Three-dimensional lightning mapping of the central Oklahoma supercell on 26 May 2004

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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 or an intra-cloud (IC) flash using LMA-inferred charge structure. The LMA analysis of the charge structure supports charge structure for 23% of the positive CGs. Most of the negative NLDN flashes that were analyzed were not confirmed by the LMA.

1. Introduction

Three-dimensional charge analysis of thunderstorms is important in understanding lightning behavior. This analysis has been made possible by the National Lightning Detection Network (NLDN) and lightning mapping arrays (LMA). The NLDN, owned and operated by Vaisala, Inc., became operational across the continental United States in 1989. Before 1989, regional networks dating back to 1976 measured CG locations in the United States (Orville 1991a). After the 1995 upgrade, the network was determined to have a detection efficiency (DE) of 80-90% for positive flashes above 5 kA (Cummins et al. 1998). The most recent upgrade to the system occurred in 2003. Many studies (e.g., Orville 2001) have investigated positive cloud-to-ground (PCG) flashes and total CG relationships. These studies used Cummins (1998) suggestion to regard positive flashes below 10 kA as intra-cloud (IC) flashes. All negative flashes were assumed to be valid. The sign of charge that is lowered to the ground determines the polarity of a flash.

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. These stations determine the three-dimensional location of lightning discharge sources. From these sources, the charge structure of active regions of the storm can be inferred. The primary analysis for negative CGs is whether the negative leader goes upward or downward and if it can be seen extending to 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 close proximity to the OK-LMA network. The NLDN flashes in the supercell during this time period suggested differing charge structure for different parts of the storm. The validity of the CG flashes and the charge structure of the

supercell will be examined. In section 2, an understand 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 was explored. Finally, in section 5, the findings will be overviewed with a next step to move for this study.

2. Data and methods

The NLDN consists of 113 sensors spread throughout the continental United States.   The NLDN uses time-of-arrival (TOA) and magnetic direction finding (MDF) techniques to locate CG flashes with an accuracy of 500m.   The TOA technique requires at least 3 stations. When lightning strikes, the location is found by the intersection of the hyperbola depicted by time distance between each pair of stations. MDF requires at least 2 stations. Each station detects the direction along which the strike occurred. By combining multiple station readings, a pin-point location is computed.   The NLDN provides latitude, longitude, polarity, strength, and multiplicity of return strokes.

The OK-LMA uses the TOA technique to locate source points throughout a lightning flash in three dimensions.   A minimum of 6 stations is needed to accurately locate a discharge source. The LMA reveals 3-D progression of the lightning discharge with a time resolution of 80 microseconds. The 3-D determination is good out to about 75 km where altitude errors start to become significant.

The 10-minute period (2300 – 2310 UTC) was chosen based on it being during a stronger portion of the supercell when the supercell was splitting with the left mover dying 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 NLDN-reported CG was investigated for validity using the OK-LMA data. To determine the validity, the charge structure of the storm at that instant was determined. From the inferred charge structure and available OK-LMA points, each NLDN CG was determined to be either a CG or an IC.

The process to determine if a flash was indeed a CG or an IC involved individually separating each NLDN flash by time and space.   The height and polarity of charge in the applicable area of the storm was noted and then the peak current reported by the NLDN was taken into account.

The charge structure varies in thunderstorms. A negatively charged leader in a normal-polarity (positive over negative) storm initiates and propagates upward into the positive charge region while the opposite is true for a negative leader in an inverted-polarity storm(Rust et al, 2005). Negative breakdown of charge propagates into the positive region allowing a clear view of 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 than in the negative breakdown. (i.e. Rust et al 2005; Théry 2001) Using this bias for negative breakdown, it is possible to infer positive and negative charge regions on each flash.

After establishing charge structure, the polarity and peak current were used to further discriminate the validity of the flash. For a negative CG flash, if there was not a clear channel towards the ground or the charge structure did not seem capable to support a NCG the negative flash was considered an IC. 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.

3. Results

The NLDN reported 72 CG flashes during the 10-minute period as seen in Figure 1. With the removal of positive flashes below 10 kA as suggested by Cummins (1998), a total of 24 positive flashes are removed in Figure 2. Finally, 11 NLDN CGs were verified as CGs by the LMA analysis (figure 3). Figure 4 shows the distribution of the gradually reduced number of CG flashes as the analysis moved forward.

The NLDN reported two PCG flashes under 5kA. The NLDN estimates an 80-90% DE above 5 kA; therefore, these two flashes could be considered ICs. In this study, there is 95% misinterpretation in the 5-10 kA range and 90% in the 10-15 kA range. Above 15 kA, however, the misinterpretation rate was 11%. An arbitrary cut-off at 15 kA might present less error than the current 10 kA suggestion. Figure 5 shows a good example of a confirmed PCG flash while figure 6 shows a good example of an IC flash that was reported as a PCG flash.

Unlike the positives flashes, which are more subjective to analysis, negative flashes are easier to confirm with more confidence as there should be a clear indication from the cloud to the ground level if the storm is close to the LMA network. In this study, 1 NDLN CG flash was confirmed as a NCG using the OK-LMA. Figure 7 shows the flash which had four return strokes associated with it. There were five IC flashes that were labeled as NCG flashes by the NLDN exhibiting a clear bi-level structure; figure 8 is an example. Since these flashes lack breakdown to ground level it is unclear the reason for why the NLDN labeled the flash as a NCG.

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. A few flashes exhibited an upper negative layer and a lower positive layer besides the two layers discussed above. There were two IC flashes of note that showed inverted polarity structure.

Figure 9 shows possibly 4 layer structure of (from ground up) possible negative, positive, negative and then the final positive layer around 10km. The IC flash in figure 10 had positive charge 8-10km and negative charge above it with no clear negative below the positive making it opposite charge structure than a majority of the rest in the storm.

The LMA generally showed a normal polarity storm (positive over negative) for the entire supercell during the evaluated NLDN CG flashes. While the negative level was hard to decipher, the positive charge layer was rather clear around 10 km. The lack of correct support of charge structure was a main reason for the rejection of most the NCG. The 1 validated NCG occurred within the northern part of the storm while the 10 validated PCG flashes occurred within the southern and front portions of the storm. 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 80-90% DE, which means that the NLDN only detects 80-90% of the actual CGs occurring leaving an unknown amount of extra flashes that are read as CG flashes. If the positive flashes below 5kA are removed (to be consistent with the NLDN DE) only 19% of NLDN reported CG flashes are validated for this study. This results in an 81% chance of false detection.

This study was not the first validation study. Thery (2001) investigated the validity of the CGs from the South Germany Lightning Position and Tracking System (LPATS) and rejected 75% of PCG flashes and 38% of NCG flashes. This study rejected 77% PCG flashes and 97% NCG flashes. While this study had a 85% rejection or false detection (when including positive flashes below 5 kA), Thery's study had only 50% rejected.

This study is limited to 10 minutes of one supercell so a next step would be to further expand upon the analysis of this storm and possible other storms. From this further analysis it can be seen if the results are just applicable to a small portion of a storm or if there is something larger to be investigated in the NLDN.

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 only 15% of the NLDN CG flashes verified as CG flashes after analysis of the LMA. This study's data set is limited leading to the limited applicability of the results. However, if the results from this 10 minute/1 supercell study consistently occur in the analysis of the NLDN CG flashes, caution should be used for lower-current NCG flashes pending a more extensive study.

Acknowledgements

References

Cummins, K.L., M.J. Murphy, E.A. Bardo, W.L. Hiscox, R.B. Pyle, and A.E. Pifer, 1998: A combined TOA/MDF techonology upgrade of the U.S. National Lightning Detection Network. *J. Geophys. Res.,* **103,** 9035-9044.

MacGorman, D.R., and W.D. Rust, 1998: *The Electrical Nature of Storms.* Oxford Univ. Press, 422pp.

Orville, R.E., 1991a: Lightning ground flash density in the contiguous United States-1989. *Mon. Wea. Rev.,* **119,** 573-577.

Orville, R.E., and G.R. Huffines, G.R., 2001: Cloud-to-ground lightning in the United States: NLDN results in the first decade, 1989-98. *Mon. Wea. Rev.,* **129,** 1179-1193.

Rust, W.D., and Coauthors, 2005: Inverted-polarity electrical structures in thunderstorms in the Severe Thunderstorm Electrification and Precipitation Study (STEPS). *Atmos. Res.,* **76,** 247-271.

Thery, C., 2001: Evaluation of LPATS data using VHF interferometric observations of lightning flashes during the Eulinox experiment. *Atmos. Res.,* **56,** 397-409.

Figures
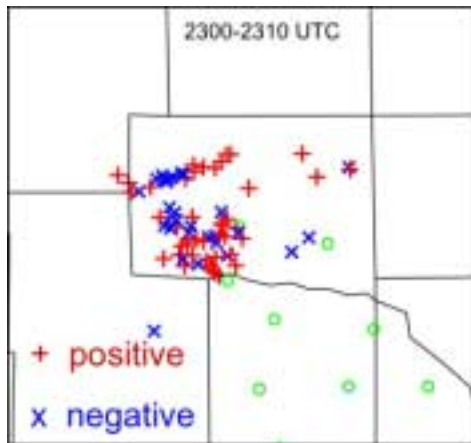
Figure 1. All 72 NLDN flashes reported between 2300-2310 UTC. The green circles are the OK-LMA stations.
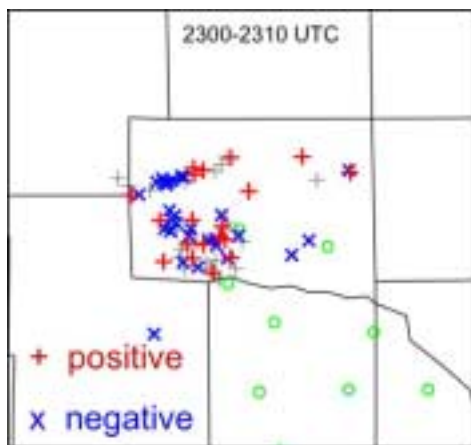
Figure 2. The "Typical" analysis of the NLDN is shown by the removal of positive flashes below 10kA in gray. No negatives were removed.
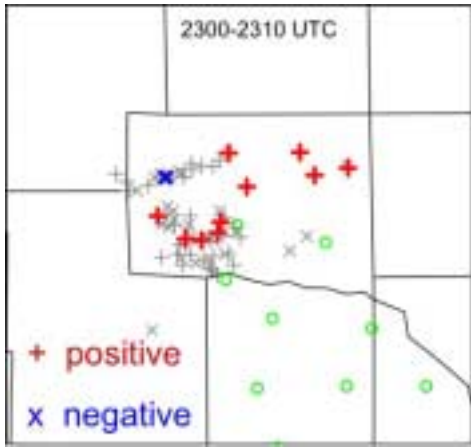
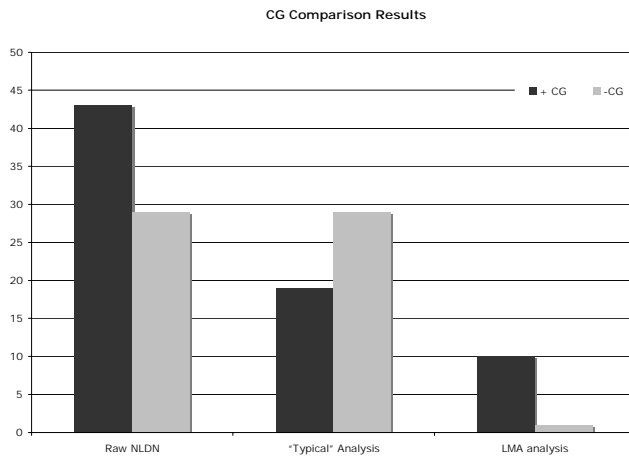Figure 3. The result of LMA analysis with 1 NCG and 10 PCG validated

Figure 4. Comparison of cloud-to-ground totals from raw NLDN, "typical" analysis and LMA analysis.
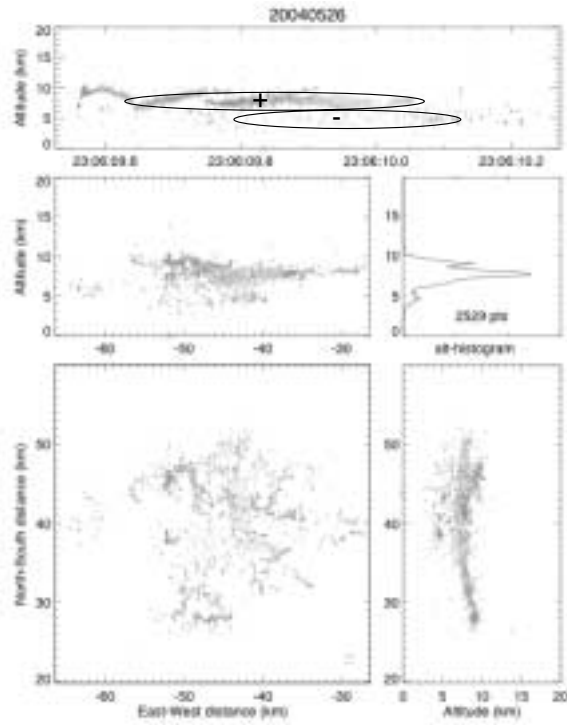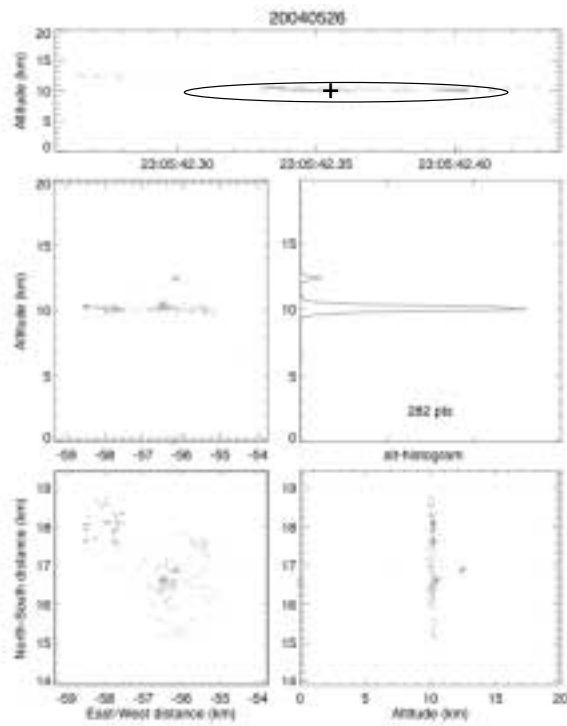
Figure 5. OK-LMA confirmed 74.8 kA PCG flash at 2306.09.834 seconds.

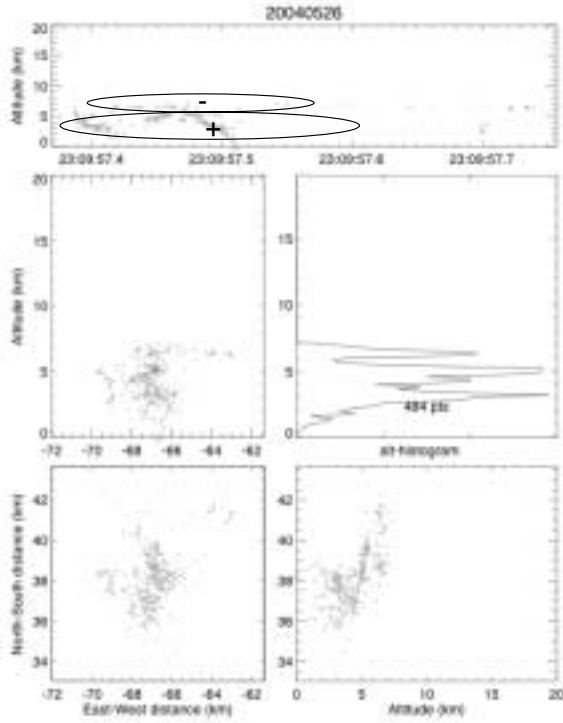Figure 6. OK-LMA suspected a positive 17.3 kA IC flash at 2305.42.401 seconds.

Figure 7. OK-LMA confirmed a -12 kA NCG flash at 2309.57.511seconds.
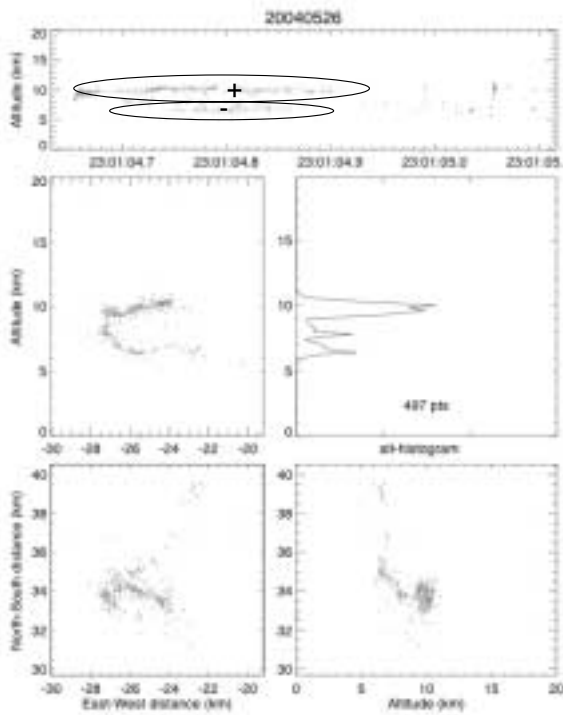

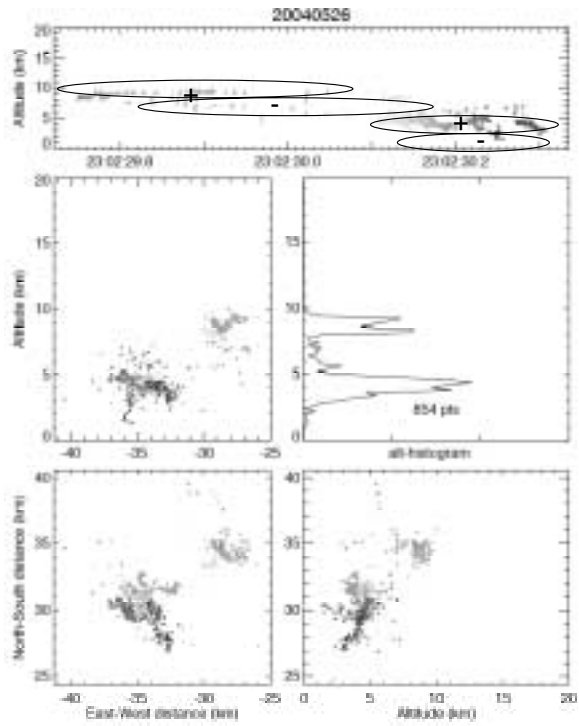Figure 8. OK-LMA suspected a negative -10 kA IC flash at 2301.04.990 seconds.

Figure 9. OK-LMA showed a possible 4-layer structure of inverted polarity at 2302.30.107

seconds. This flash was 10.4 kA according to the NLDN and not disconfirmed as a PCG.
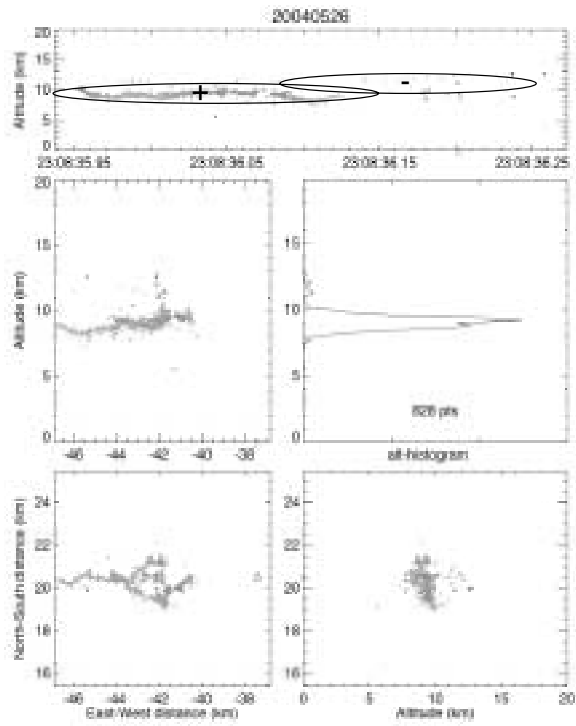
Figure 10. OK-LMA showed an inverted polarity flash at 2308.36.202 seconds. This flash was -7.4 kA according to the NLDN.