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THREE-DIMENSIONAL LIGHTNING MAPPING OF THE CENTRAL OKLAHOMA SUPERCELL ON 26 MAY 2004

Elise V. Johnson[1,*] and Edward R. Mansell[2]
[1]National Weather Center Research Experiences for Undergraduates, Norman, OK and Iowa State University
[2]Cooperative Institute for Mesoscale Meteorological Studies, Univ. of Oklahoma, Norman, OK

Abstract

Three-dimensional lightning mapping observations from the Oklahoma Lightning Mapping Array (OK-LMA) were used to analyze charge structure of a splitting supercell on 26 May 2004 during the Thunderstorm Electrification and Lightning Experiment (TELEX). The OK-LMA was used to evaluate cloud-to-ground (CG) flashes reported by the National Lightning Detection Network's (NLDN). Each NLDN flash between 2300 UTC and 2310 UTC was classified as either a CG flash (positive or negative polarity) or an intra-cloud (IC) flash using LMA-inferred charge structure. The LMA analysis supports the charge structure for 23 percent of the NLDN positive CG flashes and 7 percent of the NLDN negative CG flashes.

1. Introduction

Three-dimensional charge analysis of thunderstorms is important in further understanding lightning behavior. Comparison of 3D lightning source data with reported cloud-to-ground (CG) flashes has been made possible by the National Lightning Detection Network (NLDN) (Cummins et al., 1998; Cramer et al., 2004) and lightning mapping arrays (LMA) (Rison et al., 1999; Thomas et al., 2004). The NLDN has a 90% detection efficiency over most of the United States with a median location accuracy of 500 m or better (Cramer et al., 2004). Many studies (e.g., Orville and Huffines, 2001) have investigated positive CG (PCG) flashes and total CG relationships. These studies used Cummins et al. (1998) suggestion to regard positive flashes below 10 kA as intra-cloud (IC) flashes. All negative flashes were assumed to be valid.

While the NLDN detects CG flashes, the Oklahoma lightning mapping array (OK-LMA) maps total lightning in a storm. It shows flash development of both IC and CG flashes. The OK-LMA consists of 11 stations located in central Oklahoma and determine the spatial location of lightning discharge sources. From these sources, the charge structure of active regions of storms can be inferred. The primary analysis of classifying negative CG (NCG) flashes is determining whether the negative leader goes upward or downward and if it can be seen (through the LMA) extending to the ground.

In this study, CG flashes from the NLDN on 26 May 2004 from 2300 UTC to 2310 UTC were analyzed using the OK-LMA. The cell passed in proximity to the OK-LMA network. The NLDN flashes in the supercell during this time period suggest differing charge structure for different parts of the storm. The validity of the CG flashes with the charge structure of the supercell will be examined. In section 2, a basic overview of the lightning detection networks is presented as well as the methods used to distinguish charge layers. In section 3, the results from the comparison of the NLDN and the OK-LMA will be presented. In section 4, a discussion of these results and consequences are explored.

2. Data and methodology

The NLDN data provide CG flash strike time to the millisecond. Data from the OK-LMA were set to use a minimum of 6 stations to locate lightning

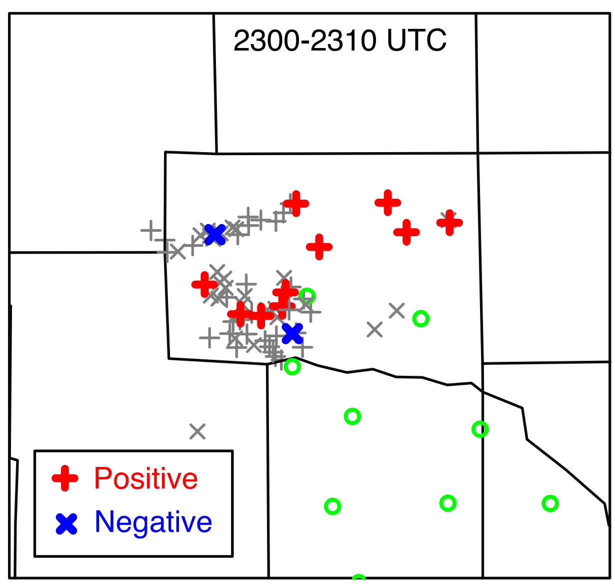

FIG. 1: CG flash reports by NLDN for 2300–2310 UTC on 26 May 2004 in central Oklahoma. The highlighted symbols represent the NCG and 10 PCG flashes that were confirmed. The gray symbols represent the misclassified NLDN flashes identified through LMA analysis.

*Corresponding author address: Elise V. Johnson, 3010 Agronomy Hall, Ames, IA 50014; e-mail: elisevj@iastate.edu

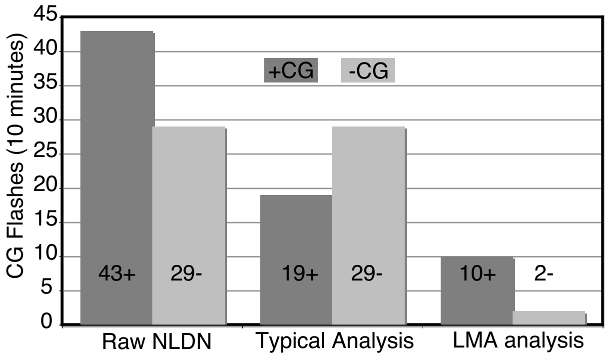

FIG. 2: Comparison of CG flash totals from the original NLDN data set with the result of a typical analysis (10 kA threshold for PCG flashes) and the LMA analyis.

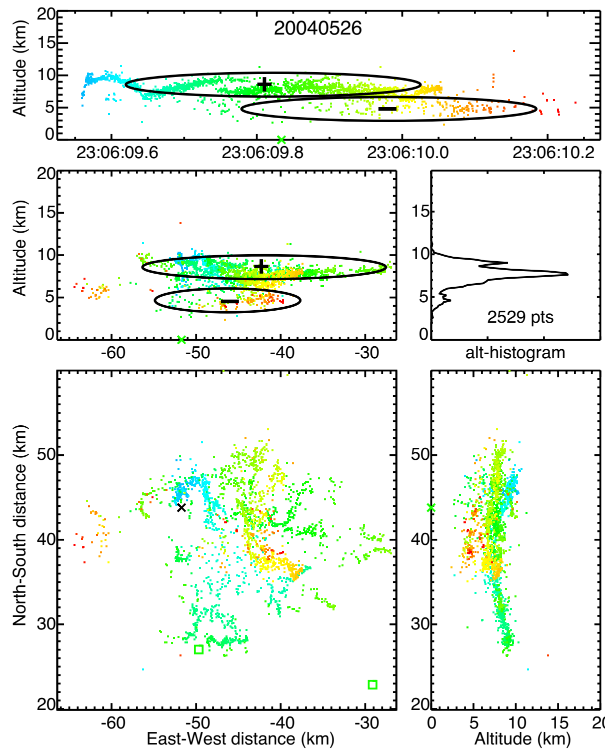

FIG. 3: A PCG flash (74.8 kA) at 2306:09.834 UTC confirmed by LMA analysis

source points. The LMA reveals 3-D progression of the lightning discharge with a time resolution of 80 μs and spatial accuracy of about 30 m over the center of the network to about 200–300 m at 100 km range. (Thomas et al., 2004). The LMA has a 3-D range of about 75 km, beyond which altitude errors become significant.

The 10-minute period (2300-2310 UTC) was chosen during a strong phase of the supercell storm when the it was in the process of splitting. The left-moving storm dissipated shortly after separation. This allowed for the comparison of the northern and southern cell. Using the XLMA software (developed at New Mexico Institute of Mining and Technology), each NDLN-reported CG flash was investigated using the OK-LMA data. The charge structure inferred from the OK-LMA was used to determine if support existed for the NLDN-reported CG flash. Each flash was classified as a confirmed CG flash, IC flash, or unconfirmed CG flash.

A negatively-charged lightning leader in a normal-polarity (positive over negative) flash propagates upward into a positive charge region, while a positive leader, which may or may not be detected, propagates downward and into a negative charge region. The opposite occurs an inverted-polarity flash (Rust et al., 2005). Negative breakdown propagates into positive charge regions, allowing a clear view of significant positive charge areas. Positive breakdown is faster, more continuous into the negative region, and radiates at lower power which makes it harder for the minimum 6 stations to detect the pulse, resulting in fewer source points that in the negative breakdown (e.g., Shao and Krehbiel, 1996; Rust et al., 2005; Théry, 2001). Using this bias for negative breakdown, it is possible to infer positive and negative charge regions for each NLDN flash. Charge regions that are not involved in lightning, however, cannot be detected by this method.

After establishing the basic storm charge structure, the polarity and peak current were used to further evaluate the flash. For a NCG flash, if there was not a clear channel towards the ground or the charge structure did not seem capable of supporting a NCG, then the negative flash was considered an IC flash. For PCG flashes, if the peak current was below 10 kA it was immediately questionable (Cummins et al., 1998). There had to be some indication of a positive channel to the ground and have the supported charge structure for a PCG to be confirmed. Radiated power was also examined, following Théry (2001), in examining the lightning activity following a PCG flash report. Unlike Théry (2001), however, no attempt was made to identify PCG flashes that may have been missed by the NLDN.

3. Results

The NLDN reported 72 CG flashes during the 10-minute study period (Figure 1). With the removal of positive flashes below 10 kA as suggested by Cummins et al. (1998), a total of 24 positive flashes are removed leaving 48 flashes. Finally, 12 NLDN CG flashes were evaluated as CG flashes by the LMA analysis (Figures 1 and 2).

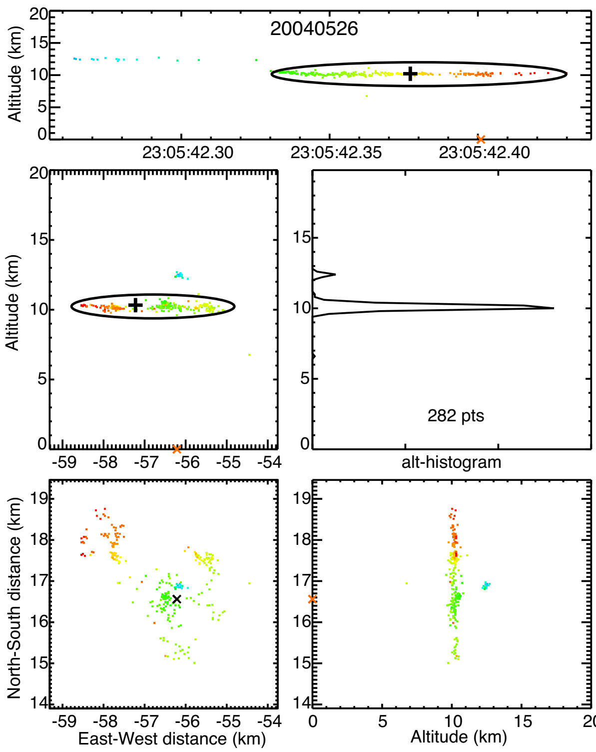

FIG. 4: An IC flash at 2305:42.401 UTC identified by the NLDN as a 17.3 kA PCG flash. There is no indication of lightning propagating below 9 km.

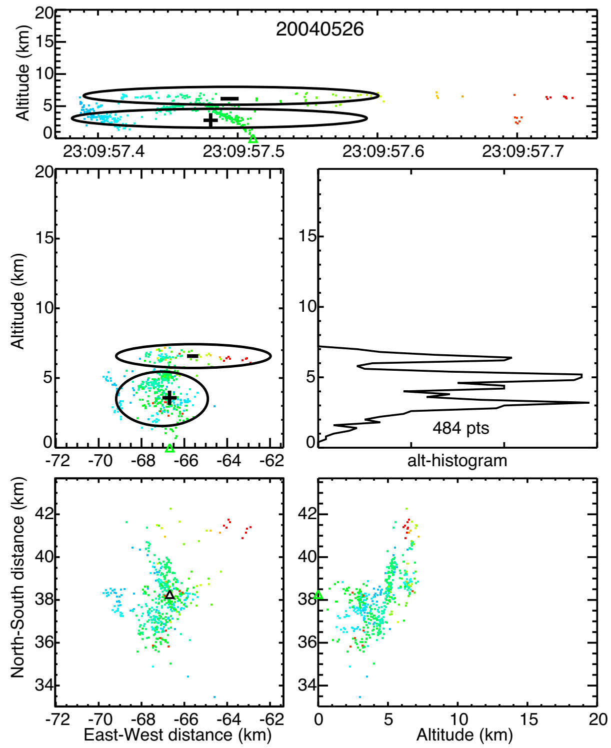

FIG. 5: A confirmed NCG flash (−12.0 kA) at 2309.57.511 UTC.

In this study, 96% of PCG flash with peak current under 10 kA were evaluated as IC flashes along with 90% of those with currents between 10 and 15 kA. Above 15 kA, however, only 11% appeared to be IC flashes. Therefore, an arbitrary cut-off at 15 kA might present less error than the current 10 kA suggestion. Figure 3 shows an example of a confirmed PCG flash, while Figure 4 shows an IC flash reported as a PCG flash.

Unlike the positive flashes, which require a more subjective analysis, negative flashes are easier to confirm with more confidence as there should be a clear indication of lightning from the cloud to the ground level if the storm is close to the LMA network. In this study, 2 out of 29 NLDN CG flahes were confirmed as NCG flashes using the OK-LMA. The 27 rejected NCG flashes had low peak currents (less than −15 kA) and only one or two return strokes. Figure 5 shows a confirmed NCG flash that had four return strokes. There were five IC flashes that were labeled as NCG flashes by the NLDN exhibiting a clear bi-level structure. For example, for the flash in Figure 6 the NLDN appears to have triggered at the time of a intracloud K-change (P. Krehbiel, pers. comm.).

The charge structure during each flash was analyzed. In general, there appeared to be a layer of positive charge around 10 km above ground level and a negative layer below around 6–8 km. Figure 7 shows a possible 4-layer structure of (from ground up) negative, positive, negative and the final positive layer around 10 km. A few flashes indicated an upper negative layer and a lower positive layer besides the two layers discussed above. i.e., showed inverted polarity structure. The IC flash in Figure 8 has positive charge at 8–10 km and negative above that with no clear negative below 8km leading to this flash exhibiting opposite charge structure than a majority of the other flashes in the storm.

The LMA flashes generally suggested a normal polarity storm (positive over negative) for the entire supercell during the 10 minute study period. Although the negative level was harder to decipher, the positive charge layer was rather clear around 10 km. The lack of correct charge structure support was a main reason for the rejection of most of the NCG flashes. It is possible that different parts of the storm may exhibit different charge structures supporting different polarity CG flashes.

4. Discussion

The NLDN has an estimated 90% detection efficiency, which means that the NLDN detects 90%

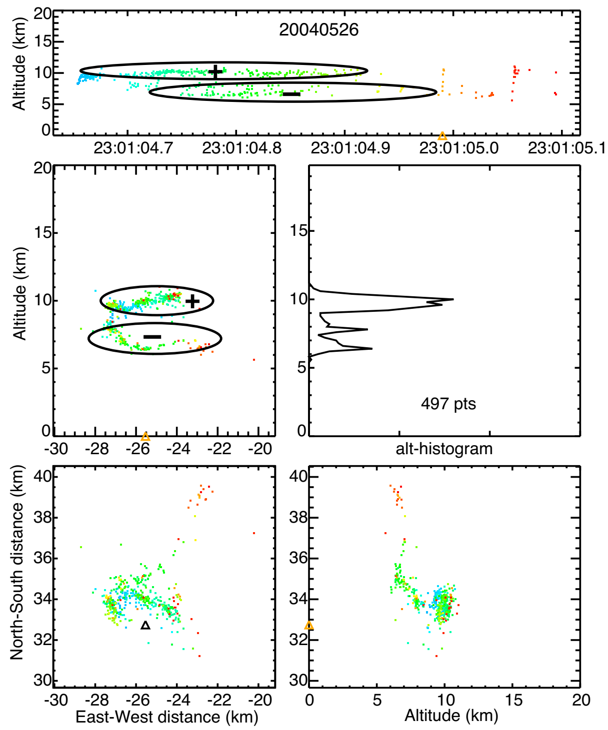

FIG. 6: A normal-polarity IC flash reported as a negative CG flash (-10.0 kA) at 2301.04.990 UTC.

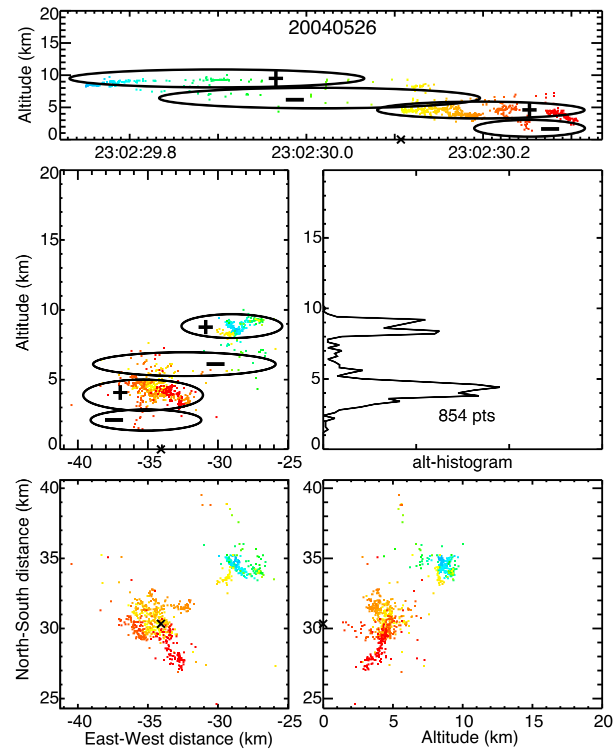

FIG. 7: A possible 4-layer structure of inverted polarity at 2302.30.107 UTC. This flash had a peak current of 10.4 kA according to the NLDN and was not disconfirmed as a PCG.

of the actual CG flashes occurring, leaving an unknown amount of extra flashes that are read as CG flashes. For this study, only 17% of the NLDN reported CG flashes were confirmed by the OK-LMA. This results in a 83% chance of misinterpretation.

Théry (2001) also investigated the validity of the CG flashes reported by the South Germany Lightning Position and Tracking System (LPATS) and rejected 75% of PCG flashes and 38% of NCG flashes based on interferometer observations. [Note that for the current study, however, newer IMPACT-ESP sensors had been installed across the NLDN (Cramer et al., 2004).] This Oklahoma-based study rejected 77% PCG flashes and, surprisingly, 93% NCG flashes. While this study had a 83% misinterpreation rate, Théry's study had only a 50% rate.

5. Conclusion

The OK-LMA and the NLDN were compared during 2300-2310 UTC on 26 May 2004 for a central Oklahoma supercell. It was found that 17% of the NLDN-reported CG flashes were confirmed by the LMA analysis. An independent analysis of source altitudes from NLDN data by K. Cummins and J. Cramer appears to corroborate the findings of this study (K. Cummins, pers. comm.) and this appears to be an issue primarily in the high and southern plains of the U.S. This study is currently limited to 10 minutes of one supercell, and further investigation is ongoing into a longer time frame within this storm. From this future analysis, it will be determined whether the results presented thus far are applicable to just a small portion of this supercell storm or are representative of a systematic problem.

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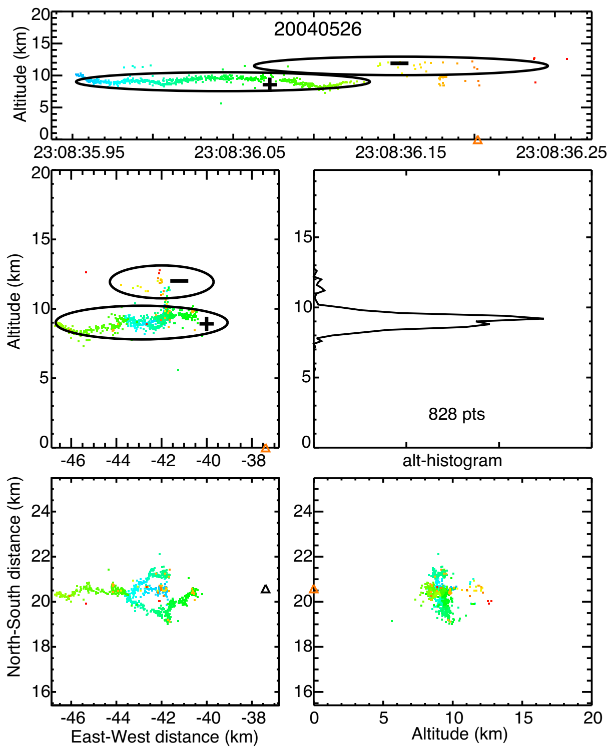

FIG. 8: An inverted polarity IC flash reported as a NCG flash (-7.4 kA) at 2308.36.202 UTC.

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