NORMAL POLARITY SEVERE THUNDERSTORMS DOMINATED BY NEGATIVE CG LIGHTNING IN THE DALLAS-FORT WORTH AREA

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BACKGROUND

Since the U.S. National Lightning Detection Network (NLDN) became fully operational in 1989, meteorologists have spent considerable time trying to identify cloud-to-ground (CG) lightning characteristics that are uniquely associated with severe weather. Many studies focused on the dominant CG lightning polarity as a potential indicator of severe weather. Knapp (1994) found that 39% of the 556 positive CG dominated (PCGD) thunderstorms (≥ 30% positive CG lightning for an hour) analyzed in their study produced severe weather. This is much larger than the generally accepted value of less than 1% of all thunderstorms producing severe weather. Nevertheless, MacGorman and Burgess (1994) found that many severe thunderstorms are negative CG lightning dominated (NCGD), however the false alarm rate is too large for using it as a severe weather indicator because there are so many NCGD storms that are not severe.

The use of 3-dimensional lightning mapping systems, such as the Lightning Mapping Array (LMA), in field programs has shown that PCGD thunderstorms usually have an anomalous electrical structure which is inverted in polarity (i.e., main negative above main positive charge layer) from normal (Rison et al., 1999). Krehbiel et al. (2002) found that severe and supercell thunderstorms were inverted in polarity from normal, non-severe thunderstorms during the STEPS field campaign that took place in northwest Kansas and eastern Colorado in 2000. These inverted storms produced predominantly positive CG lightning flashes.

Although there appears to be an important relationship between PCGD storms and severe weather, most of these storms have been studied in the central and northern plains of the United States. A number of other studies have shown that dominant storm polarity has an important regional dependence. Branick and Doswell (1992) found regional variations in dominant ground flash polarity for supercell storms. Low-precipitation (LP) supercells in northern Oklahoma, Kansas and Nebraska produced predominantly positive CG flashes, while high-precipitation (HP) supercells in central and southern Oklahoma produced predominantly negative CG flashes. Perez et al. (1997) studied thunderstorms producing F4 and F5 tornadoes and found that the PCGD storms were concentrated in the central and northern plains states. Negative CG flashes dominated all the F4 and F5 tornado producing thunderstorms in Texas. Recently, Smith et al. (2000) found that the dominant polarity of CG lightning within storms may be dependent on equivalent potential temperature (EPT) gradients. PCGD storms formed upwind of the EPT maximum and produced severe weather more often than NCGD storms, which occurred downwind of the EPT maximum. Orville et al. (2002) found that less than 20% of all CG flashes on an annual basis are positive in the Dallas-Fort Worth (DFW) area, despite DFW being located in the region of maximum probability of severe weather in the U.S. in April, May and fall (www.nssl.noaa.gov/hazard/index.html). According to Smith et al. (2000), the DFW area should be located downwind of the EPT maximum because most storms are NCGD. If that is the case, then why does it experience such a high percentage of severe weather? On the other hand, if the DFW area is often located upwind of the EPT maximum, where a higher percentage of storms are expected to produce severe weather, then why are most storms NCGD?

To date, analysis of a set of severe thunderstorms using the DFW Lightning Detection and Ranging (LDAR II) network (Demetriades et al., 2002) and the NLDN has shown that all of them were of normal polarity and dominated by negative CG lightning despite producing hail up to 7 cm in diameter and strong F2 tornadoes. This paper will cover a couple of case studies that support our claim and show the important role that can be played by normal polarity, negative CG lightning dominated thunderstorms in producing extremely damaging severe weather.

METHODOLOGY

The vertical electrical structure and dominant CG polarity were examined for a set of severe thunderstorms that passed within range of the DFW LDAR II network. The vertical electrical structure was either classified as normal or inverted based on LDAR II data. A storm was considered to have an electrical structure that was normal in polarity if (1) the layer with the higher source density was between 8 and 12 km altitude and above the lower density layer and (2) the cloud flashes exhibited an upward initial development. The initial development of cloud flashes propagates from negative to positive charge (Krehbiel et al., 2002). The dominant CG flash polarity was determined from the NLDN.

11 OCTOBER 2001 SUPERCELL

On 11 October 2001, a supercell storm produced large hail just west of Fort Worth, Texas. Figure 1 shows LDAR II lightning sources detected within this supercell between 0005:30 and 0015:30 UTC. The top panel is an altitude (y) versus time (x) plot. The lower left panel is a plan view showing latitude (y) versus longitude (x). The lower right panel is a latitude (y) versus altitude (x) cross-section. The panel just above the plan view is an altitude (y) versus longitude (x) cross-section and the panel just to its right is an altitude (y) versus source frequency (x) plot. The chosen time period includes the 2.5 cm (1 in.) hail report at 0008 UTC and the 4.4 cm (1.75 in.) hail report at 0013 UTC. The highest density layer of lightning sources is centered at ~11 km in altitude. This implies that the main positive charge layer is centered at ~11 km because negative breakdown in a positive charge region produces a more powerful VHF signal than positive breakdown in a negative charge region (Rison et al., 1999). Cloud flashes during this time interval exhibited an initial upward development (Fig. 2). This reinforces that the main negative charge region is located below the main positive charge region. The vertical electrical structure of this supercell appears to be normal in polarity.

Figure 3 shows the flashes detected by the NLDN within this supercell between 0000 and 0050 UTC 11 October 2001. During the time of the severe hail reports (0008 and 0013 UTC), the percentage of positive CG flashes remained below 11%. The percentage of positive CG flashes went up after 0020 UTC in response to the negative CG flash rate lowering rather monotonically from ~70 flashes between 0005 and 0010 UTC to ~4 flashes between 0040 and 0045 UTC. The positive CG flash rate was never greater than 10 per 5-minute interval from 0000 to 0050 UTC.

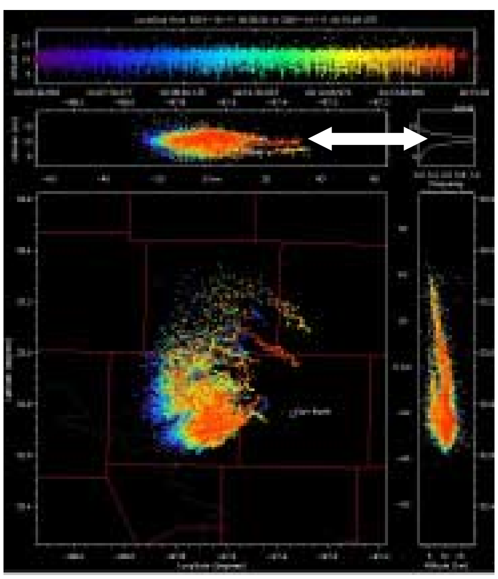

Figure 1. Lightning sources detected by the DFW LDAR II network between 0005:30 and 0015:30 UTC 11 October 2001. The white arrows point at the highest lightning source density layer as indicated by the source frequency versus altitude plot and the east-west vertical cross-section.

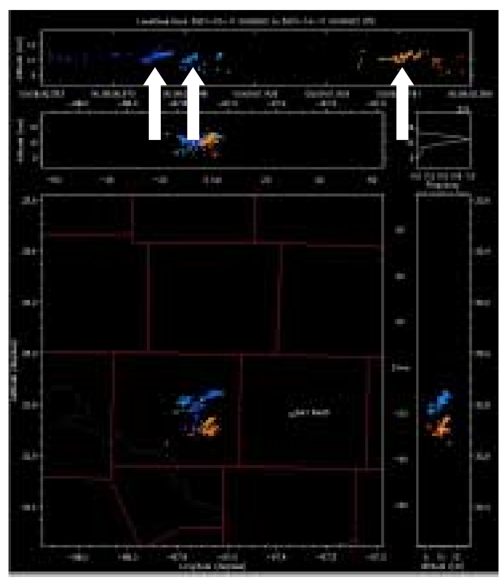

Figure 2. Same as Figure 1, except for 3 cloud flashes detected by the DFW LDAR II network shortly after 0009 UTC 11 October 2001. White arrows point at the initial upward development of three cloud flashes.

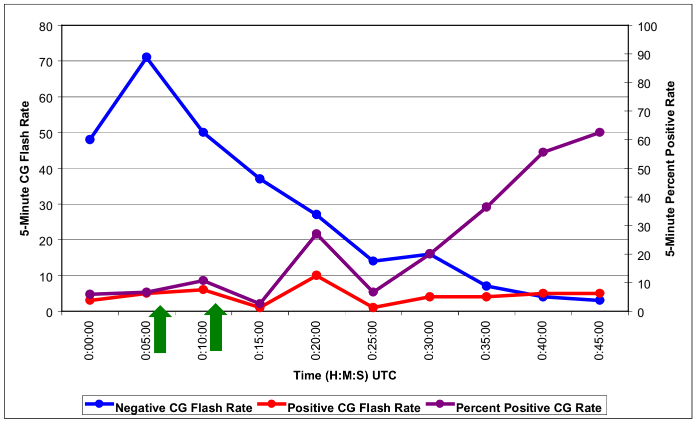

Figure 3. 5-minute CG lightning flash rates and percentage of positive CG flashes detected by the NLDN in the hail producing supercell that passed through the DFW area between 0000 and 0050 UTC 11 October 2001. The blue curve represents the negative CG flash rate, the red curve represents the positive CG flash rate and the purple curve represents the percentage of positive CG flashes. Flash rates are labeled on the left-hand y-axis and the percentages of positive CG flashes are labeled on the right. Green arrows indicate time of hail reports.

15 JUNE 2001 SQUALL LINE

An intense squall line passed through the DFW area on 15 June 2001. This squall line produced 7 cm diameter hail as it moved through north Texas and wind gusts over 111 kmh^{-1} (60 kt) in the DFW area. Figure 4 shows the lightning sources detected within this squall line by the DFW LDAR II network between 0028 and 0038 UTC. During this time interval, the largest hail reported within the squall line was 2.5 cm (1 in) at 0033 UTC and the largest wind gust reported within the squall line was 113 kmh^{-1} (61 kt) at 0040 UTC. The highest density layer of lightning sources (main positive charge layer) is centered at ~10.5 km in altitude. Cloud flashes during this time interval exhibited an initial upward development (Fig. 5). Figures 4 and 5 imply that the vertical electrical structure of this squall line was normal in polarity.

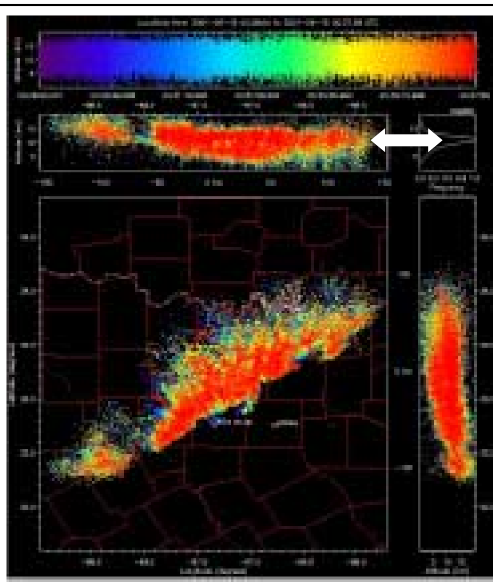

Figure 4. Same as Figure 1, except for lightning sources detected by the DFW LDAR II network between 0028 and 0038 UTC 15 June 2001.

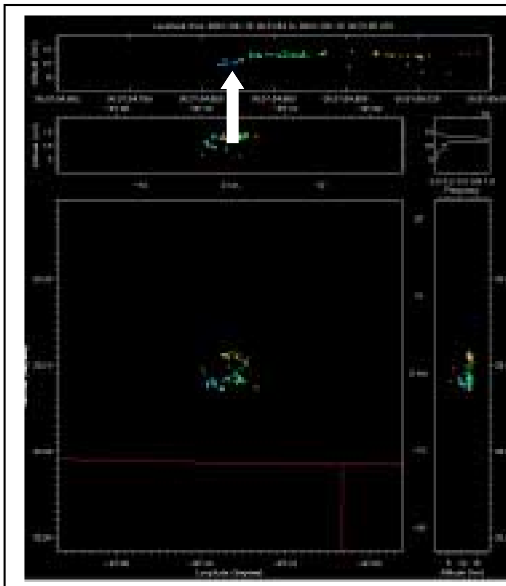

Figure 5. Same as Figure 2, except for a cloud flash detected by the DFW LDAR II network between 0031:54 and 0031:56 UTC 15 June 2001.

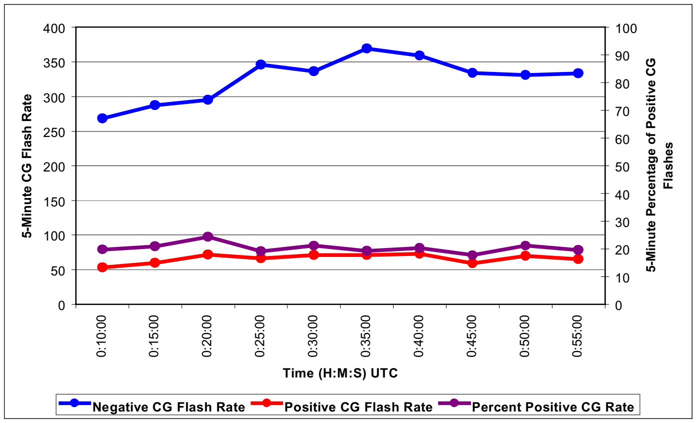

Figure 6. Same as Figure 3, except in the severe hail and wind producing squall line that passed through the DFW area between 0010 and 0100 UTC 15 June 2001.

Figure 6 shows the NLDN CG flashes detected within this squall line between 0010 and 0100 UTC 15 June 2001. Only those CG flashes that occurred within range of the DFW LDAR II network (~200 km) were used in this flash rate analysis. The percentage of positive CG flashes produced by this squall line remained quite steady throughout this time period and never went above 25%. In particular, the percentage of positive CG flashes was below 22% at the time of the 2.5 cm (1 in) hail report (0033 UTC).

CONCLUSIONS

The DFW LDAR II network and NLDN have been used to study the vertical electrical structure and dominant CG lightning polarity of thunderstorms in the DFW area. The two examples shown in this paper are representative of the severe thunderstorms that have been analyzed using both datasets. These storms were of normal polarity in the vertical and dominated by negative CG lightning flashes. Therefore, using inverted, PCGD storms as an indicator of severe weather is not as applicable in the DFW area as it is in the central and northern plains states. Total (cloud and CG) lightning parameters such as flash rates and cloud/CG flash ratios, used in conjunction with radar data, may be more effective. Future work will include determining the percentage of NCGD storms that are severe as a function of location.

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