11A.5 TORNADO SIGNATURES AND PRECURSOR ACTIVITY FROM 3-D LIGHTNING MAPPING OBSERVATIONS

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A GPS-based system for mapping lightning discharges inside storms has been developed and used to study thunderstorms in central Oklahoma, central New Mexico, and most recently during the Severe Thunderstorm Electrification and Precipitation Study (STEPS) in the high plains area of northwestern Kansas and eastern Colorado. The system is called the Lightning Mapping Array, or LMA, and produces detailed three-dimensional images both of individual lightning discharges and of the total lightning activity inside electrically active storms. The discharges are imaged by locating the sources of impulsive radio signals ('sferics') in an unused VHF television channel (60-66 MHz, U.S. Channel 3). The radiation events are located by measuring their time of arrival at a county-wide network of measurement stations. The LMA was patterned after the Lightning Detection and Ranging (LDAR) system developed at NASA's Kennedy Space Center by Carl Lennon and Launa Maier (Maier et al., 1995).

In the STEPS project, 13 measurement stations were deployed over an area about 80 km in diameter. Each station utilized GPS timing to measure the arrival times of radiation events with $\simeq$50 ns accuracy. This enabled the radiation sources to be located to within about 50–100 m over or near the network, and with gradually decreasing accuracy out to the maximum range of the instrument. The maximum range was limited by the radio horizon to an area 400–500 km in diameter. High-speed wireless communications linked the stations to an operations center where sampled data could be processed and displayed in real time. Each station detected the peak radiation event in successive 100 μs time intervals, corresponding to a maximum data rate of 10,000 s^{-1}. Typically several hundred to several thousand sources can be located per lightning flash, which show both the structure and development of the discharges inside the cloud.

The LMA observations have been found to be a good indicator of storm intensity and development. Plan views of the density of radiation sources are similar to PPI scans of radar reflectivity in that they show the convective cores of storm systems as well as the overall extent of the electrically active parts of a storm. Vertical projections show the the vertical extent and growth of the storm. Time animations of the observations show the motion and convective 'pulsations' of the storm.

Lightning is often essentially continuous and volume-filling in the large and often severe storms of the U.S. central great plains (Krehbiel et al., 2000). Of particular interest has been the discovery of lightning-free regions or 'holes' in tornadic and supercell storms that appear to be associated with strong rotating updrafts. In several cases, tornadoes formed on the western edge of the lightning holes.

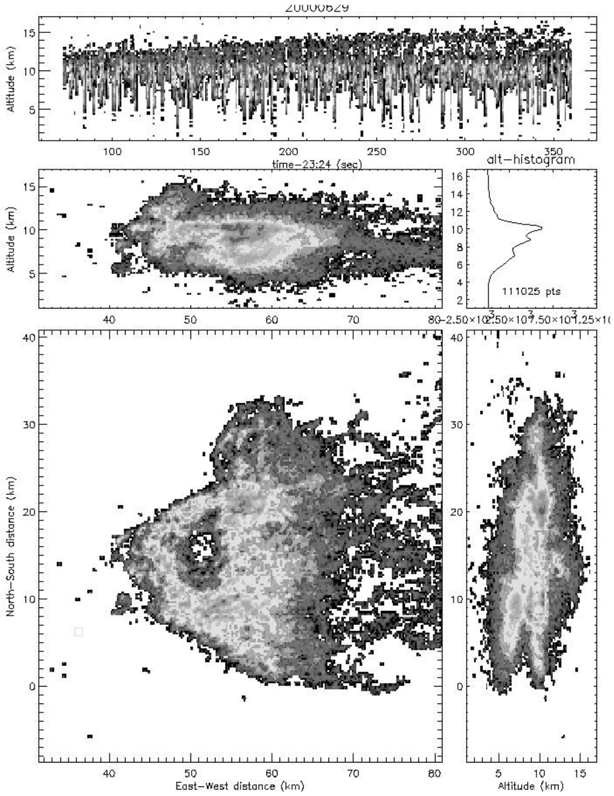

Figure 1: Lightning-free region formed during a tornadic storm observed on June 29, 2000, during the STEPS campaign. The North-South, East-West projection shows a region of low lightning activity, corresponding to a strong updraft region in the cell. An F1 tornado formed on the South-West boundary of the hole.

Also discovered by the LMA are the occurrence of frequent, short duration (sub-millisecond) discharges within the overshooting convective tops of large storms. The discharges rise up above the other lightning activity in the storm over a time span of 3–4 minutes, reaching a maximum altitude of 16 to 19 km and indicating a strong convective surge in the storm. In several cases, a progressive sequence of these surges in high-altitude lightning have been seen as precursors to tornado formation. Figure 2 is another example of a storm which produced a tornado, during the 1998 MEaPRS campaign. The altitude East-West projection shows one such surge, where the lightning rose up above the main discharge region of the cell, reaching an altitude of 14–16 km. During the last 5 minutes displayed, the independence of the high-altitude sources can be best be seen in the uppermost panel, plotting altitude as a function of time.

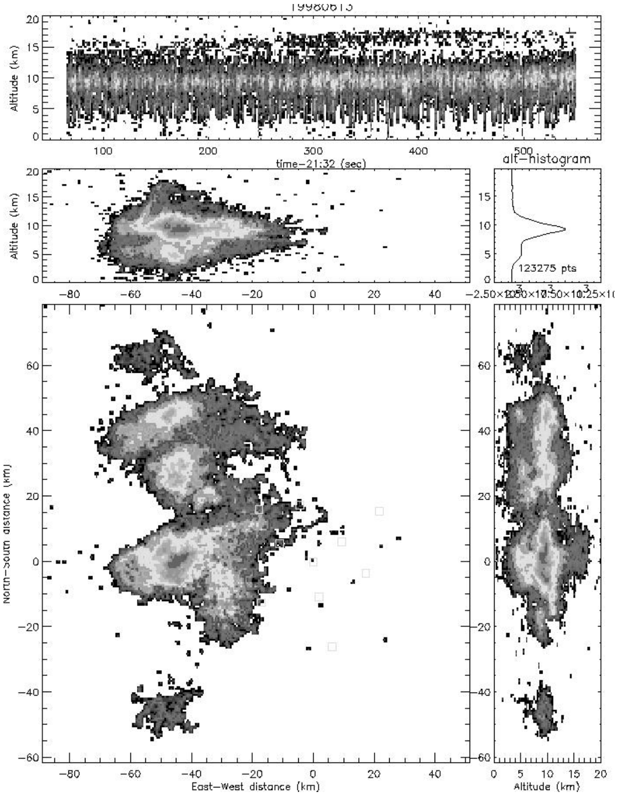

Figure 2: Lightning activity density plot for the tornadic storm of June 13, 1998 in central Oklahoma. The altitude East-West panel shows the surge of high altitude lightning activity, and the altitude as a function of time panel shows the isolation of the high-level sources.

The lightning observations are useful both for studying the electrical structure of storms as well as the lightning discharge types and processes themselves. For example, a primary goal of STEPS was to study convective storms in which the cloud-to-ground (CG) lightning is predominantly of positive polarity, namely it lowers positive charge to ground. Normal storms in their convective stages produce predominantly negative CG lightning. Numerous +CG storms were observed in STEPS. The intracloud (IC) lightning in these storms was also observed to be inverted in polarity from normal storms, namely to be between upper negative and lower positive charge. (In normal storms IC discharges tend to occur between a mid-level negative and upper positive charge regions.) This indicates that the storms are somehow 'inverted' in polarity, and raises important questions about the electrification processes.

A number of anomalous or inverted polarity storms were observed that produced substantial intracloud lightning but no cloud-to-ground discharges, either over their entire lifetime or for substantial periods in their initial stages. For example, the tornadic storm of June 29, 2000 produced large numbers of IC discharges during the first 90 minutes of its existence, but only one CG discharge (a +CG). During this time the storm gradually intensified to the tornadic stage, whereupon it started producing relatively large numbers of +CG discharges (1–4 per minute). The lack of CG activity in anomalous storms suggests that there is no 'lower' charge in the storm to initiate such discharges.

Figure 3 demonstrates the ability of the LMA to study storms over the lifetime of an entire storm. By displaying the lightning activity density over the duration of the storm, the trends in high-altitude surges can be easily identified. Also, by simultaneously displaying histograms of the CG rates, the correlation between electrification changes and storm severity can be made.

ACKNOWLEDGMENTS

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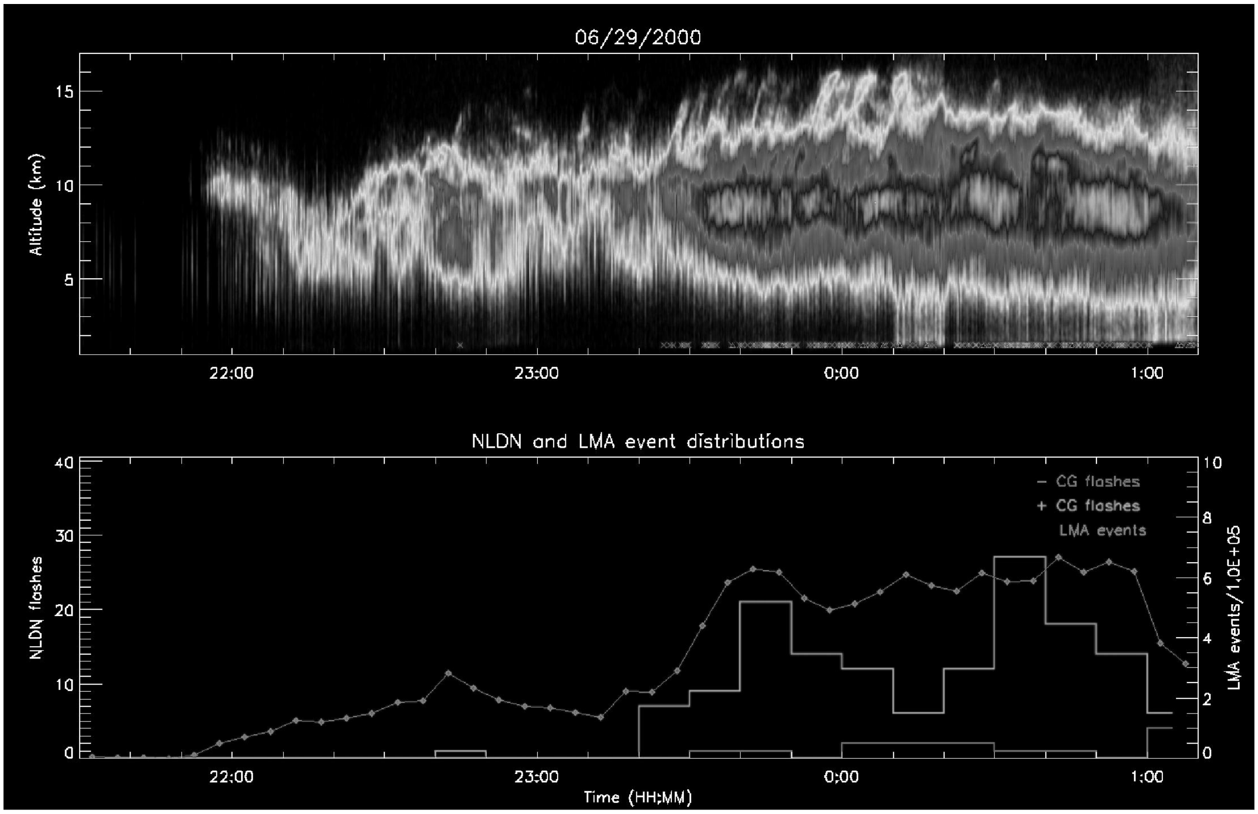

Figure 3: The upper panel shows LMA source points pixelized into a density display, over the entire lifetime of the tornadic storm on June 29, 2000. Notice the epochs of increasing high-altitude sources, appearing as surges shooting up above the main activity regions. The third surge was accompanied by the formation of an F1 tornado. The lower panel demonstrates the increase in +CG activity as recorded by the National Lightning Detection Network. For the early stages of the storm, no CG activity was detected, while later in the storm there were high +CG event rates, corresponding in time with the increase in high-altitude activity surges.