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Three-Dimensional Total Lightning Observations with the Lightning Mapping Array

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The New Mexico Tech Lightning Mapping Array (LMA) measures the total lightning activity of a storm by locating the sources of impulsive VHF radiation events produced by the lightning. The LMA produces detailed 3-dimensional images both of individual lightning discharges and of the overall lightning activity of electrically active storms. The discharges are imaged by locating the sources of impulsive radio signals in an unused VHF television channel (typically 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 the NASA Kennedy Space Center by Carl Lennon and Launa Maier (Maier et al., 1995). More detailed descriptions of the system operation and results have been given by Rison et al., (1999), Krehbiel et al., (2000), and Thomas et al., (2000), (2001).

In this paper we present results obtained during the Severe Thunderstorm Electrification and Precipitation Study (STEPS) conducted during the summer of 2000 in northwestern Kansas and eastern Colorado. For this study, thirteen measurement stations were deployed over an area 60–80 km in diameter. The LMA has been similarly deployed and operated in central Oklahoma and central New Mexico. As shown in Figure 1, the system is able to monitor lightning over a relatively large geographical area, with gradually decreasing accuracy out to the maximum range of the instrument. Figure 2 shows a closer view of the STEPS network. In addition to locating lightning, the system is able to locate and track other sources of impulsive RF radiation, in this case the steady stream of spark discharges produced by a commercial airliner flying through the downwind anvil of two storms.

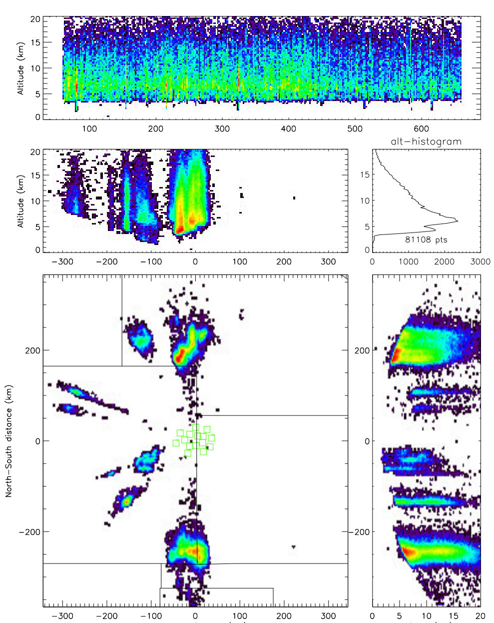

Figure 1: Observations of lightning over parts of Kansas, Colorado, and Nebraska during a 10 minute time interval on May 26, 2000. The maximum range is limited to about ±300 km by the curvature of the earth.

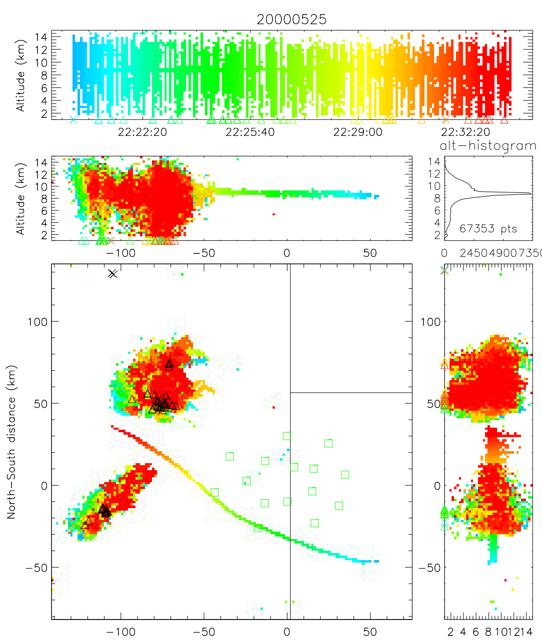

Figure 2: Closer view of the STEPS LMA network, showing lightning in two storms to the west of the network and the track of a commercial aircraft flying through the downwind anvil of the storms. The aircraft was flying at about 8.5 km altitude and was producing a steady stream of sparks as a result of collisional charging with ice crystals in the anvil.

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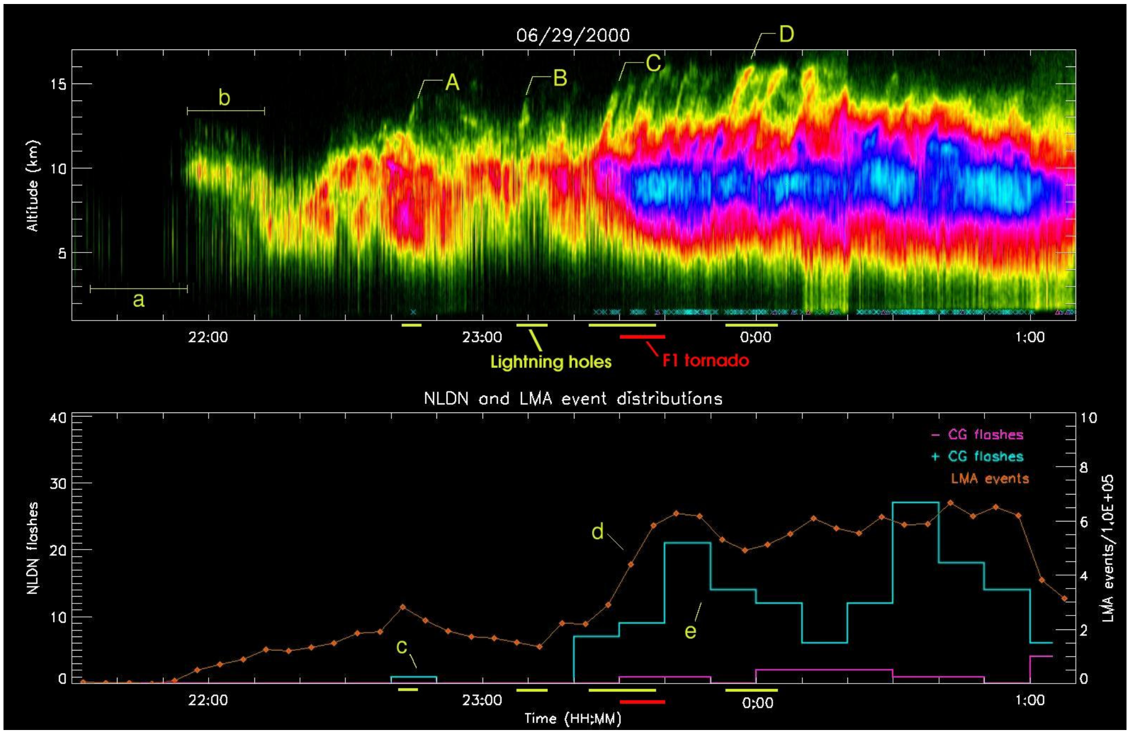

Figure 3: Height versus time plot of the lightning activity in the tornadic storm of June 29, 2000, showing a) the occurrence of a number of convective surges in the storm (the first four of which are labelled A–D), b) the times of lightning 'holes' and of an F1 tornado that accompanied the third convective surge, c) substantial intensification of the lightning activity at the time of the third convective surge and the tornado, and d) the onset of +CG lightning also at the time of the third convective surge. The storm initially electrified with a lower positive and mid-level negative charge (interval a), then developed a pseudo-normal tripolar electrical structure with an apparently dominant lower positive charge region (interval b). The charge regions then gradually subsided to produce strong and persistent inverted polarity electrification having dominant mid-level positive charge and upper negative charge. The storm produced numerous IC discharges during its first 90 min but only a single CG discharge.

Additional features of the LMA observations are as follows:

- The lightning activity in a storm has been found to be a good indicator of storm development and severity. Lightning in severe storms has been found to be essentially continuous and volume-filling. Of particular interest have been the findings that a) strong convective surges signaling the intensification of a storm are detected by the presence of upward-developing discharge events above the other activity of the storm (Figures 3, 5 and 6), and b) the occurrence (or potential occurrence) of tornados is signaled by the development of a lightning-free region, or lightning 'hole', that can accompany a convective surge (Figure 4).
- Severe and supercell storms have an anomalous electrical structure which is inverted in polarity from that of normal, non-severe storms. In particular, the intracloud (IC) lightning is inverted in polarity from that of normal storms, and the storms produce predominantly positive cloud-to-ground (+CG) lightning. Examples of inverted and normal polarity lightning are shown in Figures 7 – 10.
- Such inverted polarity storms can produce substantial IC lightning for long periods of time (or for their entire lifetime) without producing any CG lightning, or relatively few CG discharges (e.g., Figures 3 and 6). The onset of +CG lightning always appears to be associated with convective surges in the storm (Figures 3 and 6).
- The lightning in large storm systems and in dissipating storms can have substantial horizontal extent and spectacular structures (Figures 7 and 11).

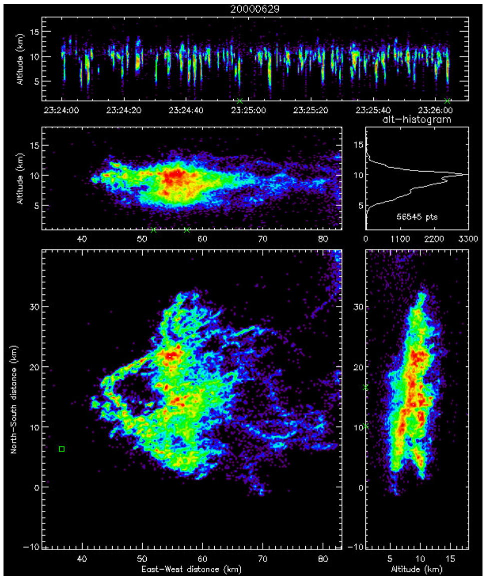

Figure 4: Lightning 'hole' that accompanied the third convective surge ('C') in the tornadic storm of June 29, 2000. The tornado (an F1) occurred on the left (west) side of the hole and was on the ground for about 15 min. The earlier convective surges caused less well-formed lightning holes. Lightning holes have been observed in other tornadic storms and appear to be a characteristic signature of the impending occurrence or potential for occurrence of a tornado.

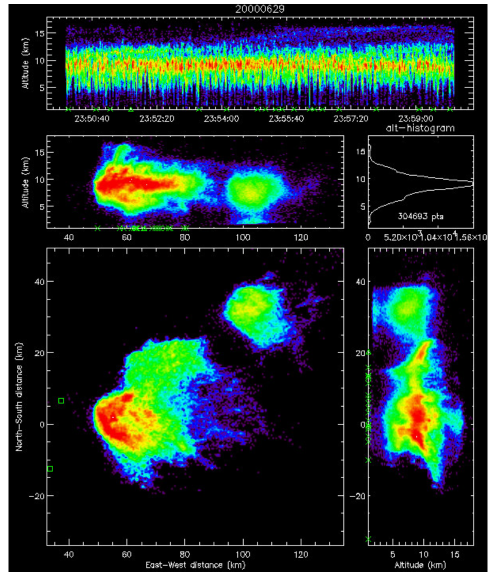

Figure 5: Convective surge 'D' in the June 29 storm. The surges are revealed by the occurrence of numerous small electrical discharges that rise up above the other lightning activity in the storm over a time span of 3–4 minutes. The upward developing discharge events are seen in the height-time panel at the top of the figure and above the core of the storm in the vertical projection panels. Such lightning activity typically ascends to 16 to 19 km altitude MSL.

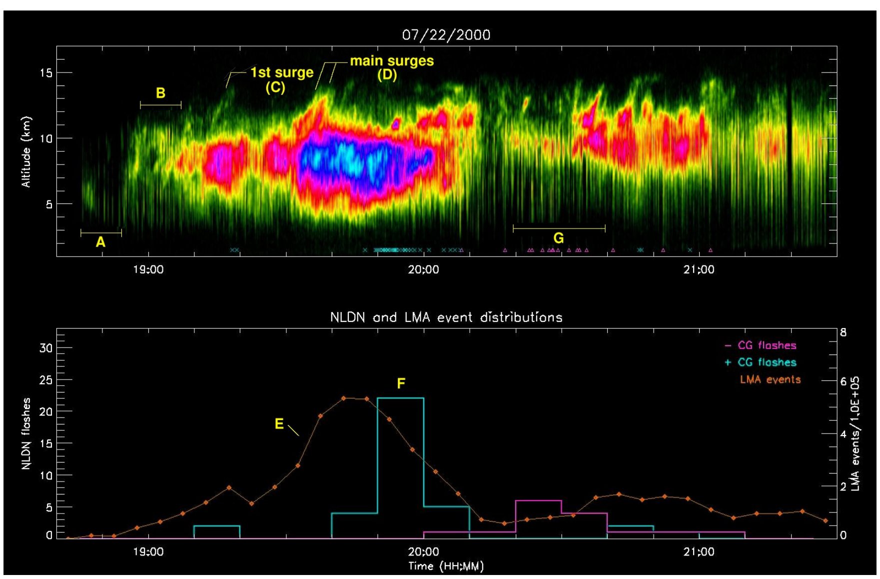

Figure 6: Height versus time plot for the first of two supercell storms on July 22, 2000. This storm produced substantial small hail at the ground during its electrically intense stage. The storm electrified in a similar manner as the June 29 storm and exhibited several convective surges but did not become tornadic. +CG discharges accompanied the initial surges; by this time the storm had developed a fully inverted electrical polarity. After 20:10 the electrical activity decreased and the storm subsequently became re-electrified with normal polarity, and produced negative CG discharges.

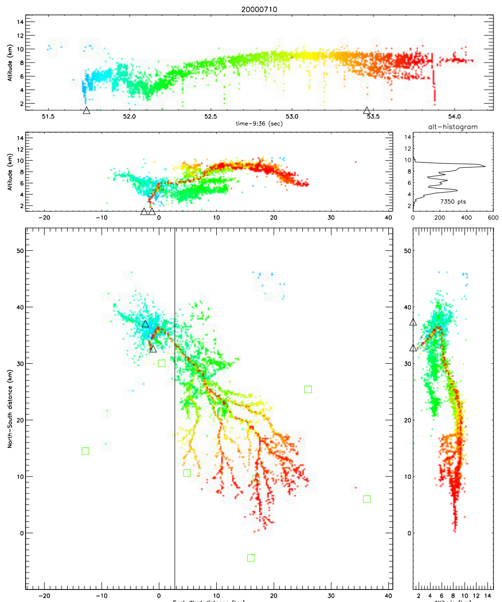

Figure 7: A normal polarity, negative CG flash (negative charge lowered to ground) that had a substantial (>50 km) incloud horizontal extent and a spectacular dendritic structure. The small triangles indicate the -CG strike points as determined by the NLDN, but provide no indication of the overall size of the discharge.

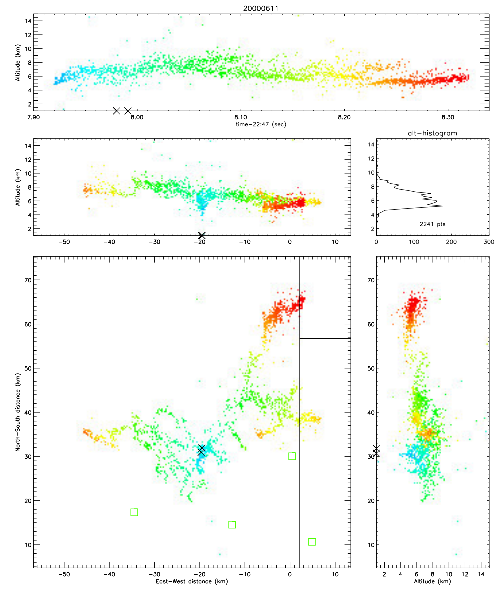

Figure 8: A positive CG discharge, which lowered positive charge to ground from the same altitude range as negative charge in normal polarity storms. The 'x' symbols indicate two NLDN-located ground strike points. The discharge developed in two directions away from the channel to ground.

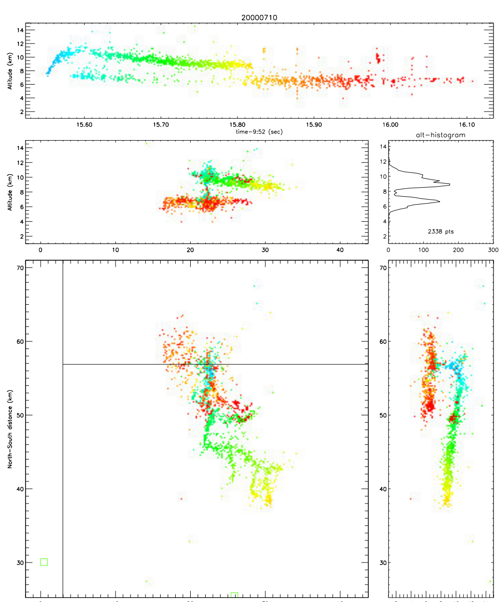

Figure 9: A normal polarity, bilevel intracloud (IC) discharge, between negative charge at mid-levels (6-8 km altitude MSL) and positive charge in the upper part of the storm. Normal polarity ICs are characterized by upward initial development at VHF and by delayed activity in the negative charge region. More VHF activity occurs in the upper positive region than in the mid-level negative charge region.

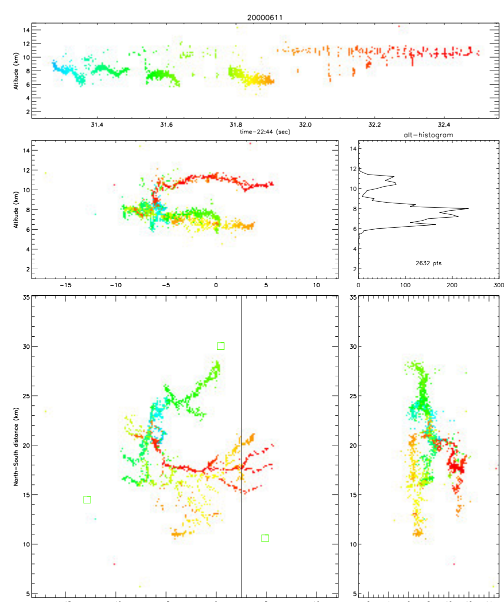

Figure 10: An inverted polarity bilevel IC discharge, between mid-level positive and upper negative charge. The inverted discharges are characterized by downward initial development at VHF and by more sources in the mid-level (positive) region than in the upper (negative) region. Storms having inverted polarity IC discharges were common in STEPS and were the dominant form of lightning in supercell and severe storms.

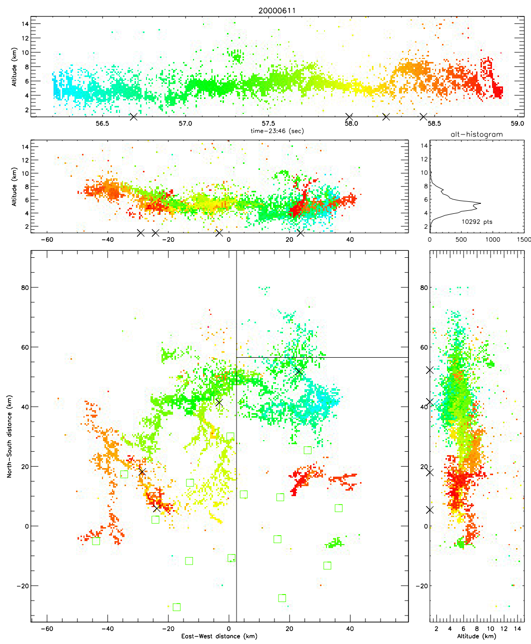

Figure 11: A horizontally extensive (80 km) positive CG discharge in the trailing stratiform region of an MCS. Four +CG strokes occurred at widespread locations as the discharge propagated through the stratiform region. Immediately following each stroke the radiation sources rapidly expanded away from the ground strike point. This is the type of lightning that initiates sprites and elves high in the atmosphere.

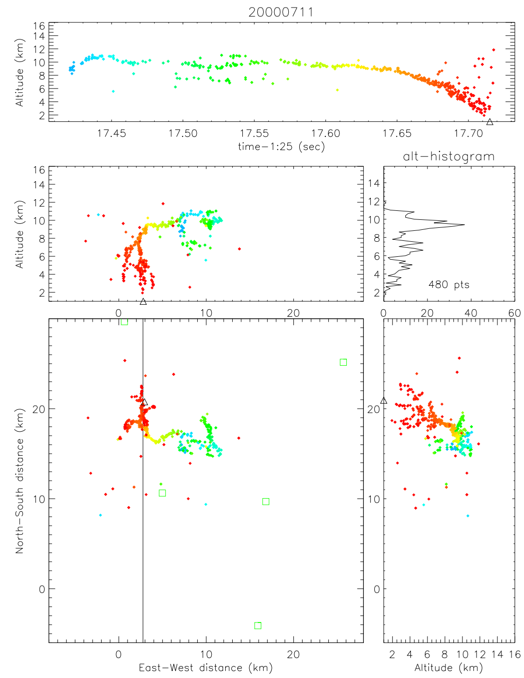

Figure 12: Initial results of high time-resolution (10 μs) observations with the LMA, in this case of a normal polarity -CG flash, showing detailed branching of the stepped leader to ground. The discharge was a 'bolt from the blue' flash from STEPS that was almost identical in nature to the New Mexico flash of Figure 13.

Additional points of interest concerning the LMA and its observations are:

- The LMA normally has a time resolution of 80 or 100 μs, enabling it to locate as many as 10,000 or so radiation events per second. However, the system can also be operated with an enhanced time resolution of 10 μs to provide finely detailed pictures of individual lightning discharges. An initial example of such observations from STEPS is shown in Figure 12. The LMA is currently being operated at Tech's Langmuir Laboratory in central New Mexico in a compact array configuration (8 stations within a 5-km diameter area plus 4 outlying stations) for highly detailed studies of lightning.
- The mapping system has shown numerous instances of lightning 'bolts from the blue', and provides a clear and simple explanation of their occurrence (Figure 13). In particular, bolts from the blue begin as a normal polarity IC flash between mid-level negative and upper positive charge in a storm, then develop sideways out of the cloud, either from within the upper positive charge region (Rison et al., 1999), or from partway along the vertical channel between the two charge levels (Figures 12 and 13). Bolts from the blue have been identified previously in observations from the LDAR system at Kennedy Space Center, Florida by Forbes and Hoffert (1998).
- Experimental observations of a pulsed RF transmitter on board a sounding balloon show that the LMA is able to locate events with a high degree of accuracy, on the order of 10 m rms in the horizontal, and 20 m rms in the vertical for events between about 2 and 10 km altitude above the network of stations (Thomas et al., this conference). The sounding observations demonstrate the feasibility of locating multiple, lightweight, low-power pulse transmitters in other kinds of ground or airborne applications.

In conclusion, three-dimensional observations of the total lightning activity in storms provide a valuable and complementary means of characterizing the storms, and can be used to indicate when the storms intensify and become severe.

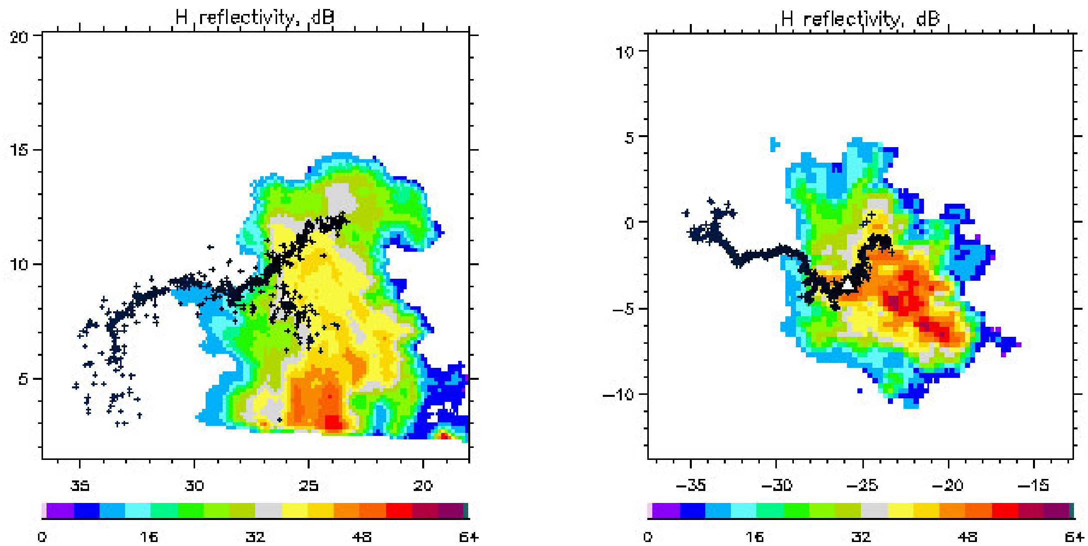

Figure 13: A lightning 'bolt from the blue' observed over Langmuir Laboratory in central New Mexico during 1999. The discharge is shown in vertical projection (left) and horizontal projection (right), overlaid upon vertical (RHI) and plan (PPI) cross-sections of the radar echo through the storm. The flash began as a normal polarity IC discharge, with negative-polarity breakdown developing upward between midlevel negative and upper positive charge in the storm. The breakdown then exited the storm to the left (west), apparently along positive screening charge at the radar echo boundary, and turned downward as a negative stepped leader to ground. The ground strike point was about 9 km (5–6 miles) west of the core of the storm, well outside the storm's radar echo. The storm presumably had an excess of midlevel negative charge and a deficit of upper positive charge, but the flash was initiated above rather than below the negative charge region and therefore began as an IC discharge.

ACKNOWLEDGMENTS

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