LIGHTNING EVOLUTION IN THE SEVERE STORMS IN TEXAS ON 7 APRIL 2002

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ABSTRACT: The severe Texas storms of 7 April 2002 are investigated using GOES 8, NLDN, and 3D total lightning data from the LDAR II network in the Dallas–Ft. Worth region. Storms developed from an unstable surface boundary and quickly evolved into tornadic supercells, later merging into a squall line with flash floods and large hail. Satellite data reveal possible predictive potential of cloud top structures prior to tornado formation. The 3D lightning data characterizes the storms as normal polarity dipoles with main charge layers at about 7 and 11 km AGL. Horizontal flash extent and branching both increase as the squall line develops a trailing stratiform part.

INTRODUCTION

On 7 April 2002, a severe storm event developed over the Texas panhandle which showed interesting storm evolution and transition phenomena, as well as remarkable lightning activity. The thunderstorms developed over west Texas as a shortwave trough was advancing out of the southwest USA. Atmospheric conditions were favorable for severe thunderstorm formation. A warm front over north Texas, a dryline over extreme west Texas, and numerous outflow boundaries over northwest and north–central Texas from overnight convection were present during the late morning and early afternoon. These surface features, combined with temperatures in the range 23–26 °C, moderate instability, sufficient deep layer shear, and the left exit region of a 300 hPa jet streak, enabled rapid thunderstorm development after 1700 UTC. The first developing storms were isolated supercells, but after 2000 UTC, these quickly organized along a line and later transformed into a large squall line from south of San Antonio to north of Dallas, moving east-southeasterly. The squall line had developed to the east of the dryline, accompanied mainly by damaging winds and hail, sometimes up to 4 cm in diameter. Several tornadoes were reported as well, most notably the Throckmorton tornado. Its time and location are depicted in Fig. 1 by the asterisk.

The storm that produced this tornado developed as an isolated thunderstorm around 1925 UTC, ahead of the developing squall line. The storm quickly strengthened, and began to cross an old, persistent outflow boundary, noted by storm chasers as a thin line of wispy scud. Just west of Haskell (cf. Fig. 1 for places mentioned in the text), the first author observed this cell from 1917–1945 UTC as it produced hail of at least 2.5 cm in diameter when crossing highway 380. Just after 2000 UTC, a severe thunderstorm warning was issued for that cell in Throckmorton County. By 2028 UTC, a well defined, very low wall cloud formed, with scud rapidly ascending into the base. At 2029 UTC, the National Weather Service issued a tornado warning for this cell, and at 2031 UTC, the first condensation funnel formed and reached to the surface. Storm chasers noted that the rear–flank downdraft (RFD) of the storm was very warm, probably even slightly warmer than the storm's inflow (e. g. Markowski, 2002). The tornado continued to move east–northeast and developed a large funnel. A few minutes later, it entered its rope stage and then dissipated soon after. The tornado lasted at least 19 min, from 2031 to 2050 UTC. Another large funnel was present to the north of the old one, but it did not manage to develop any further.

Figure 1: Map showing Oklahoma–Texas border region, the Throckmorton tornado site (asterisk), and the Dallas–Ft. Worth metroplex where the LDAR II network is located.

Storms on that day were also effective rain producers. Within 24 h, accumulated precipitation was up to 75 mm in Throckmorton county. In the Dallas–Ft. Worth (DFW) area, the first author observed the storms in the later evening hours of 7 April (roughly 2330 to 0100 UTC). Here, even heavier precipitation led to flash flooding. Rainfall accumulation was 81 mm at DFW airport, surpassing the 1900 mark of 78.5 mm in 24 h, and parts of north Texas received up to 127 mm precipitation. At this stage, the storms were accompanied by extremely intense lightning activity.

Our analysis focuses on the characteristics of lightning evolution during the transition from isolated supercells to the mesoscale convective system. To detect and determine systematic changes of flash characteristics in these storms can contribute to our understanding of lightning formation related to storm severity.

DATA DESCRIPTION

Cloud-to-ground lightning (CG) activity of the storms from 7 to 8 April was monitored by the two-dimensional National Lightning Detection Network (NLDN, cf. Cummins et al., 1998). In the Dallas–Ft. Worth region, highly–resolved three–dimensional total lightning data from the local LDAR-II network (e. g. Cummins et al., 2000; Demetriades et al., 2002a,b; Demetriades and Murphy, 2003) operated by Vaisala were available. The DFW LDAR II network normally consists of 7 sensors with 20–30 km baselines. However, on 7 April the network was somewhat comprised because two sensors were not operational. The LDAR II detects pulses of radiation (“sources”) produced by the electrical breakdown processes of lightning in 5 MHz VHF bands currently centered at frequencies from 61–64 MHz. The VHF sources are used to reconstruct the propagation of individual intracloud (IC) or CG flashes in three dimensions with a time–of–arrival procedure (cf. MacGorman and Rust, 1998). The DFW LDAR II network can normally map flashes in 3D within approximately 150 km of the network center, degrading in performance with increasing range. On 7 April, the network did not perform this well because of the two non–operational sensors. Vaisala is currently working on modeling the expected network performance on that day. In addition, GOES 8 satellite data have also been recorded to be able to relate lightning activity to cloud top features. Total data availability is as follows: **NLDN:** Flash data giving 2D location, peak current, polarity, and stroke multiplicity, covers the timespan from 7 April, 0000 UTC to 8 April, 1852 UTC. **LDAR:** 3D location and time information from individual lightning VHF sources within 150 km range around Dallas–Ft. Worth International Airport are available from 7 April, 0015 UTC to 8 April, 0600 UTC. **GOES:** GOES 8 channel 1 to 5 data with 4 km resolution cover the period from 7 April, 1200 UTC to 9 April, 1200 UTC.

RESULTS

GOES 8 channel 4 (longwave IR) enhanced satellite data shown in Fig. 2 document the evolution from individual cells on a surface boundary (arrow in Fig. 2a, cf. Massura and Hansing, 2003) to a line of severe thunderstorms (Fig. 2b). Arrow 1 indicates a ring–like elevated cloud top for the Throckmorton cell anvil. Arrow 2 points to its rapidly overshooting top, taking on a V–shape six minutes before the tornado.

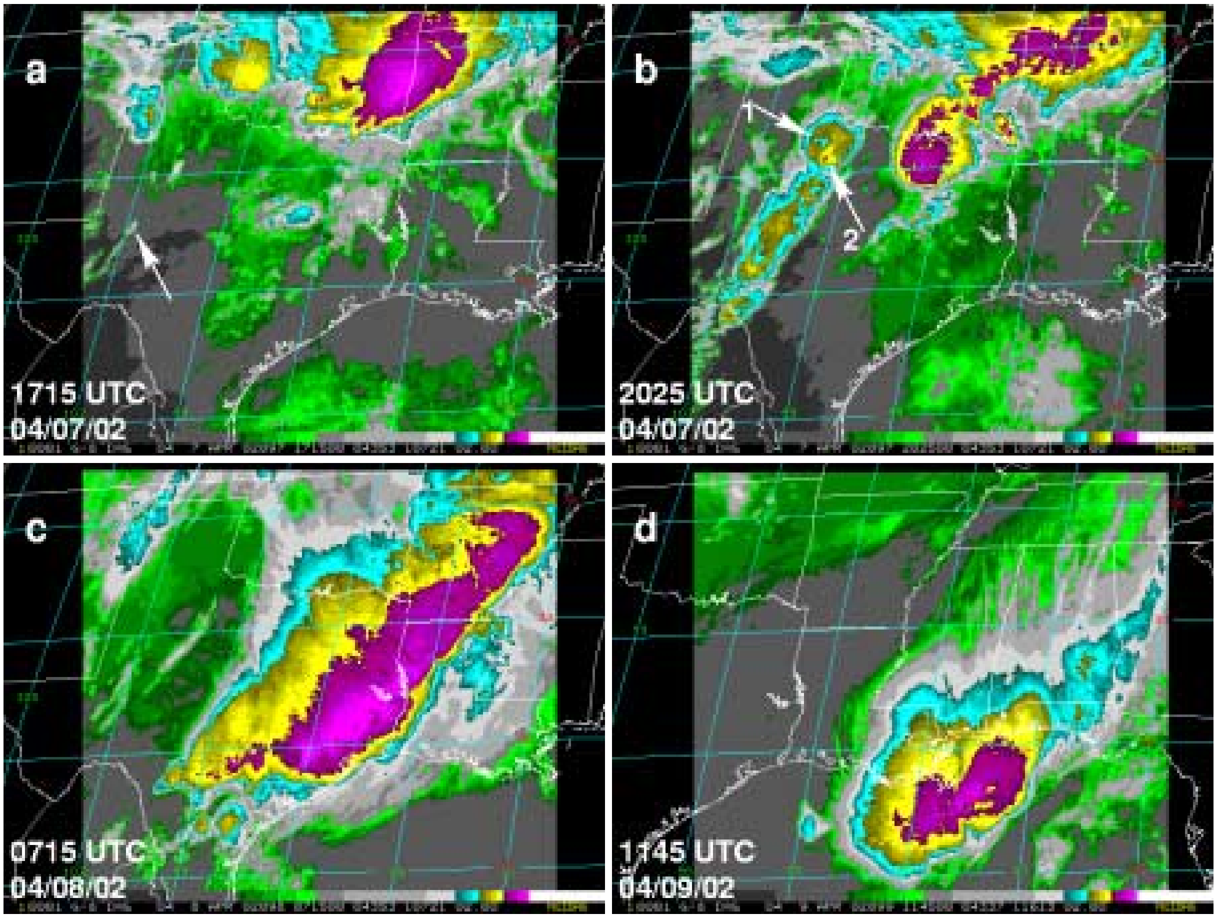

Figure 2: GOES 8 images from 7 April, 1715 UTC (a) to 9 April, 1145 UTC (d). In panel d), the data area has been shifted to the east to track the MCS. Arrow in a) indicates convective initation along the boundary layer line, in b) arrow 1 shows the ring–like anvil top structure, and arrow 2 the V–shaped cloud overshoot near Throckmorton.

During the night and the following day, the squall line merged with the remnants of a precipitating system in southeast Oklahoma (Fig. 2c) and evolved into an east–southeastward–moving mesoscale convective system (MCS), affecting the Texas coastline and moving further offshore, where the system finally decayed halfway to Florida on 9 April, cf. Fig 2d.

The NLDN data showed a strong increase in CG lightning activity during storm development: For the region of Fig. 2, the numbers of CG flashes per hour were about 250 between 1900 and 2100 UTC, 380 h^{-1} between 2100 and 2200 UTC, and 550 to 685 h^{-1} up to 0100 UTC on 8 April. After that, lightning activity dropped below 200 h^{-1} again.

The LDAR II lightning data were analyzed in the period from 1900 UTC on 7 April to 0200 UTC on 8 April. This covers the period of the Throckmorton tornado (which however is slightly out of the 3D range for the DFW LDAR II), and the merging of the individual storms to the large squall line and the lightning activity in the trailing stratiform part of the squall line progressing to the Gulf of Mexico.

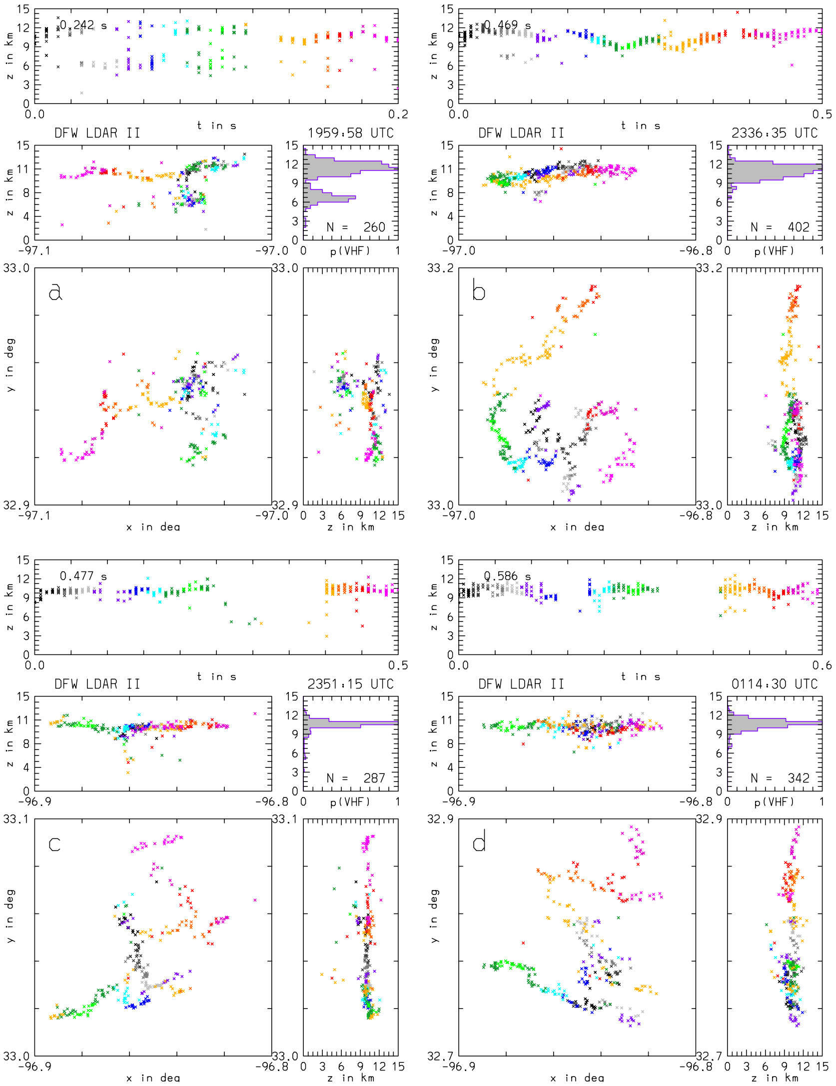

Figure 3: Four individual IC flashes from the DFW LDAR II network: a) 1959 UTC, b) 2336 UTC, c) 2351 UTC (7 April), d) 0114 UTC on 8 April.

Fig. 3 gives four examples of individual flashes from this period. Panels a–d show the flashes at 1959, 2336, 2351, and 0114 UTC in projections to horizontal and vertical planes, give a height distribution of the detected VHF signals, and indicate the temporal evolution of the flashes in a time–height plot at the top of each flash graph.

At 1959 UTC storms were still strongly developing. The corresponding IC flash in Fig. 3a shows clear bi–level structure with main levels of flash propagation at about 7 km and 10–12 km AGL, most likely corresponding to the main negative and positive charge layers, respectively (Krehbiel et al., 2002). Similar observations of bi–level IC flashes were made in European supercell storms (e. g. Dotzek et al., 2001) with an interferometric VHF 3D total lightning detection system (Defer, 1999).

When the storms were close to the Dallas–Ft. Worth Metroplex, IC flashes grew in horizontal extent and in their degree of branching. Bi–level height distributions were less pronounced now. Instead, VHF signals from IC flashes were more likely confined to the positive charge layer in the storms (Fig. 3b), sometimes leading to very narrow peaks in the flash histograms, as for instance for the flash at 2351 UTC in Fig. 3c (Krehbiel et al., 2002). Only few VHF sources can usually be mapped from streamers propagating through negative charge, compared to those in the positive charge layer. With further storm propagation to the east, the Dallas region was located under the stratiform anvil region of the squall line. The IC flash detected at 0114 UTC (Fig. 3d) shows the largest horizontal extent of the flashes and its VHF sources are also confined to the main positive charge region at about 11 km AGL.

Aside from such highly branched flashes extending over several tens of kilometers, a significant fraction of detected VHF sources grouped into smaller flashes with a low number of VHF sources. Some of these only consisted of single isolated VHF emissions. Care must be taken in interpreting these extremely brief electrical discharges, as only 5 LDAR II sensors were operational on 7 April, resulting in a lowered 3D reconstruction performance. However, these short duration events (sometimes called "baby lightning") are also found with interferometric 3D lightning mapping techniques (cf. Lang, 1997; Defer, 1999; Dotzek et al., 2001) and appear to be physically sound phenomena (Mazur, 2002, pers. comm.). Yet their role, possibly as indicators of impending larger lightning discharges, is not yet fully understood.

CONCLUSIONS

Our first analysis of lightning activity and cloud top features in the Dallas–Ft. Worth area on 7 and 8 April 2002 showed the following:

- There are changes in lightning characteristics coupled to the storms' evolution from isolated supercells to a large squall line with trailing stratiform region.
- Satellite cloud top observations show indications of growing storm severity for the Throckmorton tornado, both with the overshooting, V–shaped core and the anvil region with a ring structure of cold cloud tops.
- 3D total lightning observations indicate a normal polarity, dipolar structure, as indicated by the predominant features of observed IC flashes.
- CG lightning activity rose by a factor of 2.5 during the phase of strongest storm development.

Future work will clarify the location of maxima in electrical activity related to satellite–derived cloud top structures.

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