16B.6 LIGHTNING, ELECTRIC FIELD, AND RADAR OBSERVATIONS OF THE STEPS 25 JUNE 2000 STORM

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1. INTRODUCTION

The field phase of the Severe Thunderstorm Electrification and Precipitation Study (STEPS) took place in the late spring and early summer of 2000. The broad objective of STEPS was to gain a better understanding of the interactions between kinematics, precipitation particles, and electrification of severe thunderstorms in the High Plains of the United States. The High Plains region of northeast Colorado, southwest Nebraska and northwest Kansas was chosen for the study because there is a climatological maximum of storms producing predominately positive cloud-to-ground (CG) lightning in this region (Carey et al. 2003). One focus of STEPS was to understand how the charge structure in thunderstorms with mostly positive CG lightning compares with the charge structure in thunderstorms with mostly negative CG lightning.

The storm that was in the STEPS domain on 25 June 2000 was chosen for extensive study because it had mostly positive CG lightning and because electric field measurements indicated that its charge structure was inverted from that of a typical thunderstorm. Evidence of inverted-polarity charge structure within thunderstorms has recently been presented by Marshall et al. (1995), Rust and MacGorman (2002), and others. This structure is defined by Rust and MacGorman as the lowest region of charge being negative, the uppermost region being positive, and the charges in between alternating in polarity. The 25 June 2000 storm is unique in that it contains both inverted-polarity and normal-polarity charge structure and flashes.

To understand the evolution of storm structure and electrical structure involved in this case, three analysis times were chosen—0154 UTC, 0224 UTC, and 0244 UTC on 25 June 2000. During these times, two balloon-borne electric field meters were launched to collect electric field measurements through the storm. The storm was also within the 3-dimensional (3-D) range of a Lightning Mapping Array (LMA) system, which uses a time-of-arrival system to map intracloud (IC) and cloud-to-ground (CG) lightning channels [See Rison et al. (1999) and Krehbiel et al. (2000) for more information on this LMA.] Radar data were collected by the Goodland, KS WSR-88D and the NCAR/ATD S-Pol radar during the duration of the analysis period. Data from these sources along with CG location data from the National Lightning Detection Network (NLDN) are used for this study.

2. STORM OVERVIEW

2.1 *Synoptic and Mesoscale Background*

The 25 June 2000 storm formed from the combination of several storm cells that began in northeastern Colorado. A surface boundary moved westward through the STEPS domain in the morning, bringing easterly, upslope winds into the region. There was a strong east-west dewpoint gradient across eastern Colorado and western Nebraska and Kansas, but the setup was not that of a typical dryline case, as the surface winds were from the east in the dry as well as in the moist air. An approaching upper-level disturbance with a weak cold front provided enough surface forcing for the storm to develop.

Environmental conditions became more favorable for supercell formation as the day progressed. Environmental soundings were taken by the mobile GLASS units at 2326 and 2330 UTC on 24 June 2000. The hodographs indicate the environment was favorable for splitting storms. There was, in fact, a splitting storm that preceded the storm analyzed in this study. The splitting storm developed in far northwestern Kansas and split just as the main storm became organized. Although the two halves of the splitting storm died rather quickly, they did play a role in the development of the main storm. Outflow from the dying, splitting cells intersected the main storm, causing new cells to develop. The changes in storm structure at these times are reflected in both the radar data and the lightning data.

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2.2 *Polarimetric Radar Overview*

A polarimetric radar overview of the 25 June 2000 storm is presented in Fig. 1, which shows 3 km MSL S-Pol reflectivity (Z), differential reflectivity (Z_{DR}), specific differential phase (K_{DP}), and cross-correlation coefficient (ρ_{HV}) at 0226 UTC. In addition to depicting the storm at its most intense stage, it is also a time at which both balloon-borne EFMs (launched at 0154 and 0212 UTC, respectively) were in the storm. At this time, the convective cells had formed a short line with maximum radar reflectivities of between 55 and 60 dBZ. High Z_{DR} in advance of the line indicates the presence of large drops within the convective updraft, some of which may have been serving as hail embryos when lofted above the freezing level. In fact, an analysis of Z_{DR} and ρ_{HV} at 2.5 km indicates that the cell centered at X=8 km, Y=40 km may have been producing small hail. Precipitation in all other cells, however, appeared to consist entirely of moderate to heavy rain. Analyses of polarimetric variables at levels from 6.0 – 9.0 km MSL revealed fairly uniform fields with no indication of obvious microphysical features that might be associated with the cloud electrification observations.

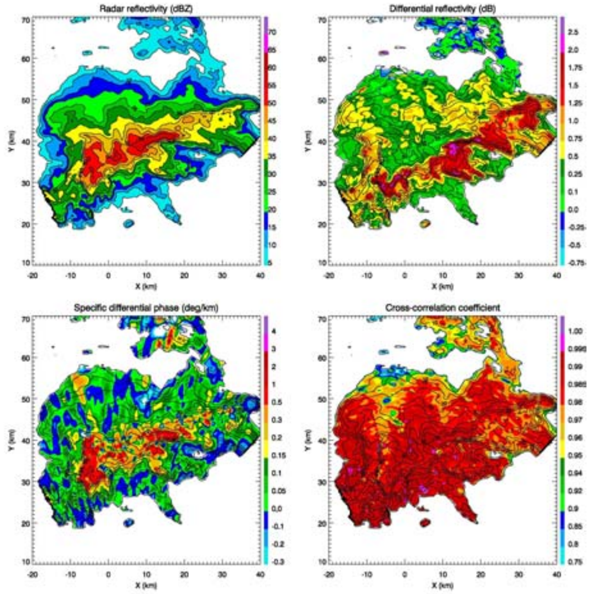


Fig. 1. Reflectivity (Z), differential reflectivity (Z_{DR}), specific differential phase (K_{DP}), and cross-correlation coefficient (ρ_{HV}) for the 25 June 2000 storm at 0226 UTC and 3.0 km MSL.

3. ELECTRICAL ANALYSIS

3.1 *Cloud-to-Ground Flashes*

As mentioned previously, the 25 June 2000 storm had predominately positive ground flashes during its lifetime. These positive ground flashes increase in number at the time when the intracloud flashes are decreasing in number (Fig. 2). Radar data indicate that the storm's intensity is also decreasing at this time.

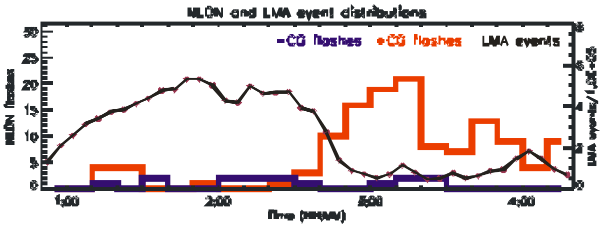


Fig. 2. Time plot of the number of negative ground flashes, positive ground flashes, and LMA events for the 25 June 2000 storm. The number of LMA events is related to the total number of intracloud and ground flashes.

Many previous studies have found that positive ground flashes occur when the lowest region of charge in a storm is positive (e.g., Brook et al. 1982; MacGorman and Neilsen 1991; Pawar and Kamra 2004), but in this case the positive cloud-to-ground flashes did not begin until negative charge appeared to develop between the positive charge and the ground. Not many flashes illuminated this negative charge region, and it appeared very shallow compared to the positive charge layer above it. This is similar to what Mansell et al. (2002) found in a numerical storm simulation. They found that positive CG flashes typically began between the lowest region of negative charge and the lowest region of positive charge.

3.2 *LMA-inferred Charge Structure*

The charge structure of the storm as inferred from IC flashes recorded by the LMA is interesting for several reasons. First, the charge structure differed from one part of the storm to another at any given time. These structures ranged from two to four regions of charge, and there were up to four different structures in the storm at one time. The charge structures often changed over time as well. To demonstrate the changes in charge structure that took place, the storm has been divided into four sections (A through D), as shown in Fig. 3. The sections were chosen subjectively based on charge and storm structure and were examined through time for changes in charge structure.

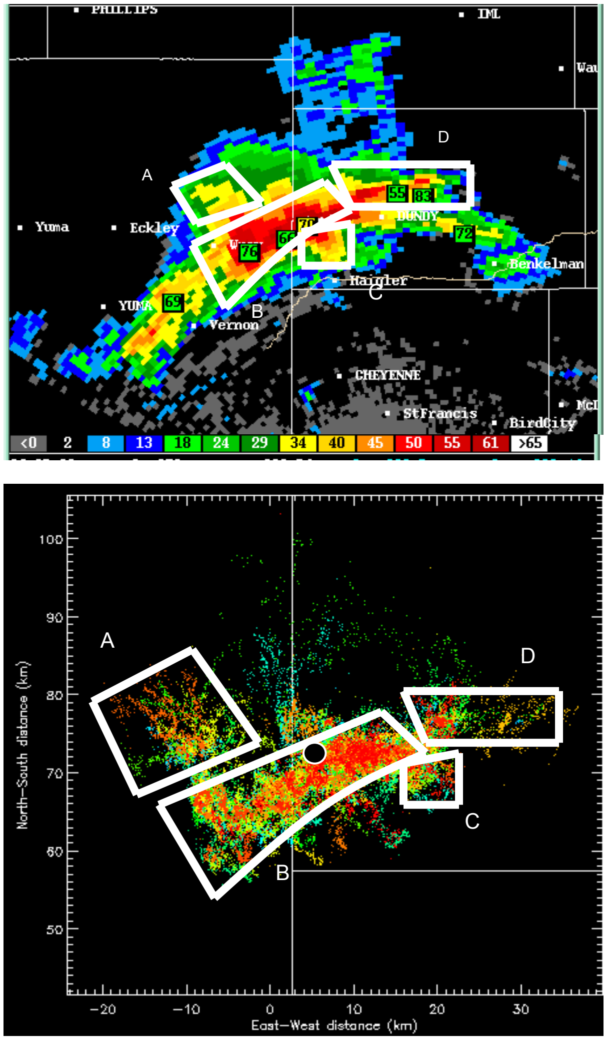


Fig. 3. (a) Sections A through D are marked on base scan reflectivity from the Goodland, KS WSR-88D at 0224:13 UTC 25 June 2000. (b) One minute of LMA data (bottom) centered on the time of the radar base scan. The black circle indicates the location of a positive CG flash.

Each section, A through D, had a different charge structure depending on the analysis time. At times, the charge structures were the same in more than one section, but this was not always the case. A summary of the charge structures in each of the four regions at the three analysis times is shown in Fig. 4. Such a variety of charge structures in the same storm has never before been documented.

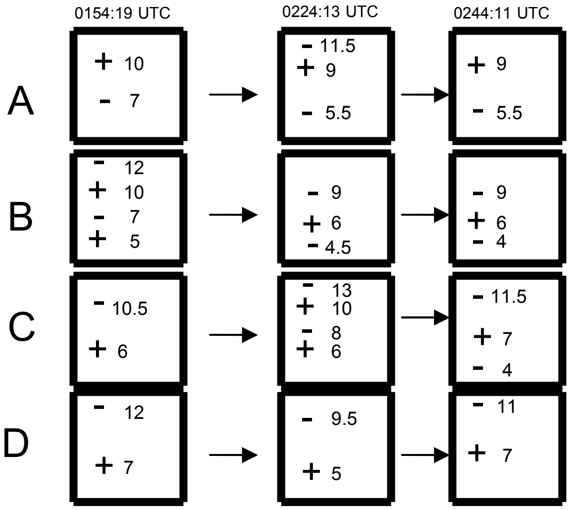
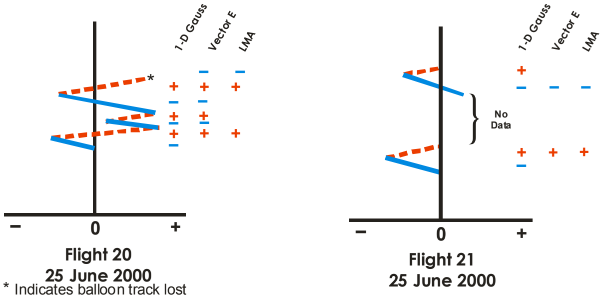


Fig. 4. A summary of the charge structures in each section at the three analysis times. The charge polarity and center height are indicated. All heights are given in kilometers relative to MSL.

3.3 *Electric Field Analysis*

Two balloon-borne electric field meters were launched into the storm to collect electric field data. The one-dimensional approximation of Gauss's law (1-D Gauss) method (see Schuur et al. 1991) and 3-D electric field vectors (see Rust et al. 2004) were used to analyze the electric field data and determine charge structure near the balloons' paths. There are discrepancies between charge structures determined from 1-D Gauss, the 3-D vectors, and the LMA-inferred charge for both flights (Fig. 5).



Flight 20
25 June 2000

Flight 21
25 June 2000

* Indicates balloon track lost before out of cloud.

Fig. 5. Stylized profiles (full and partial) of vertical electric field (E_z) versus altitude. No scaling is implied, although the sketches are the approximate shape of the profiles. The profiles depicted are for the in-cloud portion of the sounding, so all peaks in E_z and inferred charges are in the cloud. The * indicates that the **E** data ceased before the instruments were out of cloud top. Adapted from Rust et al. (2004).

The difference in inferred charge structure depending on the analysis technique can be reasonably accounted for in some instances. The 1-D Gauss method indicates more charge regions than the other two methods but also has more assumptions applied to it than the other methods. These assumptions are invalid at times. Also, the LMA method cannot detect charge regions that do not contain lightning. Finally, the electric field vectors in combination with the other two methods help to resolve lightning-deposited charge and complex charge geometries. Each method of charge detection has different strengths and weaknesses; and, therefore, each indicates a charge structure different from the others.

4. DISCUSSION AND SUMMARY

The 25 June 2000 storm of STEPS was interesting in several ways. The majority of the ground flashes produced by the storm lowered positive charge to ground. The lowest charge region at the time of the ground flashes was negative, and the timing of them coincided with the downward trend in total lightning flashes. Also, different charge structures existed within the storm at the same time, and those charge structures changed over time.

From electric field measurements taken by the balloon-borne electric field meters, three charge profiles were indicated using three different charge analysis techniques. In the past, the 1-D Gauss analysis method has been heavily relied upon to infer thunderstorm charge structure; however, its limitations become apparent when compared with the other techniques. The pros and cons of each technique need to be weighed as the charge analysis is being done. The best method of charge analysis seems to be to use all three methods together to converge on a best guess of the charge structure.

5. ACKNOWLEDGMENTS

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