THE ADVANTAGES OF TOTAL LIGHTNING OVER CG LIGHTNING FOR THUNDERSTORM CELL IDENTIFICATION AND TRACKING AND ITS COMPLEMENTS TO RADAR REFLECTIVITY

N.W.S. Demetriades, M.J. Murphy, R.L. Holle and P. Richard

Vaisala Inc.
Tucson Operations

INTRODUCTION

Three-dimensional radar reflectivity data and the algorithms used to help meteorologists interpret these data are extremely important in nowcasting. However, a number of inherent problems arise when tracking thunderstorm cells with 3-dimensional reflectivity. These problems include (1) identifying cells in a complex multi-cellular thunderstorm environment, (2) detecting thunderstorm cells at close range from the radar, (3) Storm Cell Identification and Tracking (SCIT) echo top altitude trends that exaggerate or misidentify thunderstorm growth and decay (Howard et al., 1997), and (4) volume scans that take 5 minutes to complete. Vaisala has two total (cloud and cloud-to-ground) lightning detection technologies that can help address some of these problems. Both technologies provide a much richer dataset than cloud-to-ground (CG) lightning data alone. The SAFIR system detects total lightning at VHF in two dimensions and the Lightning Detection and Ranging (LDAR II) system detects lightning at VHF in three dimensions.

DATA

Reflectivity data from the Melbourne, FL and Fort Worth, TX WSR-88D radars were used to make comparisons to the Kennedy Space Center (KSC) and Dallas-Fort Worth (DFW) LDAR networks, respectively. A complete description of the KSC and DFW LDAR networks used in this study is in Lennon and Maier (1991) and Demetriades et al. (2002). The echo top trends for the Melbourne WSR-88D were obtained using output from version 3.2 of the SCIT algorithm (Johnson et al. 1998). CG lightning data analyzed in the DFW area were obtained from the U.S. National Lightning Detection Network (NLDN).

Reflectivity data from the Trappes Meteo-France 5-cm radar were used to make comparisons to the Meteo France (MF) SAFIR network which consists of 3 sensors in the Paris, France area. These data were supplied to Vaisala courtesy of Meteo-France. A complete description of the MF SAFIR network used in this study can be found in Soula and Chauzy (2001). CG lightning data analyzed in the Paris, France area were also obtained from the MF SAFIR network.

METHODOLOGY

Initial comparisons between total and CG lightning focused on the primary lightning areas covered by each dataset during individual thunderstorm cases. Primary lightning areas encompassed 80-90% of all detected total and CG lightning. For these same cases, the leading and trailing edges of lightning activity were identified and the distance between the total and CG lightning boundaries were calculated. Comparisons with radar base reflectivity involved the area covered by all radar echoes and the area covered by only those echoes that were > 30 dBZ (proxy for active convection).

In order to identify thunderstorm cells, lightning density plots were created once every 5 minutes using ~1 km^2 grids. A linear scale was used for displaying the density values. The maximum density value of the linear scale for each plot depended on the lightning production of that storm. A time period of 5 minutes was used because this was the longest time that lightning could be displayed before storm propagation and new storm development began to cause lightning contamination from other cells, and it corresponds closely with the length of a radar volume scan.

The lightning top that was used for comparisons with the echo top was calculated using the following procedure. Lightning pulses were restricted to only those that occurred within the convective core. This was accomplished by using only those lightning pulses within 3 km of the center point of the cell, which was defined as the center of the highest ~9 km^2 lightning density areas as shown on the 5-minute lightning density plots. The 95th percentile altitude of lightning pulses within the cell was then computed every 2 minutes from this dataset.

LIGHTNING EXTENT

Figures 1 and 2 compare NLDN CG flashes overlain on LDAR II pulses to radar base reflectivity during the passage of a squall line across the DFW area on 13 October 2001. Lightning cores (CG) and regions (VHF sources) were defined during this 5-minute period. The areas defined did not include isolated VHF sources and CG flashes. The area covered by VHF sources is ~2.5 times the area covered by CG flashes. VHF sources extend the leading and trailing edges of lightning activity, as defined by CG flashes, by up to 30 km within the southernmost line of storms (blue rectangle). The area of all radar echoes is ~2 times that of VHF sources, and reflectivity stronger than 30 dBZ is ~15% smaller. If the VHF sources in this dataset identify the true extent of lightning activity within these storms, CG flashes only account for ~40% of the active region, while >30 dBZ echoes underestimate this area by ~15%.

THUNDERSTORM CELL IDENTIFICATION

14 May 1998 Thunderstorms

Figure 3 compares radar base reflectivity with SAFIR-detected VHF source density and CG flash density on 14 May 1998. The continuity of sources within the VHF source density plot (center panel) shows the easternmost cell (black arrow), which is intensifying, and a cell just to its west (blue arrow). This corresponds well with the reflectivity image from that time period (black and blue arrows). The scattered VHF lightning activity to the west of the central cell is associated with a splitting cell as indicated on radar (purple arrows). By comparison, the lack of continuity within the CG flash density plot makes it very difficult to visually identify the easternmost, intensifying cell and the cell just to its west.

15 June 2001 Squall Line

Early on 15 June 2001 a strong squall line passed through the DFW area. This squall line produced hail of ~7 cm in diameter and wind gusts over 113 kph (70 mph) as it moved through north Texas. Figure 4 shows the base reflectivity data from the Fort Worth WSR-88D at 0054 UTC. The leading convective portion of the squall line is delineated by a fairly uniform line of reflectivities over 45 dBZ. This case demonstrates how difficult it is to distinguish individual cells within a squall line using base reflectivity alone. The 5-minute LDAR II density image from this time shows the highest lightning density cores along the leading convective portion of this squall line, and lower lightning densities where flashes occasionally propagated through the trailing stratiform rain region (Fig. 5). This is a typical example of LDAR II's ability to identify individual cells within convective portions of squall lines. Notice that at least 5 separate cells can be identified within the line with LDAR II.

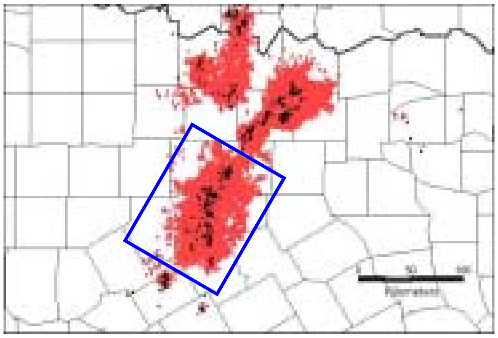

Figure 1. Map of LDAR II lightning pulses (red) and NLDN CG flashes (black) detected between 0103 and 0108 UTC 13 October 2001. A total of 88,912 lightning pulses and 392 CG flashes were detected within 200 km of the center of the DFW LDAR II network. The blue rectangle encompasses the lightning produced by the southernmost line of storms.

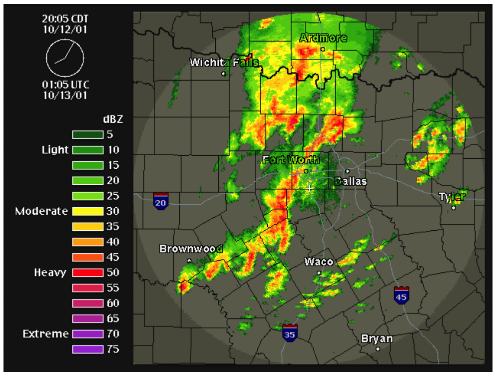

Figure 2. Fort Worth, TX WSR-88D base reflectivity image beginning at 0105 UTC 13 October 2001. (The Weather Underground, 2001, www.wunderground.com).

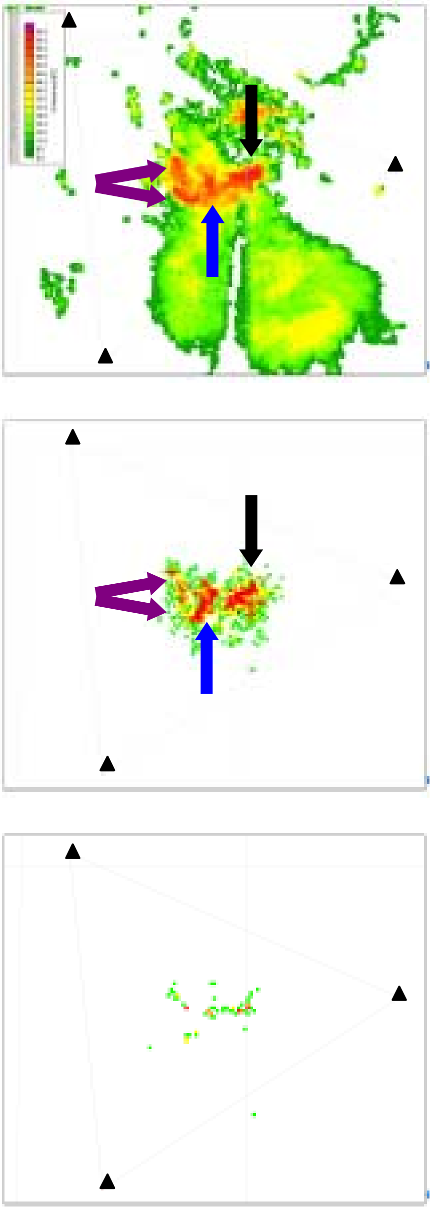

Figure 3. Radar base reflectivity (top), SAFIR VHF source density (center), and SAFIR CG flashes (bottom) between 0030 and 0035 UTC 14 May 1998 over the Paris, France area. Radar volume scan began at 0030. Radar reflectivities between 0 and 32 dBZ, 32 and 40, 40 and 56, 56 and 68, and >68 dBZ are shown by shades of green, yellow, orange, red and purple, respectively. The northernmost high reflectivity area is ground clutter. Lightning flash densities of 1, 2, 3 and >3 flashes per km^2 are shown as green, yellow, orange and red, respectively. Triangles represent locations of SAFIR sensors. Arrows point to 4 cells (see text).

RADAR ECHO TOP AND LDAR LIGHTNING TOP COMPARISON

On 9 July 1997 both the KSC LDAR network and the Melbourne, FL WSR-88D detected a severe thunderstorm that produced hail of ~2 cm diameter. Figure 6 shows the echo top and lightning top analysis for this storm. At 2107 UTC, this cell was located ~50 km due north of the Melbourne WSR-88D. During the next hour, it propagated toward the south and moved into the WSR-88D cone of silence. This is clearly evident from the echo top analysis that

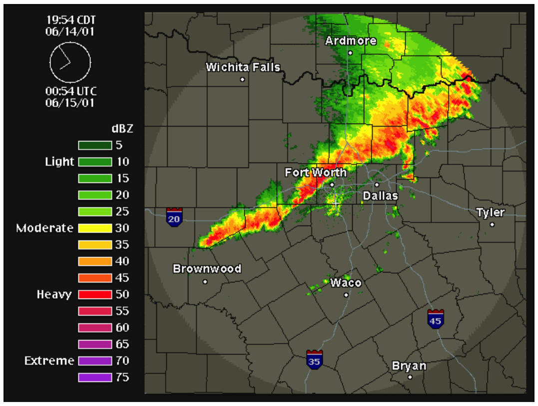

Figure 4. Same as Figure 2, except from 0054 UTC 15 June 2001.

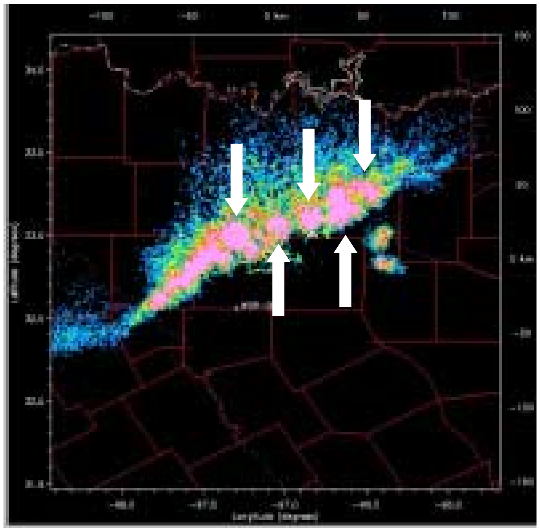

Figure 5. DFW LDAR II lightning pulses detected between 0051:30 and 0056:30 UTC 15 June 2001. Bright pink represents ≥ 20 lightning pulses per ~1 km^2 grid box. The white arrows point out five individual convective cells within the squall line.

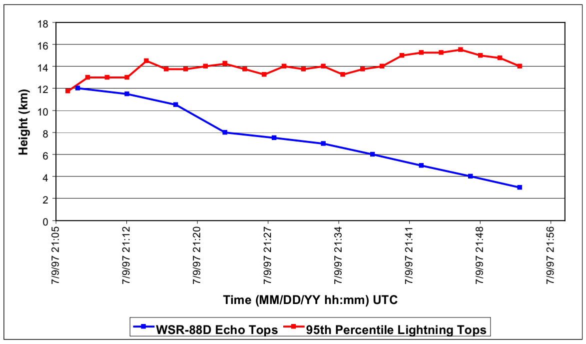

Figure 6. SCIT echo top trends obtained from the Melbourne, FL WSR-88D and lightning top trends calculated from the KSC LDAR network for the severe thunderstorm that produced hail of ~2 cm diameter at 2143 UTC 9 July 1997.

shows a gradual descent from 12 km at 2107 UTC to 3 km at 2152 UTC. The lightning top initially shows a slight ascent and then levels off at ~14 km until 2134 UTC. The reflectivities also remained consistently high between 2107 and 2134 UTC (not shown). After 2134 UTC, the lightning tops gradually ascended until they reached 15.5 km at 2146 UTC. The reflectivities also increased during this time period. During the lightning top ascent, the storm began producing hail at 2143 UTC.

CONCLUSIONS

Comparisons of the spatial extent of lightning activity within thunderstorms showed that total lightning extended tens of kilometers beyond cell boundaries as defined by CG lightning. Thunderstorm cell identification was greatly improved with the use of total lightning density over CG lightning density. Total lightning has also been able to identify thunderstorm cells more accurately in complex multi-cellular environments such as squall lines. The continuity that total lightning data showed over time allows it not only to identify, but also track thunderstorm cells well. In a number of thunderstorms, altitude trends obtained from echo tops exhibited unrealistic growth and decay and were better represented by lightning altitudes. The continuous data stream provided by both the SAFIR and LDAR II technologies allowed cells to be tracked with more rapid update cycles than the typical 5-minute update time of radar. In summary, such information complements radar by providing a higher level of detail in both time and space for thunderstorm growth and decay.

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