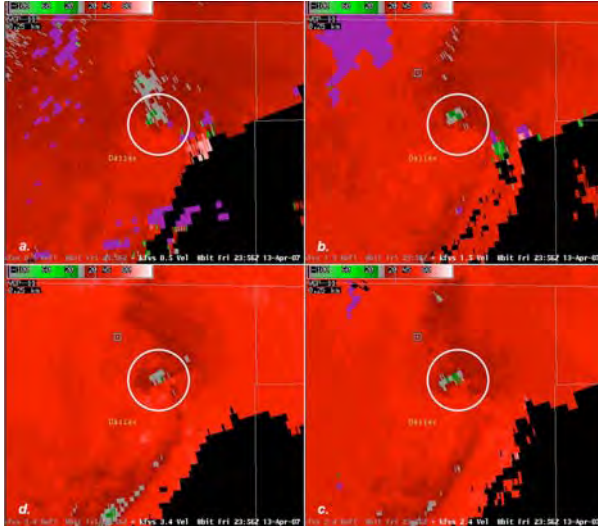


Figure 23. Four panel display of low level velocities over Dallas county at 2356 UTC on 13 April 2007. Images are: (a) 0.5 degree, (b) 1.5 degree, (c) 2.4 degree, and (d) 3.4 degree velocity scans. Encircled region is the location of the FED minimum shown in Fig. 21.

Thus, if a cell were producing high total lightning flash rates, it could be possible to display as many as ten lightning images per radar update. While this is a very exciting proposition, more work will need to be done in order to quantify what amount of data needs to be displayed in each time step, and what changes in FED or GSD are significant over each time period, as trends may differ significantly for 30 second images as opposed to the current default 2 minute images. Additionally, while the potential for rapid updates is quite useful, it should be remembered that currently the primary sensor for the detection of severe weather is the WSR-88D radar, and LDAR data must be used in such a way that it does not detract from the forecaster's ability to monitor the radar output. While images of FED and GSD are useful, the analysis of these images takes up both display space within the AWIPS system and time from the forecaster in which they will not be able to monitor data from the Doppler radar. In this regard, in future work it may be beneficial to develop an algorithm to track total lightning characteristics of a cell, similar to the storm cell identification and tracking (SCIT) algorithms currently in use with AWIPS. Such an algorithm could be set to trigger an alarm if certain thresholds in lightning activity (say total flash rate or source altitude) were reached. Additionally, an algorithm could be used to detect issues with network performance, such as phase distortion, and disregard changes in the data that are unphysical. This is perhaps the best way to use the LDAR data on days when widespread convection is occurring, as it can be used to highlight cells that may be more likely to produce severe weather, which could then be monitored with greater emphasis by the warning forecaster (Goodman et al. 2005). By using the LDAR data in conjunction with Doppler radar measurements, the

potential for predicting severe weather events could be increased.

ACKNOWLEDGMENTS. This project was funded in part funded by a Sub-award with the University Corporation for Atmospheric Research (UCAR) under the sponsorship of National Oceanic and Atmospheric Administration (NOAA), U.S. Department of Commerce (DOC) as part of the Cooperative Program for Operational Meteorology, Education and Training (COMET) Outreach Program. The Texas A&M University authors (McKinney and Carey) would also like to acknowledge the support of the National Science Foundation (ATM-0442011). We wish to acknowledge Vaisala Inc. for continued access to their LDAR II network and case studies. Finally, we would like to thank Dr. Martin Murphy and Mr. Nick Demetriades of Vaisala Inc. for their support in LDAR II case study selection, data quality control, and data processing.

REFERENCES

- Bridenstine, P. V., C. B. Darden, J. Burks, and S. J. Goodman, 2005: The Application of Total Lightning Data in the Warning Decision Making Process. *Conference on Meteorological Applications of Lightning Data*, San Diego, CA, Amer. Meteor. Soc. CD preprints.
- Carey, L.D., M.J. Murphy, T.L. McCormick, and N.W.S. Demetriades, 2005: Lightning location relative to storm structure in a leading-line, trailing-stratiform mesoscale convective system. *J. Geophys. Res.*, **110**, D03105, doi:10.1029/2003JD00437.
- Demetriades, N., M. J. Murphy, and R. L. Holle, 2002: Lightning Detection and Ranging (LDAR) II: Results From Vaisala-GAI's Dallas-Fort Worth Research Network and Kennedy Space Center's Operational Network. *International Lightning Detection Conference*, Conference Preprint.
- Federal Meteorological Handbook No. 11, Doppler Radar Meteorological Observations Part C: WSR-88D Products and Algorithms, FCM-H11C-2006. April 2006, Washington, D.C.
- Goodman, S.J., R. Blakeslee, H. Christian, W. Koshak, J. Bailey, J. Hall, E. McCaul, D. Buechler, C. Darden, J. Burks, T. Bradshaw, and P. Gatlin, 2005: The North Alabama Lightning Mapping Array: Recent severe storm observations and future prospects. *Atmos. Res.*, **76**, 423-437.
- Krehbiel, P.R., R.J. Thomas, W. Rison, T. Hamlin, and M. Davis, 2000: GPS-based mapping system reveals lightning inside storms. *EOS*, **81**, 21-22, 25.
- Lang, T. J., L. J. Miller, M. Weisman, S. A. Rutledge, L. J. Barker, V. N. Bringi, V. Chandrasekar, A. Detwiler, N. Doesken, J. Helsdon, C. Knight, P. Krehbiel, W. A. Lyons, D. MacGorman, E. Rasmussen, W. Rison,

- W. D. Rust, and R. J. Thomas, 2004: The Severe Thunderstorm Electrification and Precipitation Study. *Bull. Amer. Meteor. Soc.*, **85**, 1107-1125.
- Lojou, J.-Y. and K.L. Cummins, 2005: On the representation of two- and three-dimensional total lightning information. *Extended Abstracts, Conf. on Meteorological Applications of Lightning Data, San Diego, CA, Amer. Meteor. Soc., CD preprints.*
- MacGorman, D.R., W.D. Rust, P. Krehbiel, W. Rison, E. Bruning, and K. Wiens, 2005: The Electrical Structure of Two Supercell Storms during STEPS. *Monthly Weather Review*, **133** 2583-2607.
- Murphy, M. J., and N. W. S. Demetriades, 2005: An analysis of lightning holes in a DFW supercell storm using total lightning and radar information. *Extended Abstracts, Conf. on Meteorological Applications of Lightning Data, San Diego, CA, Amer. Meteor. Soc., CD preprints.*
- NCDC, 2005: *Storm Data*. Vol. 47, No. 4, 264 pp. [Available from National Climatic Data Center, Federal Building, 151 Patton Ave., Asheville, NC 28801.]
- NCDC, 2007: *Storm Data*. Vol. 49, No. 4, 318 pp. [Available from National Climatic Data Center, Federal Building, 151 Patton Ave., Asheville, NC 28801.]
- Patrick, G. R., and N. W. S. Demetriades, 2005: Using LDAR II total lightning data in an operational setting: Experiences at WFO Fort Worth, TX. *21st Conference on Weather Analysis and Forecasting, 17th Conference on Numerical Weather Prediction*, Washington, D.C., Amer. Meteor. Soc.
- Steiger, S. M., R. Orville, and L. Carey, 2007a: Total Lightning Signatures of Thunderstorm Intensity over North Texas, Part I: Supercells., *Mon. Wea. Rev.*, **135**, 3281-3302..
- Steiger, S. M., R. Orville, and L. Carey, 2007b: Total Lightning Signatures of Thunderstorm Intensity over North Texas, Part II: Mesoscale Convective Systems. *Mon. Wea. Rev.*, **135**, 3303-3324...
- Williams, E. R., B. Boldi, A. Matlin, M. Weber, S. Hodanish, D. Sharp, S. Goodman, R. Raghavan, and D. Buechler, 1999: The behavior of total lightning activity in severe Florida thunderstorms. *Atmos. Res.*, **51**, 245-265.