6.7 USING LDAR II TOTAL LIGHTNING DATA IN AN OPERATIONAL SETTING: EXPERIENCES AT WFO FORT WORTH TX

Nicholas W.S. Demetriades*
Vaisala, Inc.
Tucson, AZ

Gregory R. Patrick
NOAA/NWS Weather Forecast Office
Fort Worth, TX

1. INTRODUCTION

Data from the Dallas – Fort Worth (DFW), Texas area LDAR II (Lightning Detection and Ranging) system is being delivered in real-time to the Weather Forecast Office (WFO) in Fort Worth/Dallas (FWD). LDAR II detects > 95% of all total (cloud plus cloud-to-ground) lightning flashes and can map the horizontal extent of these flashes in three dimensions. Since the majority of lightning stays in the clouds and never reaches the ground, VHF lightning detection networks, such as LDAR II, can provide valuable thunderstorm data for the meteorological community. Data with a 2 minute update interval is being fed into the FWD Advanced Weather Interactive Processing System (AWIPS) system from Vaisala, Inc. via a server located at the National Weather Service Southern Region Headquarters Office (SRH) in downtown Fort Worth TX. Images of Flash Extent Density (FED), Flash Initiation Point Density, and Source Density can be viewed in Display 2-Dimensional (D2D) software within AWIPS.

This paper focuses on the use of total lightning data at WFO FWD during spring 2005. FED imagery seems to be the most versatile of the three available data types for use in an operational forecast setting and is not as susceptible to range degradation effects. Several examples of using FED imagery will be shown to highlight uses of total lightning in a WFO setting. Potential uses include serving as a complement to radar data during severe weather episodes, aviation forecasting aid, and public safety and awareness tool.

* *Corresponding author address:* Nicholas W. S. Demetriades, Vaisala Inc., 2705 E. Medina Road, Tucson, AZ 85706; Email: nick.demetriades@vaisala.com

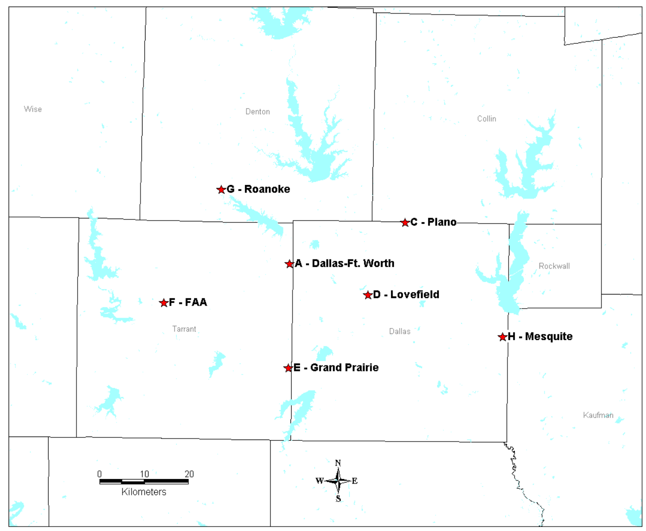

Figure 1. Map showing locations of the 7 sensors that comprised the DFW LDAR II network during spring 2005. Sensor "A" is located at Dallas-Ft Worth International Airport (KDFW).

2. BACKGROUND AND DATASET

The DFW LDAR II network is made up of 7 sensors with 20 to 30 km baselines (Fig. 1). These sensors detect pulses of radiation (sources) produced by the electrical breakdown processes of lightning in 5 MHz VHF bands that currently have center frequencies ranging from 61 to 64 MHz. These pulses of radiation are used to reconstruct the path of individual cloud and CG lightning flashes in three dimensions.

The DFW LDAR II network can map lightning flashes in three dimensions within approximately 150 km of the center of the network, degrading in performance with increasing range. Lightning flash detection efficiency is expected to be greater than 95% within the interior of the network (a range of 30 km from DFW International Airport – sensor A) and greater than 90% out to a range of

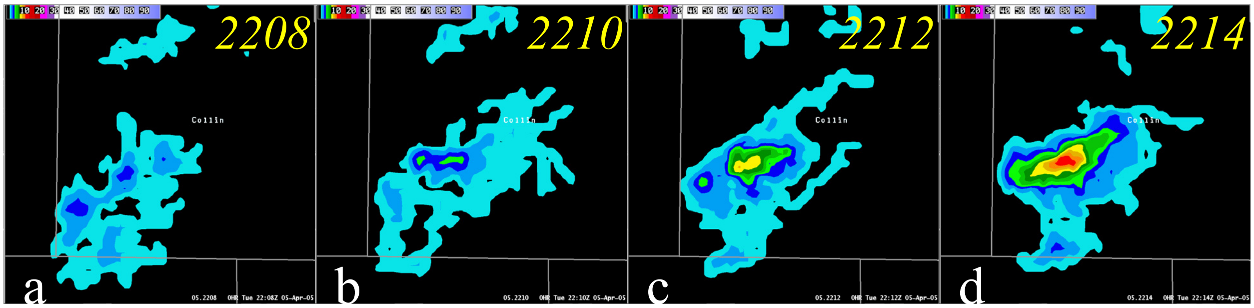

Figure 2. Flash Extent Density (FED) imagery of convection in Collin County between (a) 2208 UTC; (b) 2210 UTC; (c) 2212 UTC; (d) 2214 UTC on 05 April 2005. Note the significant increase in FED values, shown in the yellow and red shadings, in this six minute time span.

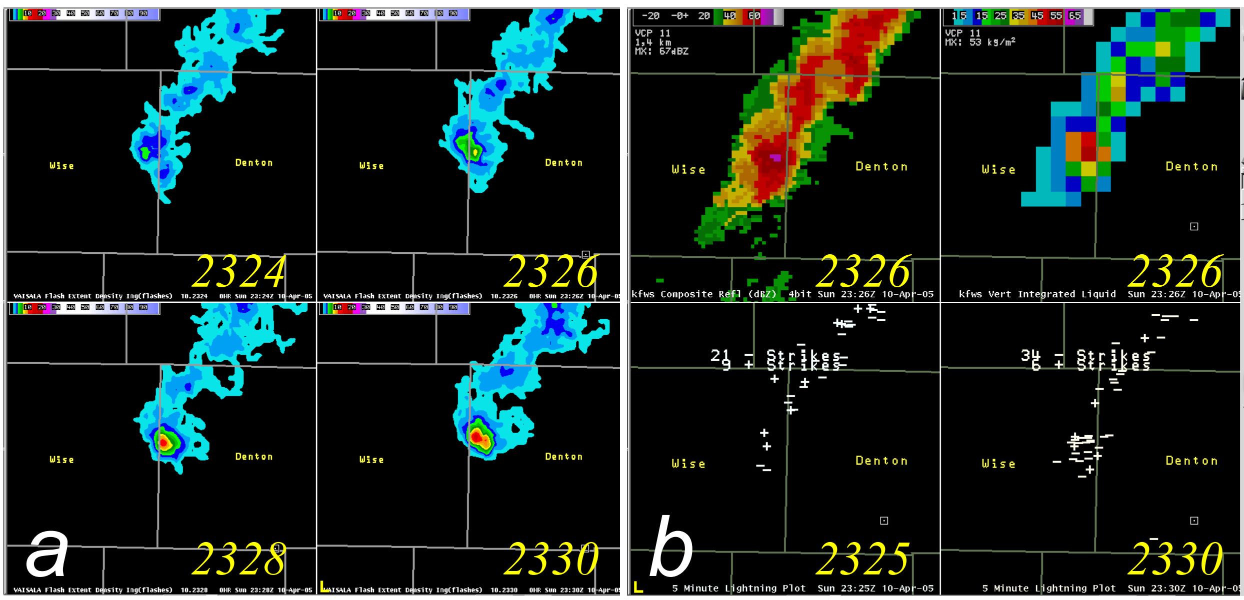

Figure 3. AWIPS D2D imagery from 10 April 2005. (a) Four panel image of FED between 2324 UTC (upper left) and 2330 UTC (Lower right) shows increase in values from 5 flashes km^{-2} min^{-1} to 15 flashes km^{-2} min^{-1} near the Wise-Denton County line. (b) KFWS Composite reflectivity at 2326 UTC (upper left); KFWS Vertically Integrated Liquid (VIL) product at 2326 UTC (upper right); NLDN 5 minute strikes ending at 2325 UTC (lower left); and NLDN 5 minute strikes ending at 2330 UTC (lower right).

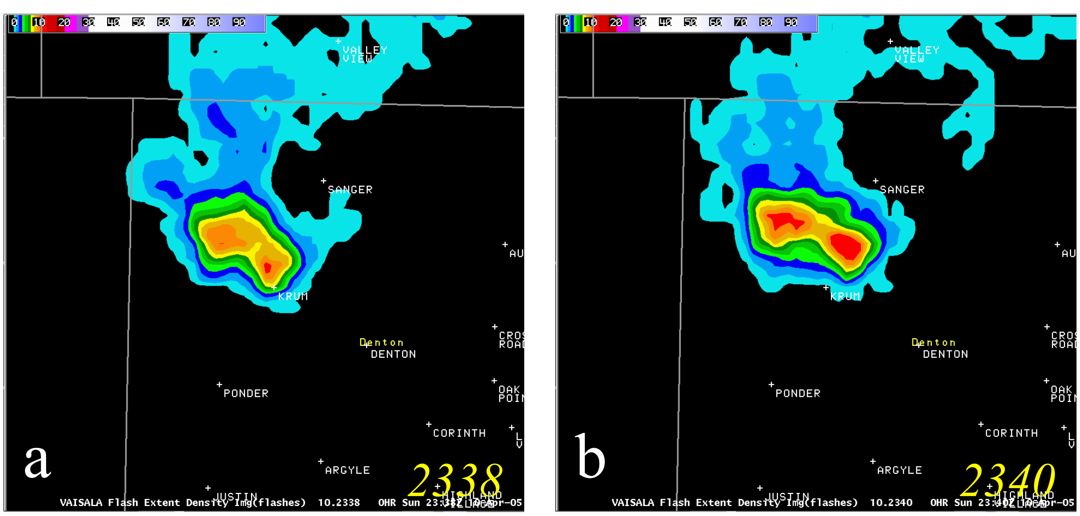

Figure 4. FED imagery of convection in Denton County on 10 Apr 2005. (a) 2338 UTC and (b) 2340 UTC.

120 km from DFW. Expected three-dimensional location accuracy for individual pulses of radiation is between 100 and 200 m within the network interior, and better than 2 km to a range of 150 km from the center of the network.

Nine total lightning products are currently being sent to WFO FWD. Seven of these products consist of VHF lightning source densities that are accumulated in different altitude slices. LDAR II can detect 100s to 1000s of VHF lightning sources per flash. The current altitude slices being sent to the WFO in FWD are: (1) 0-20 km, (2) 0-3 km, (3) 3-6 km, (4) 6-9 km, (5) 9-12 km, (6) 12-15 km and (7) 15-18 km. The other two total lightning products consist of lightning flash information. The first of these lightning flash products consists of the density of the initiation points of lightning flashes. The initiation point of a flash is defined as the first VHF lightning source detected by a lightning detection network after all lightning sources are grouped together into flashes according to specific time and space criteria. The second lightning flash product consists of the flash extent density (FED). FED is defined as the number of lightning branches that pass through a specific grid box area (1 km^2 for this project) during a specific time interval (two minutes for this project) after all lightning sources are grouped together into flashes according to specific time and space criteria. FED tends to provide forecasters with a more consistent product because VHF source detection efficiency lowers at a faster rate than VHF flash detection efficiency with increasing distance from the center of the LDAR II network.

3. SEVERE WEATHER APPLICATIONS

FED imagery, derived from LDAR II data, can be used to complement data from WSR-88D. FED can provide clues on thunderstorm structure, severity, and intensity trends – and the 2 minute update frequency could provide forecasters with additional information and confidence of storm severity. It should be emphasized that LDAR II data is best used to augment WSR-88D information – the forecasters are tasked with assimilating all available datasets to make warning decisions.

Trends in flash rates, as documented by Hodanish, et al. (1998), have been shown to provide useful information with regard to storm severity. Other studies have shown that intensifying updrafts are positively correlated with increasing total lightning flash rates (Goodman et al., 1988; Williams et al., 1989). An example of how increasing trends in flash rates were used in severe weather operations is shown in Fig 2. Between 2208 UTC and 2214 UTC on 05 April 2005, values AND areal extent of FED increased substantially as a severe thunderstorm moved across Collin County. Based on reflectivity signatures on the KFWS WSR-88D, a severe thunderstorm warning had already been issued for the Collin County storm at 2148 UTC. However, the substantial increase in total lightning activity provided an additional clue that severe weather was an increasing threat with this thunderstorm. 25 mm diameter hail occurred near Frisco in western Collin County at 2214 UTC.

Another example of how flash rate trends were used in warning decision making is depicted in Fig. 3a, which shows FED imagery between 2324 UTC and 2330 UTC on 10 April 2005. Flash rates increased significantly with convection moving from Wise County into Denton County during the 6 minute period ending at 2330 UTC. Fig. 3b shows KFWS WSR-88D imagery and National Lightning Detection Network (NLDN) cloud-to-ground (CG) graphics for the time period 2325 UTC to 2330 UTC. It should be noted that the warning forecaster issued Severe Thunderstorm Warnings for Wise County at 2251 UTC and for Denton County at 2301 UTC, well before the observed increase in flash rates depicted in Fig. 3a. However, as the storm moved into Denton County, the increase in total lightning flash rates for the 6 minute period ending at 2330 UTC increased forecaster confidence in the strength of the storm. Reports of hailstones up to 19 mm diameter were reported with the thunderstorm as it moved into Denton County west of Sanger. This thunderstorm produced a significant downburst later in its lifetime, as detailed in the next paragraph.

An example of how FED was used to infer storm structure and evolution is shown in Fig. 4. At 2338 UTC and 2340 UTC on 10 April 2005, the FED imagery takes on a bow shape, reminiscent of a radar bow echo (Przybylinski 1995). It is believed that the developing downburst quickly removed the precipitation particles in the region of subsiding air, contributing to the relative minimum in total lightning activity. At 2345 UTC, base reflectivity data from the KFWS WSR-88D at KFWS (Fig. 5) confirms the presence of a bow shaped echo in Denton County. Wind damage with an estimated peak gust of 38 ms^{-1} (74 kts)

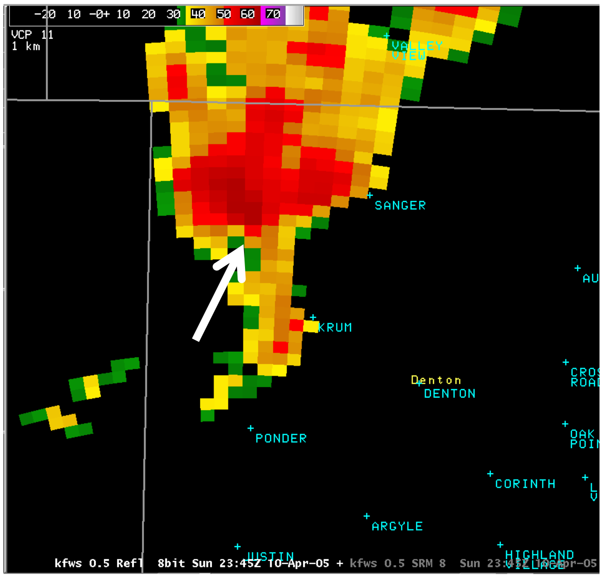

Figure 5. KFWS 0.5 degree Reflectivity image at 2345 UTC on 10 Apr 2005. White arrow depicts the developing downburst region as determined by base velocity data and spotter reports.

was reported in Denton County west of the town of Sanger at 2348 UTC as an area of thunderstorm downburst winds affected northern parts of Denton County. FED was used in this case to more quickly establish temporal continuity with developing storm features, an important part of the warning decision making process (Lemon 1980).

Another example from 05 April 2005 highlights an additional use of FED imagery in an operational setting. Fig. 6 shows how FED helped highlight the most electrically active and possibly most intense updraft regions in a cluster of multicell convection. The KFWS WSR-88D Composite Reflectivity image at 2214 UTC shown in Fig. 6a showed several strong areas of greater than 55 dBz reflectivity across Collin County. In contrast to the Composite Reflectivity image, the FED imagery (Fig. 6b) showed a *single* area of high flash rates across extreme western Collin County, effectively highlighting the most significant thunderstorm. The Vertically Integrated Liquid (VIL) output from KFWS at 2214 UTC (Fig. 6c) also highlighted the same area in western Collin County with values of 50 - 55 kg m^{-2}. With a 2 minute update frequency of FED, forecasters may gain a slight advantage in using FED over volume-based WSR-88D output for determining the most significant regions in multicell convective clusters.

An interesting case of new updraft development in a right-moving supercell storm is depicted in a series of FED images shown in Fig. 7. On this day, supercell thunderstorms were anticipated as vertical wind shear through a deep layer was sufficient for mesocyclone formation on a day with surface-based convective available potential energy (CAPE) values of 1500 J kg^{-1} and 0 – 6 km shear values of 25 m s^{-1}. The low level focusing feature was a dryline that had developed into central Texas during the late afternoon hours.

The four images of FED shown in Fig. 7 highlight new updraft development on the right flank of the supercell moving across southeast Tarrant County between 2112 UTC and 2118 UTC on 25 April 2005. At 2112 UTC and 2114 UTC, a small, elongated area of FED values around 3-5 flashes km^{-2} min^{-1} appears on the southern flank of an area of much higher FED values. By 2116 UTC (Fig. 7c), the small maximum on the southern flank of the lightning activity appears as an appendage with FED values up to around 8 flashes km^{-2} min^{-1}. The two minute update frequency of the LDAR II data contributed to a more cohesive depiction of updraft redevelopment in this particular case.

Forecasters need to be careful when interpreting the actual and relative values of FED. Total lightning detection decreases with increasing range outside of the interior of a regional VHF total lightning network. Two supercell thunderstorms at 2127 UTC on 25 April 2005 had similar WSR-88D reflectivity signatures but very different values of FED. Fig. 8 shows images of KFWS radar reflectivity data as well as an FED image of the two storms that were both within 60 km of the center of the LDAR II network. In this example, the southernmost supercell thunderstorm near Alvarado (Fig 8a) with lower sustained values of FED (Fig. 8d) was actually more intense, based on ground truth reports and radar derived storm structure attributes, than a similar supercell storm farther north. The lower FED values in the southern storm could be attributed to decreasing detection efficiency with range from the DFW LDAR II network or real lightning production by this storm or a combination of both. Fig. 8d shows FED associated with both supercells at 2126 UTC on 25 April 2005. The southern storm across Johnson County, with FED values up to 10 flashes km^{-2} min^{-1}, was a prolific hail producing supercell, with stones up to 30 mm diameter reportedly covering the ground near Alvarado. The northern storm near the Tarrant-Dallas County line, with

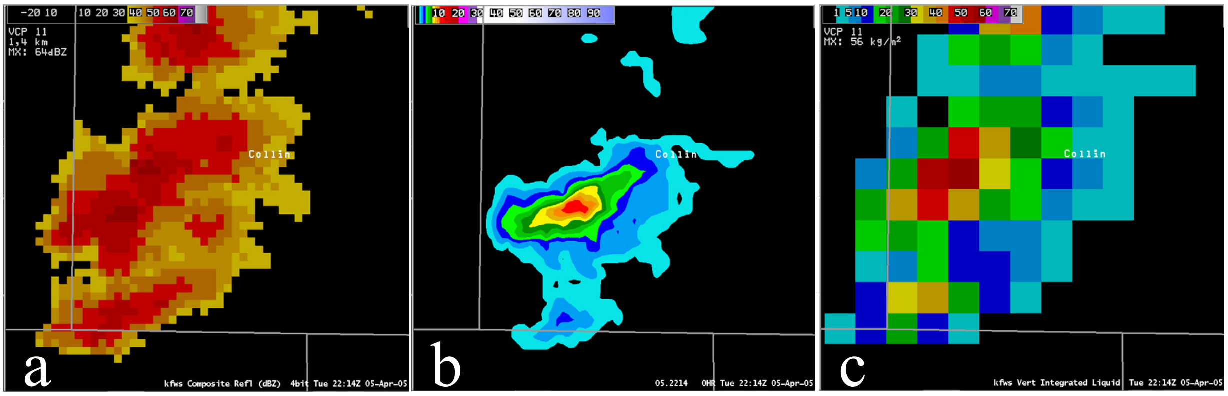

Figure 6. (a) KFWS Composite Reflectivity showing 35 dBz and higher values at 2214 UTC on 05 April 2005; (b) FED imagery at 2214 UTC; (c) KFWS VIL imagery at 2214 UTC. The FED imagery effectively highlighted the most significant convection in southwest Collin County.

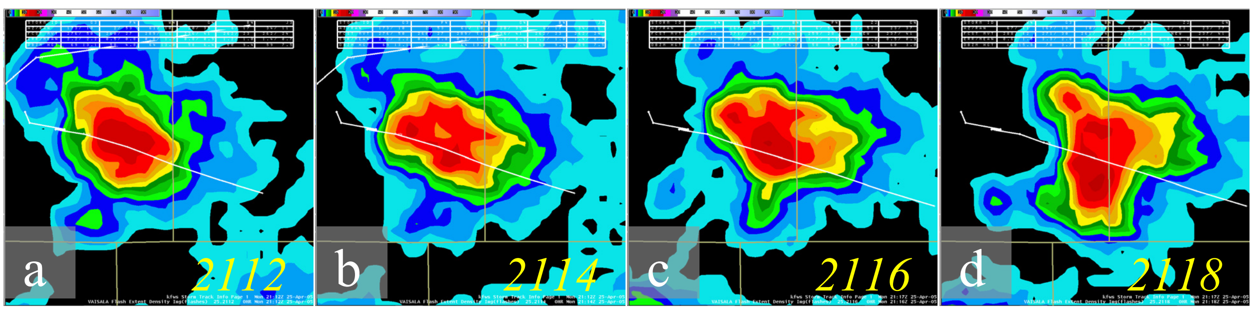

Figure 7. Series of four FED images depicting new updraft development on the right flank of a southeast moving supercell thunderstorm on 25 Apr 2005. (a) 2112 UTC; (b) 2114 UTC; (c) 2116 UTC; (d) 2118 UTC. Solid white line on each image depicts past and extrapolated positions of the radar storm centroid as output from the KFWS WSR-88D storm tracking algorithm and is the same on each of the 4 images. By 2118 UTC, the highest FED values are to the south of the extrapolated storm track.

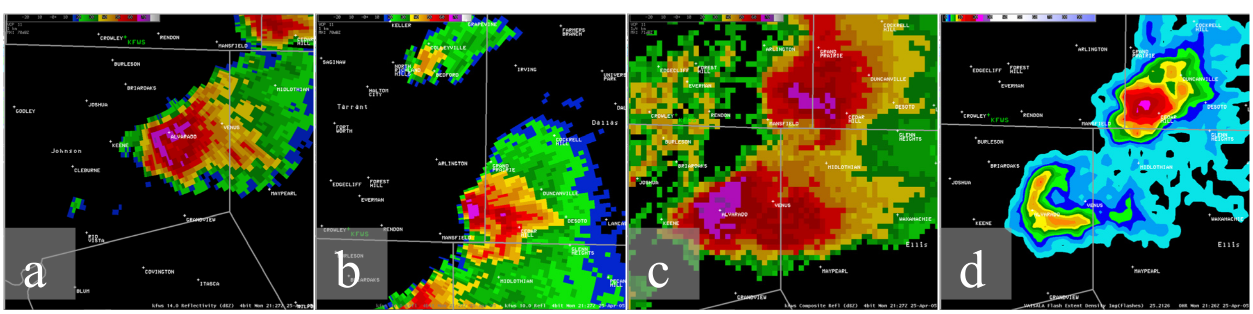

Figure 8. Three images from KFWS WSR-88D at 2127 UTC and one FED image at 2126 UTC on 25 Apr 2005. (a) Base Reflectivity at 14.0 degree elevation slice shows maximum reflectivity of 70 dBz just west of Alvarado in Johnson County. The center of the radar beam intercepts the storm near Alvarado at approximately 5.6 km; (b) Base Reflectivity at 10.0 degree elevation slice shows maximum reflectivity of about 65 dBz northwest of Cedar Hill near the Tarrant-Dallas County line. The center of the radar beam intercepts the storm at around 5.2 km AGL; (c) Composite Reflectivity showing both storms; (d) FED imagery at 2126 UTC shows values as high as 22 flashes km^{-2} min^{-1} in the northern storm, but only as high as 10 flashes km^{-2} min^{-1} in the southern storm.

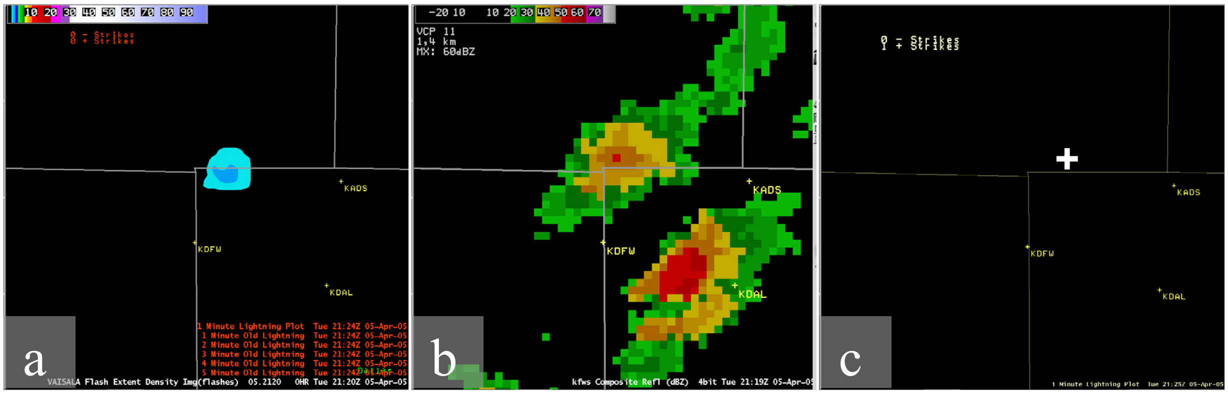

Figure 9. (a) FED imagery at 2120 UTC on 05 April 2005 overlaid with NLDN CG data for 5 minute period ending at 2124 UTC. Some total lightning activity was evident north of KDFW, but no cloud-to-ground strikes were reported at this time; (b) KFWS Composite Reflectivity image at 2119 UTC on 05 April 2005 shows two developing convective cells near KDFW; (c) NLDN CG data at 2125 UTC on 05 April 2005 depicts a single positive cloud-to-ground strike (large white "+" symbol) north of KDFW.

FED values up to 22 flashes km^{-2} min^{-1} was producing sporadic reports of 20 mm diameter hail. It should be noted that both storms produced brief, weak tornadoes during their lifetime.

4. AVIATION AND PUBLIC SAFETY APPLICATIONS

In some cases, the presence of cloud lightning in an area can precede the occurrence of CG strikes by several minutes (Weber et al. 1998). An example of how FED was used as a forecaster aid for anticipating the location and timing of the first cloud-to-ground lightning strike is shown in the sequence of images in Fig. 9. This was a case of convection developing along a dryline which extended north to south across Tarrant County at 2100 UTC. At 2120 UTC, the FED imagery showed the presence of total lightning, but no CG lightning, in convection developing 10 km NNE of Dallas Fort Worth International Airport (KDFW) (Fig. 9a). The first CG strike with the developing convection was noted at 2125 UTC as the updraft continued to gradually strengthen.

Fig. 10 depicts total lightning in the anvil region of a supercell thunderstorm. The total lightning signal extended about 60 km to the northeast of the thunderstorm centroid. With southwesterly upper level winds (Fig. 10b), the anvil region of the mature cumulonimbus is well east of the active updraft region. The FED imagery in Fig. 10a shows the highest flash rates in southwest Dallas County near the highest radar reflectivity. The low values (less than 1 flash km^{-2} min^{-1}) of FED well to the east of the maximum indicate areas affected by total lightning in the anvil region of the supercell thunderstorm. The low values of FED extend into Rockwall County, about 60 km to the northeast of the radar reflectivity centroid. Although cloud-to-ground lightning strikes were not observed as far away as Rockwall County at this time, the presence of cloud lightning activity as depicted by FED imagery gave forecasters a better understanding of the cloud-to-ground lightning threat from the anvil region of this supercell.

An example of total lightning activity in a relatively weak convective region is shown in Fig. 11. In this late night case on 14 May 2005, isolated cloud-to-ground lightning strikes were occurring well to the north of convective cells that developed in an area of elevated instability. Fig. 11a depicts low values of FED and an isolated cloud-to-ground lightning strike that occurred across northern and central Denton County after 0600 UTC on 14 May 2005. KFWS radar imagery shown in Fig. 11b shows higher reflectivity values in a convective cell near Lewisville about 30 km to the southeast of the isolated cloud-to-ground lightning strike. The pattern of the branching indicated in the FED imagery suggests that the CG strike originated near Lewisville; this conclusion would be difficult to surmise using 88D imagery alone. By viewing FED imagery along with radar imagery, forecasters were better able to understand the lightning threat which was applicable to short term forecast products and aviation weather forecasts.

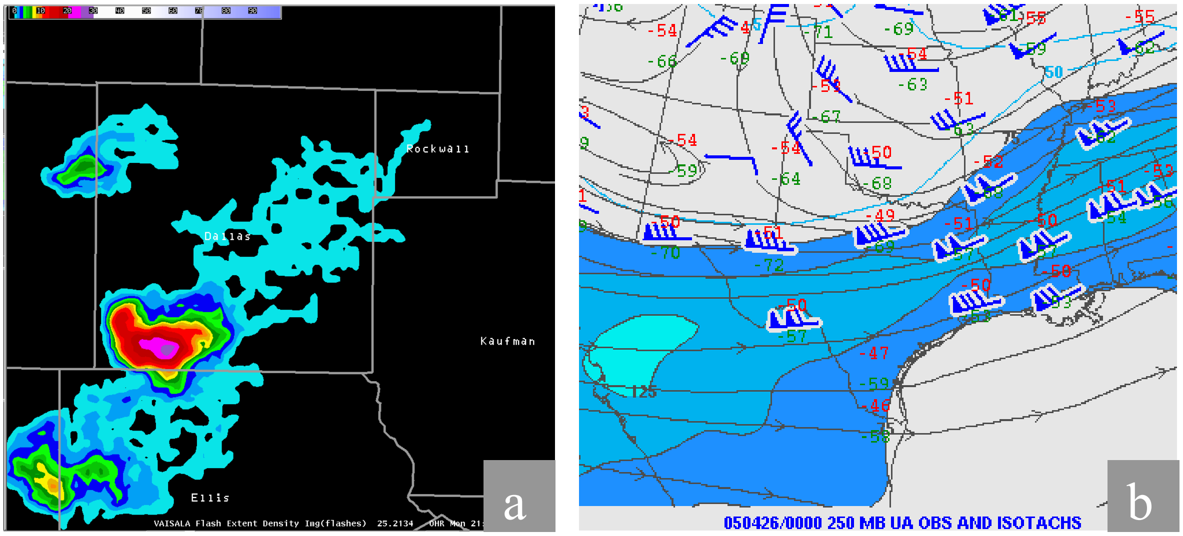

Figure 10. (a) FED imagery at 2134 UTC on 25 April 2005. Supercell storm with FED values as high as 25 flashes km^{-2} min^{-1} was over southwest Dallas County, with low values of FED extending as far as 60 km to the northeast into Rockwall County; (b) Storm Prediction Center objectively analyzed 250 hPa upper air chart at 0000 UTC on 26 April 2005 showing streamlines and wind barbs in kts. Blue shading highlights wind speed values of 39 m s^{-1} (75 kts), 51 m s^{-1} (100 kts), and 64 m s^{-1} (125 kts). The graphic shows winds at 250 hPa from the southwest at 40 m s^{-1} across north TX.

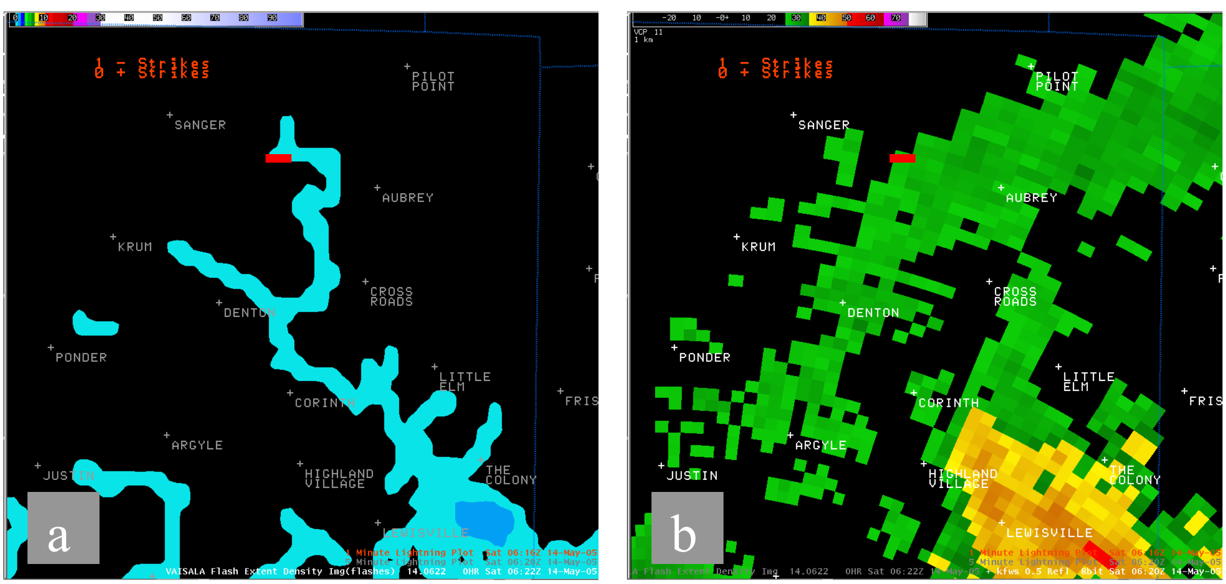

Figure 11. (a) FED imagery (light blue shading) at 0622 UTC and 1 minute cloud-to-ground lightning from NLDN (red) at 0616 UTC on 14 May 2005. Low values of FED across central Denton County seem to indicate branching originating from higher FED region in the extreme lower right part of the image; (b) KFWS WSR-88D 0.5 degree reflectivity image showing only values of 25 dBz and higher at 0620 UTC on 14 May 2005. Highest reflectivity values are associated with a convective cell in the lower right part of the image near Lewisville and were associated with higher values of FED.

5. CONCLUSIONS AND IDEAS FOR FUTURE WORK

Images of FED have proven to be a useful complement to WSR-88D data during convective weather events. Qualitative trends in FED values have been valuable supplementary information for forecasters faced with convective warning decisions and aviation forecast responsibility. Patterns in color-contoured FED imagery were used to infer storm structure and evolution, although temporal consistency and D2D data smoothing are considerations that must be acknowledged before applying radar-based pattern recognition techniques to FED imagery. NWS forecasters exposed to an operational total lightning dataset will eventually gain a better understanding of three dimensional thunderstorm and lightning structure -- leading to improved forecast and warning services.

Ideas for future work include developing a customized AWIPS overlay that depicts the effective coverage of the DFW LDAR II network. This overlay would give operational forecasters a means to quickly assess whether or not a given area of convection is within the range of reliable total lightning detection. The idea of creating a time-integrated source density product is being explored. An enhanced, graphical lightning hazard message could be distributed from AWIPS by creating a 20 minute summation of total lightning activity; this type of product could help delineate the CG lightning threat in stratiform regions of mesoscale convective systems and thunderstorm anvils.

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