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LIGHTNING AND ELECTRICAL STRUCTURE OF A HEAVY-PRECIPITATION SUPERCELL STORM DURING TELEX

Don MacGorman[1,2], Kristin Kuhlman[2,3], David Rust[1,2], Mike Biggerstaff[2,3], Paul Krehbiel[4], and Bill Rison[4]

[1]NOAA/National Severe Storms Laboratory, Norman, Oklahoma, USA
[2]Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma and National Severe Storms Laboratory, Norman, Oklahoma, USA
[3]School of Meteorology, University of Oklahoma, Norman, Oklahoma, USA
[4]New Mexico Institute of Mining and Technology, Socorro, New Mexico, USA

1. INTRODUCTION

The Thunderstorm Electrification and Lightning Experiment (TELEX) observed a heavy-precipitation (HP) supercell storm in central Oklahoma on 29 May 2004. In a HP supercell storm, the initial location of the mesocyclone, which is the parent rotation of tornadoes, is always embedded well within the precipitation of the storm, instead of being initially on the edge of the storm (as in classic and low-precipitation supercell storms). Two 5-cm wavelength mobile Doppler radars were positioned near the storm and collected volume scans every 3 minutes for 3 h beginning as the storm became supercellular. The storm had supercell characteristics for the entire analyzed period. The Oklahoma Lightning Mapping Array provided three-dimensional data as the storm intensified to become a supercell and while it produced several tornadoes and provided two-dimensional data from the time of storm initiation in western Oklahoma. A 10-cm wavelength polarimetric radar (not analyzed here) also provided data for much of this period.

2. DATA

The main tools used to investigate lightning in this study are the Oklahoma Lightning Mapping Array (LMA) and the National Lightning Detection Network (NLDN). As described in Krehbiel et al. (2000), the LMA maps total lightning of thunderstorm in three dimensions. As a lightning flash propagates it emits very high frequency (VHF) radiation; the LMA uses a time of arrival technique synchronized by the Global Positioning System to locate these sources. The Oklahoma LMA consists of 11 antennas spaced 10-22 km apart and centered approximately 30 km west of Norman, OK. The time and three dimensional location of each source is determined by the difference in the time-of-arrival between pairs of stations. Tens to thousands of points may be mapped by the LMA for any given lightning flash. Over the period of a few minutes the LMA can give detailed maps of the total lightning activity for the storm.

In addition, two 5-cm mobile radars provided dual-Doppler radar data, and in-situ measurements were made of winds, standard thermodynamic parameters, and the electric field by using upsondes and balloon-borne electric filed meter. Two separate successful launches were made into the 29 May 2004 storm and both traversed the anvil region.

2.1. Storm overview

On 29 May 2004 multiple storms initiated on the dryline located near the western Oklahoma Texas border. The first cells moved quickly off the dryline toward the northeast into an area of greater moisture in the boundary layer, with CAPE values around 4000 J kg. The cell farthest south became dominant between 2230 and 2300 UTC. By 2330 UTC, it had developed supercell characteristics, including a hook echo and its motion had turned more easterly. By 2345, the cirrus shield from the anvil on the southern storm reached over 300 km away from the main core and reflectivity of approximately 25-30 dBZ remained fairly steady in much of the anvil as the storm moved across OK. The reflectivity in the anvil of the northern storm decreased quickly as the parent updraft weakened just after 0010 UTC. The southern storm continued to intensify through 0030 UTC and then continued producing tornadoes sporadically as it moved eastward through the state, until it finally dissipated near the Arkansas border around 0800 UTC.

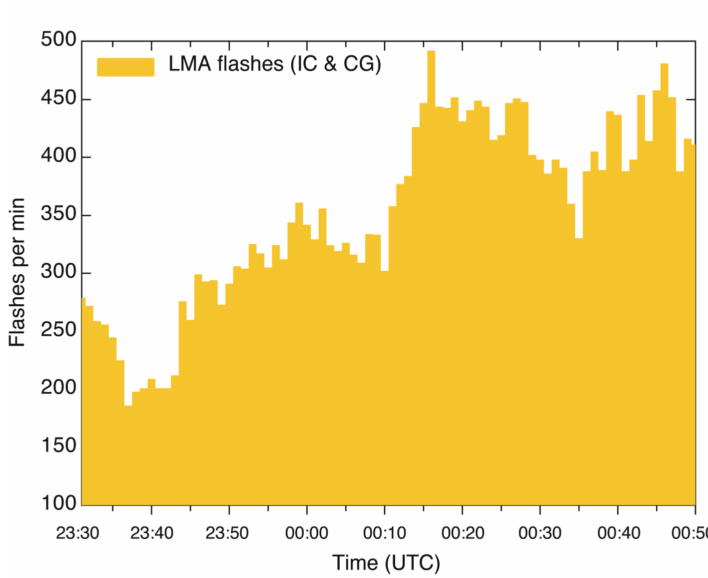

Figure 1: Total Flash rate for 29 May 2004.

2.2. Lightning activity

The total flash rate from 2330-0050 UTC, as shown in Fig. 1, includes both storms, the northern storm which had previously shown supercellular characteristics and the southern storm which was dominant during the entire analyzed period. The flash rates ranged from a minimum of 200 flashes per min around 2340 UTC to a maximum of almost 500 flashes per min at 0016 UTC. Flashes of less than 10 mapped points were not included in this calculation. The majority of these flashes occurred around and downshear of the updraft core and were initiated around 10 km MSL. An examination of 56 individual flashes that occurred within 5 seconds beginning at 0017:13 UTC (Fig. 2) depicts typical initiation heights and propagation length and location of flashes within the core of the supercell. The extent of flashes mapped by the LMA within the main storm core was usually no longer than 5-10 km horizontally and 3 km vertically (the extent of many flashes was even shorter).

Flashes occurring in the anvil, however, typically had much larger horizontal extent than flashes in the main body of the storm. . One of the most impressive examples of lighting activity in the anvil region occurred at 2321 UTC. Fig. 3 shows the CG location relative to the storm reflectivity and the LMA mapped lightning. The CG initiated just below 10 km MSL, in a region of the interaction between the anvils of the northern and southern cells roughly 80 km downshear from the main core. The lightning channels then followed regions of charge as they propagated

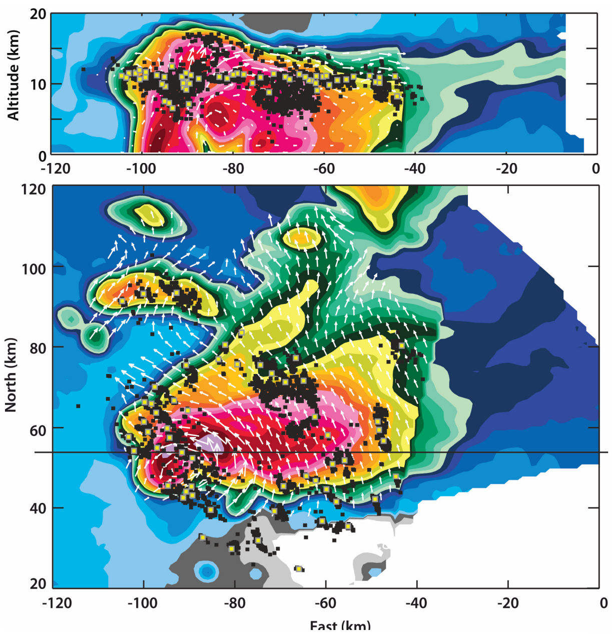

Figure 2: 56 flashes occuring within the 5 second period of 00:17:13-00:17:18 UTC, superimposed on reflectivity and synthesized horizontal winds from the SMART-R Doppler radar volume scans beginning at 0016 UTC. LMA VHF source pointes indicated by black squares and initiation points depicted by yellow squares. Top: Vertical profile along 55 km north. Bottom: z=2.8 km AGL.

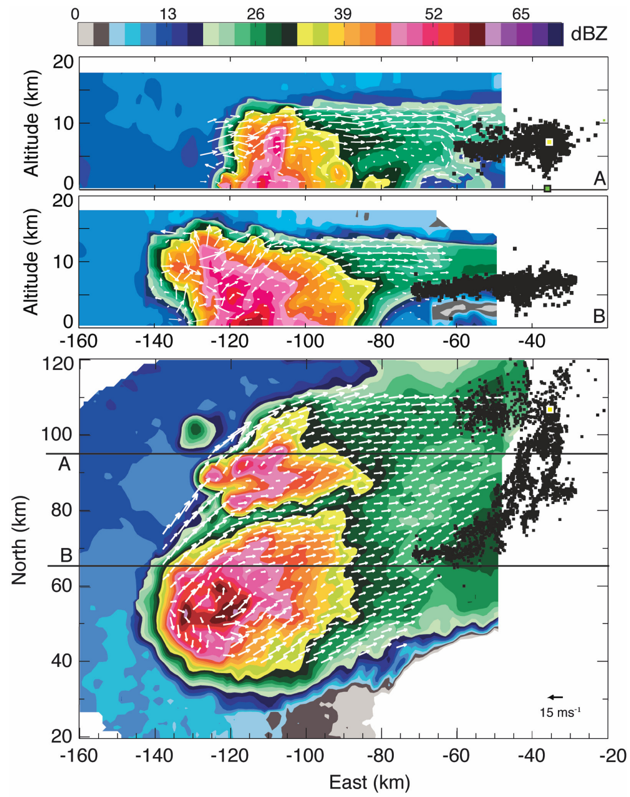

Figure 3: As in Fig. 2 for SR dual-Doppler analysis beginning at 2321 UTC at 8.3 km, LMA sources for flash from 23:21:45.2-23:21:46.9

back towards the core of the storm, a distance of approximately 50 km, , within 1.2 seconds. Many other negative CG flashes were initiated in the anvil of the storm more than 40 km from the storm core, though most of these were somewhat closer to the storm and had shorter channels.

The charge structure of the storm was determined by using the LMA sources and noting that the LMA preferentially maps negative leaders (i.e., positive charge) because negative leaders produce much more noise than positive leaders at the radio frequencies used by the LMA. Surrounding the main updraft core at least four layers of charge were active at different periods. Progressing away from the core into the anvil only 2 to 3 layers of a charge were evident from the lightning activity (Fig. 4). The majority of lightning was initiated near 10 km, between an upper negative charge and mid-level positive charge. In the area surrounding the main updraft an additional negative charge region was sometimes evident between 8-9 km and below 5 km with positive charge in the middle. This middle layer of positive charge seemed to be at least partially linked to the positive charge region extending out into the anvil region. Only two layers of charge were evident in lightning activity in the distant anvil: a positive charge below 10 km and a negative charge above. Charge layers inferred from the Electric Field Meter (EFM), which traversed the anvil, agree with the charge analysis from lightning activity: positive charge existed between 7 and 10 km MSL with a smaller negatively charge region above and an additional negatively charged region below the positive charge. Measurements of the vertical electric field within the anvil ranged up to 90 kVm^{-1}.

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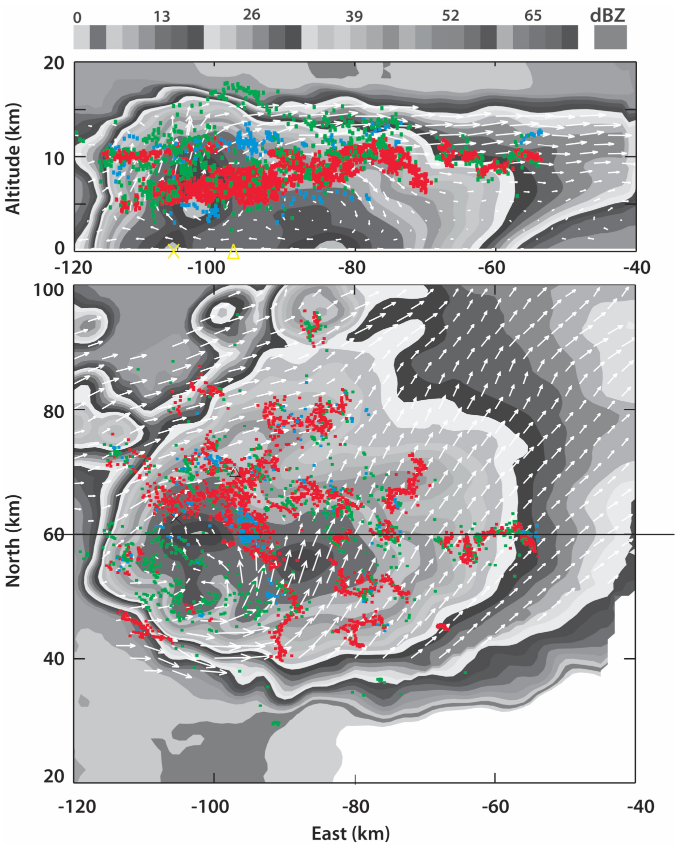

Figure 4: Charge analysis from flashes occuring within the 5 sec period of 23:52:53-23:52:58 UTC. LMA VHF source points occurring in positive charge indicated by red squares and negative charge by blue squares. Green squares are undetermined. DBZ and wind vectors are from a dual-doppler analysis beginning at 2354 UTC.

3. DISCUSSION AND CONCLUSIONS

The charge structure inferred from lightning activity for this storm provides a unique insight into thunderstorm charging. The electrical structure of the long-lived southern storm seemed to have an inverted vertical polarity, with graupel and hail carrying positive charge and cloud ice carrying negative charge to the anvil. The electrical structure of the dissipating northward moving storm had normal polarity, with graupel carrying negative charge and cloud ice carrying positive charge into the anvil. The anvil of the northern storm was lower than the anvil of the southern storm and extended in a more eastward direction that crossed the southern anvil. The interaction of these two anvils, at different heights, provided a unique charge structure, which maximized the electric field in this region and allowed lightning to be initiated in the anvil tens of kilometers from the storm core, an unusual situation. The criss-crossing at different heights allowed for a tripole charge distribution with a main positive in mid-levels and negative charge regions above and below that height. Lightning commonly initiated where the anvils crossed, about 60 km away from the core of the supercell storm, throughout this period of interaction between the two storms.

Note that this does not explain all lightning initiation in the anvil far from the storm core. Lightning was initiated in the anvil at comparable distances from the core in both the northern and southern supercells at times when the anvil of the other storm either did not exist or was nowhere near. Yet, without charge generation in the anvil, one would expect charge densities and electric field magnitudes gradually to decrease with distance into the anvil. Thus, it appears likely that the charge needed to initiated lightning at these other times was generated in the anvil itself.

4. ACKNOWLEDGEMENTS

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