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SPATIAL DISTRIBUTION OF LIGHTNING DATA RELATIVE TO KINEMATICS IN A HP TORNADIC SUPERCELL DURING TELEX

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ABSTRACT

The Thunderstorm Electrification and Lightning Experiment (TELEX) observed a high-precipitation tornadic supercell storm on 29 May 2004. The available observation systems included the Oklahoma Lightning Mapping Array (LMA), the KOUN S-Band polarimetric radar, and two mobile SMART-R C-Band radars. Thunderstorm charge is thought to be produced by microphysical interactions between graupel and cloud ice followed by differential sedimentation to produce regions of net charge. If so, the kinematics of the storm govern spatial relationships between regions of microphysical charging and the location and geometry of those charge regions.

On 29 May 2004, lightning flashes near the core of this storm, although quite frequent, tended to have shorter duration and smaller horizontal extent than typical flashes in other storms having less frequent lightning. We suggest that this is due, at least in part, to small pockets of opposite charge lying in close proximity to each other. Thus, each polarity of lightning leader propagates only a relatively short distance before reaching regions of unfavorable electrical potential. In the anvil, however, lightning extended tens of kilometers from the reflectivity cores in roughly horizontal layers, consistent with the charge spreading through the anvil in broad sheets. Though lightning has been previously observed in anvils, typically this lightning is initiated in or near the core of the storm and extends out into the anvil. Yet, in the 29 May 2004 storm, flashes initiated in the anvil region and the subsequent leaders progressed back towards the core of the storm. Some of these flashes were negative cloud-to-ground flashes that initiated over 50 km away from the core and struck ground beneath the anvil close to the initiation point. We hypothesize that interaction between the anvil of this supercell and a somewhat lower anvil of opposite polarity from a weaker left-moving cell to the north was responsible for initiating this lightning.

1. INTRODUCTION

Convective storm kinematics effect not only the total flash rate of storms (Lang et al. 2004; Wiens et al. 2005), but how the leaders of the individual flashes progress. In highly turbulent storms, it is likely that smaller pockets of opposing charge will be in close proximity to each other, initiating lightning but not allowing for lightning to travel long horizontally. Also, frequent lightning may quickly neutralize small areas of charge through which subsequent lightning is unlikely to propagate. This would inhibit future flashes from progressing long distances. It is possible that the very large flash rate observed in the 29 May supercell relative to most storms was aided by the small extent of flashes that were observed. This issue will be examined by analyzing mapped lightning flashes for periods having greatly different flash rates and comparing flashes in this storm with flashes in smaller, less severe storms.

In addition, the maximum density of lightning leaders should reflect the locations of which charge is replenished most rapidly, and this would be expected just downshear of the main updraft core. In an analysis of lightning in a supercell storm, Ray et al. (1987) found that the majority of lightning tended to be located downshear from the main updraft core in the reflectivity core. It was surmised by Ray et al. (1987) that the lightning activity reflected the wind field within the storm. Similar to Ray et al. (1987), first analyses of observations from the 29 May supercell depict most surges in lightning activity are located downshear from the main updraft, with virtually no activity within the updraft core and reduced activity upshear from the updraft core. The maximums in lightning activity are expected to reflect the locations of replenishment of charged hydrometeors, which would

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be just downshear of the main updraft core.

The kinematics of the anvils of supercell storms are quite different from the storm core. A thunderstorm anvil is formed as bouyant air within the thunderstorm updraft reaches its equilibrium, and the air is forced to spread out horizontally. The result is a flat shaped cloud similar in appearance to a blacksmith's anvil. The asymmetry of the thunderstorm anvil is due to environmental winds pushing the diverging air downshear the updraft downwind. In the central plains, anvils often extend over 100 km downshear from the main convective core. Lightning activity within anvils is ordinarily confined to regions closest to the storm core where the electric field is generally greater, with flashes initiating near the core and following the layers of charge horizontally downshear into the anvil. The 29 May 2004 supercell produced lightning in this fashion, but also had an unusually high amount of lightning which initiated over 50 km away from the core and propagated back towards the storm core.

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. Hundreds 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, 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 through the anvil region.

a. Storm Background

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 towards the northeast into an area of greater moisture in the boundary layer and CAPE values around 4000 J kg. The cell farthest south became dominant between 2230 and 2300 UTC, developing supercell characteristics, including a hook echo, with motion becoming more easterly by 2330 UTC. By 2345, the cirrus shield from the anvil on the southern storm reached over 300 km away from the main core and reflectivity for the anvil, approximately 25-30 dBZ, remained quasi-steady state as the storm moved across OK. The reflectivity from the anvil on the northern cell decreased quickly as the cell's updraft weakened just after 0010 UTC. The supercell continued to intensify through 0030 UTC and remained strong moving eastward through the state until finally dissipating near the Arkansas border around 0800 UTC.

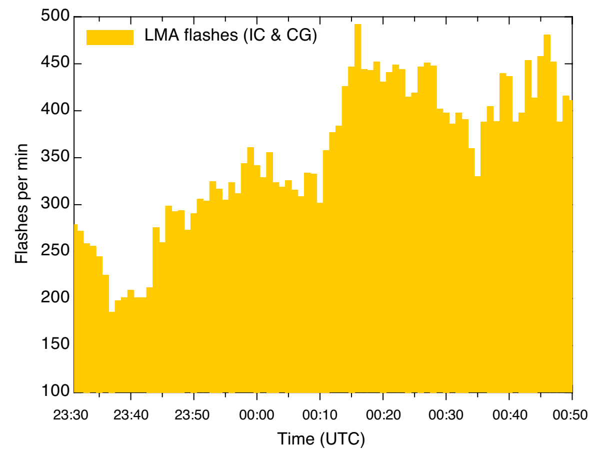

Figure 1: Total Flash rate for 29 May 2004.

b. Lightning Activity

The total flash rate (TFR) from 2330-0050, as shown in Fig. 1, includes both storms–the northern storm that had previously shown supercellular characteristics and the southern storm which was dominant during the entire period. The TFR ranges from a minimum of 200 flashes per min around 2340 UTC to a maximum of near 500 flashes per min at 0016 UTC. Flashes of less than 10 points were not included in this calculation. The majority of these flashes occurred around the updraft core and just downshear, initiating around 10 km. An examination of 56 individual flashes that occurred within 5 seconds starting at 0017:13 UTC (Fig. 2) depicts typical initiation heights and propagation length and location of flashes within the core of the supercell. The leader length, as determined from LMA source continuity, within the area surrounding the core was generally no longer than 5-10 km horizontally and 3 km vertically (the extent of most flashes was quite a bit shorter).

Flashes occurring in the anvil, however, were typically of much longer extent. 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

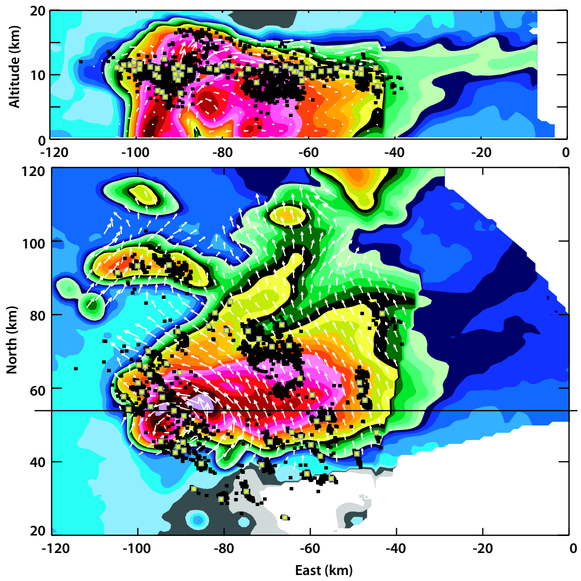

Figure 2: 56 flashes occuring within the 5 second period of 00:17:13-00:17:18 UTC, superimposed on reflectivity and synthesized horizontal winds from the SMART-R Doppler radar volume scans beginning at 0016 UTC. LMA VHF source pointes indicated by black squares and initiation points depicted by yellow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

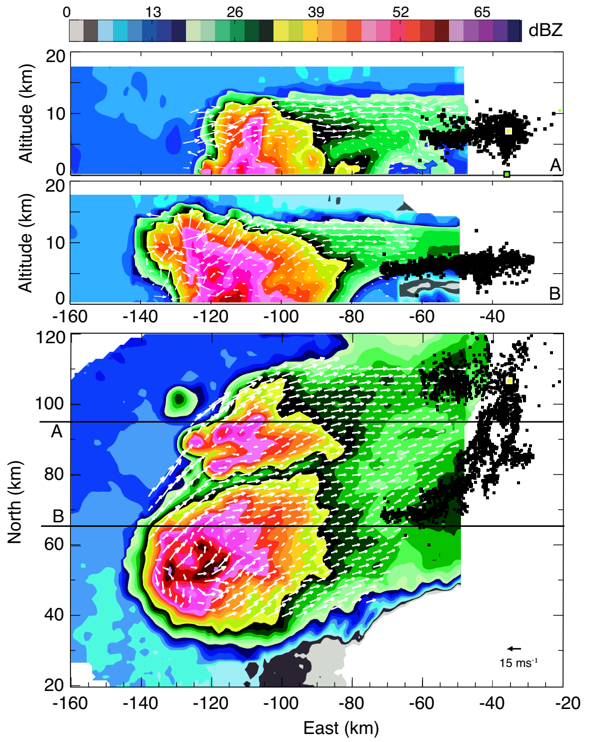

Figure 3: As in Fig. 2 for SR dual-Doppler analysis beginning at 2321 UTC at 8.3 km, LMA sources for flash from 23:21:45.2-23:21:46.9

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 back towards the core of the storm, a distance of approximately 50 km, within 1.2 seconds. Numerous other negative CG flashes initiated in the anvil of the storm, though few were at the this distance or displayed leaders of the length of this particular flash.

The charge structure of the storm is determined using the LMA sources, noting that the LMA preferentially maps negative leaders (i.e., positive charge) because negative leaders produce much more noise at the radio frequencies used by the LMA than positive leaders. Surrounding the main updraft core at least four layers of charge are active at different time periods, progressing further away from the core only 2 to 3 layers of a charge are evident from the lightning activity (Fig. 4). The majority of lightning is 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 is sometimes evident between 8-9 km and below 5 km with positive charge in the middle. This mid-layer of positive charge seems to at least partially linked to the positive charge region extending out into the anvil region. Only two layers of charge are evident through 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 cloud ranged from 20 to 90 $kV\ m^{-1}$.

3. DISCUSSION AND CONCLUSIONS

The charge structure inferred from lightning activity for this storm provides a unique insight into thunderstorm charging. While the electrical structure of the main storm (the 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 weaker, northward moving storm had normal polarity, with graupel carrying negative charge and cloud ice carrying positive charge into the anvil, which was lower in altitude and extended in a more eastward direction that crossed the anvil of the main storm. The interaction of these two anvils, at different heights, provided a unique charge structure which maximized the electric field in this region allowing for a higher activity than "normal" for lightning in the anvil region. 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

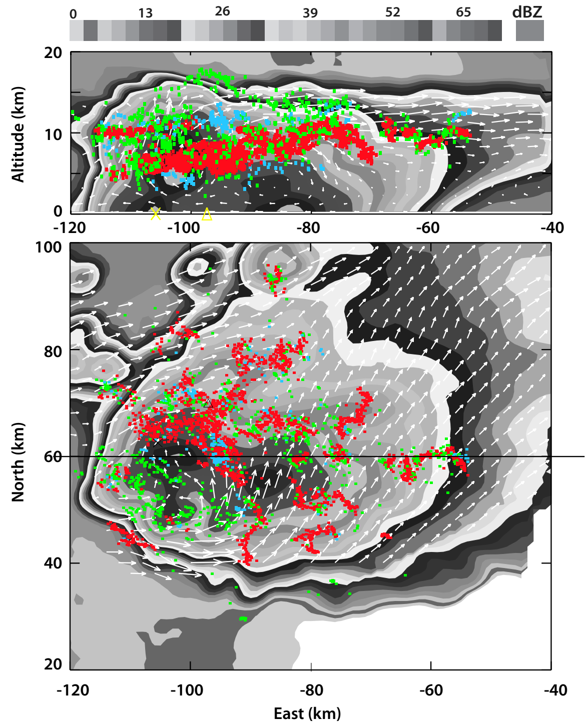

Figure 4: Charge analysis from flashes occuring within the 5 second period of 23:52:53-23:52:58 UTC. LMA VHF source points occuring in positive charge indicated by red squares and negative charge by blue squares. Green squares are undetermined. DBZ and wind vectors are from a dual-doppler analysis beginning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

between the two storms. Although many more flashes initiated within the core of the storm, this lightning had much shorter horizontal extent than lightning initiating within the anvil. This lightning frequently initiated in close proximity to other flashes, representative of charge replenishment from the updraft region.

3. ACKNOWLEDGEMENTS

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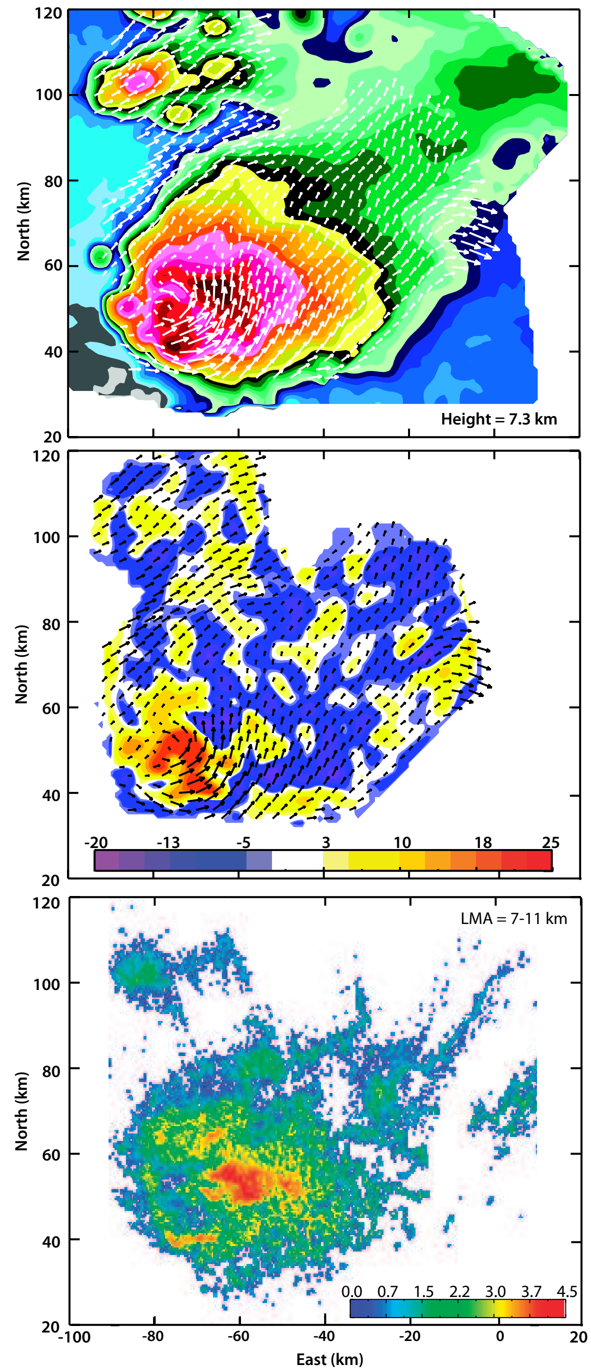

Figure 5: (a) Reflectivity and synthesized horizontal winds from the SMART-R Doppler radar volume scans beginning at 0038 UTC. (b) Vertical velocity from and horizontal winds from the dual-doppler synthesis at 7.3 km AGL. (c) LMA VHF source density from 7 to 11 km.