2008
20th International Lightning Detection Conference
21-23 April • Tucson, Arizona, USA
2nd International Lightning Meteorology Conference
24-25 April • Tucson, Arizona, USA

# OBSERVATIONS OF CLOUD-TO-GROUND LIGHTNING IN THE GREAT PLAINS

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## 1. Introduction

In July, 2005, a field campaign was conducted in the Great Plains of eastern Colorado, western Kansas, and southern Nebraska to obtain 60 field/sec video imagery of lightning in correlation with reports from the U.S. National Lightning Detection Network (NLDN). A total of 342 GPS time-stamped cloud-to-ground (CG) flashes, containing at least 547 strokes, were obtained in 17 different recording sessions during 13 storms. Using NEXRAD radar imagery, the storms recorded during these sessions were classified as either single-cell storms or multiple-cell storms. The radar imagery was combined with NLDN reports to show when and where in the storm development the positive and negative flashes occurred, and to determine if the flashes we recorded were biased by the sampling. In this paper, we discuss the potential sampling bias in our dataset, and we examine the spatial and temporal relationships between the radar reflectivity and lightning in single-cell and multiple-cell storms.

## 2. Methodology

### *2.1 Video Recording System*

Lightning return strokes were recorded using one or two Canon GL1 digital video camcorders with 720x480 pixel resolution. During the data analysis, the standard 30 video frames per second were de-interlaced to provide 60 fields per second that could be viewed on a standard video monitor [Parker and Krider, 2003]. The camera exposure time was set to 16.7 ms to eliminate any dead time between fields. Different strokes that followed the same channel to ground may not have been resolved by the video camera if they had an interstroke interval of less than 33 ms. Each video field was time-synchronized to GPS time, and the GPS times were used to correlate video strokes with NLDN reports. A more detailed discussion of the video recording system and the methods of analysis can be found in Parker and Krider (2003), Biagi et al. (2007), and Fleenor et al. (2008).

In this study, a ground stroke was considered to have occurred within a particular video field if that field contained a clearly visible channel between the cloud and the ground. Strokes that remained luminous for two or more consecutive fields were assumed to have a continuing luminosity, and in some cases, the appearance of continuing luminosity may have been produced by an unresolved subsequent stroke. Any increases in the continuing luminosity of the channel were assumed to be M components [Thottappillil et al., 1995].

For this study, a session was defined in terms of the recording interval at each camera location. The recording sessions (see Table 1 to follow) did not necessarily coincide with the entire life cycle of the lightning that occurred in an individual storm. For many sessions, the recording began in the middle of the lightning activity and/or ended before the lightning activity had ceased. Since the sessions do not record the entire life cycle of the storm, or even all the flashes that occurred in a given recording interval, the dominant polarity of the lightning in each session may not be representative of the storm as a whole. This issue will be discussed in more detail in section 3.4.

### *2.2 NLDN Data*

The NLDN data used in this study were taken from an archived database that was provided by the Vaisala Thunderstorm Unit in Tucson, AZ. The NLDN reports contained the GPS time, location, type of impulse, an estimate of the peak current ($I_p$), and polarity of each stroke [Cummins et al., 1998].

The NLDN groups separate strokes into flashes when all strokes occur within 10 km of the first stroke and the time-interval between strokes is less than 500 ms [Cummins et al., 1998]. To be consistent with the NLDN, we used these same criteria when we grouped video strokes into video flashes.

*2.3 Radar Data*

Level II archived radar data [Crum et al., 1993] were obtained from the Garden City, KS, and Lincoln, NE, WSR-88D (NEXRAD) radars through the National Climatic Data Center. Each volume scan had nine elevation angles ranging from 0.5° to 19.5° that were repeated every 5 to 6 minutes. A description of the WSR-88D beam characteristics and scan strategies is given in Klazura and Imy (1993).

The radar reflectivities used in this study were composites that provide the highest reflectivity in a vertical column above each grid point. For some analyses, the gridded data were converted to contours of constant reflectivity, and then the NLDN data in consecutive 15-minute intervals were overlaid on the reflectivity pattern so that each 15-minute interval was centered on the time of the radar scan.

## 3. Results

A total of 103 negative flashes and 204 positive flashes were recorded on video during 17 video recording sessions. It should be noted that the polarity of the flashes recorded tended to remain the same during an individual recording session (see Table 1).

The radar imagery was combined with NLDN reports to determine when and where in the storm development the positive and negative flashes occurred, and to determine if the flashes that were recorded were biased by the sampling. The storms recorded on video were grouped into two categories: single-cell thunderstorms and multiple-cell thunderstorms. For this study, a storm that appeared to be a single, isolated cell on radar for its entire life cycle was regarded as a single-cell thunderstorm. Any storm that did not meet this criterion on radar was regarded as a multiple-cell thunderstorm.

3.1 *Single-Cell Storms*

Nine of our recording sessions were of single-cell storms as seen on radar, and of these, 5 were dominated by negative CG strokes on video, and 4 were dominated by positive CG strokes on video. Figures 1 and 2 show a portion of the life-cycles of 2 single-cell storms; one on July 7, 2005 that was dominated by negative strokes (Figure 1), and one on July 4, 2005 that was dominated by positive strokes (Figure 2). Positive NLDN reports are indicated by a '+', and negative NLDN reports are indicated by an 'x'. The location of the video camera location is indicated by a black star, the maximum azimuthal extent of the flashes recorded on video is shown by the black lines, and the NLDN reports that were recorded on video are circled in white. For these figures, the low-amplitude NLDN reports (e.g. negative strokes with an $|I_p| \leq 10$ kA and positive strokes with an $I_p \leq 20$ kA) were removed since many of these events in the GP are likely cloud pulses [Biagi et al., 2007; Fleenor et al. (2008)]. From these maps, it is clear that the dominant NLDN polarity recorded on video is associated with flashes occurring near the convective core, and all single-cell storms exhibited this pattern.

Table 1. The date, recording interval (minutes), and session polarity (%) for the recording session in the Great Plains. Sessions highlighted in gray were dominated by negative CG flashes and sessions not highlighted were dominated by positive CG flashes.

| Session | Date 2005 | Recording Interval (min) | Session Polarity (%) |
|---|---|---|---|
| 1 | 3 July | 60 | Negative (100) |
| 2 | 4 July | 28 | Positive (100) |
| 3 | 5 July | 72 | Positive (94) |
| 4 | 5 July | 41 | Positive (100) |
| 5 | 6 July | 18 | Negative (100) |
| 6 | 6 July | 23 | Positive (92) |
| 7 | 6 July | 104 | Negative (100) |
| 8 | 6 July | 6 | Negative (100) |
| 9 | 7 July | 103 | Positive (100) |
| 10 | 7 July | 31 | Negative (100) |
| 11 | 7 July | 14 | Positive (100) |
| 12 | 10 July | 18 | Positive (100) |
| 13 | 10 July | 83 | Positive (98) |
| 14 | 11 July | 84 | Positive (92) |
| 15 | 11 July | 11 | Positive (100) |
| 16 | 11 July | 10 | Positive (100) |
| 17 | 13 July | 60 | Negative (100) |

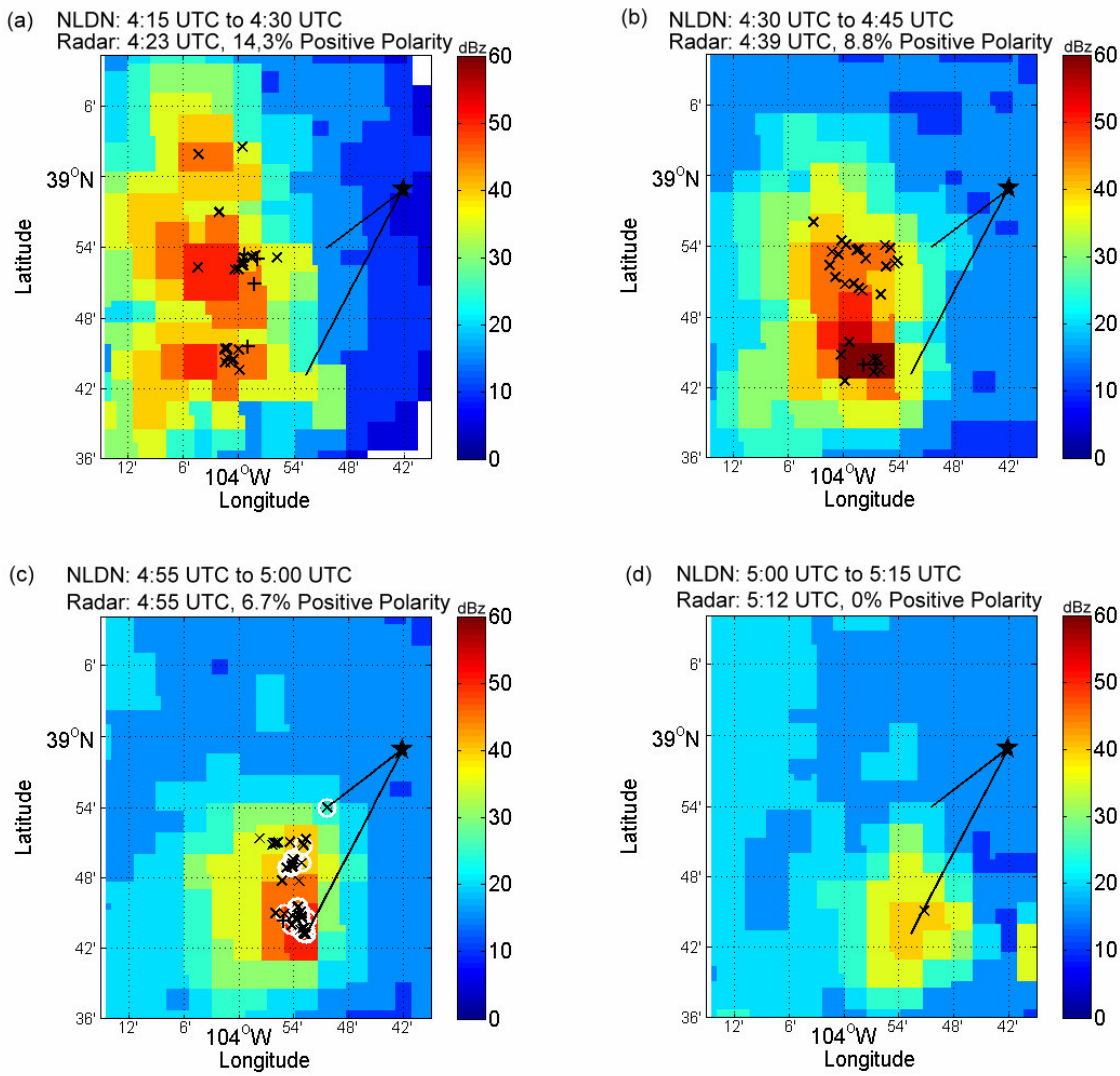


Figure 1. Composite reflectivity contours and the locations of NLDN stroke reports for a single-cell storm on July 7, 2005. The times of the radar scans are (a) 4:23 UTC, (b) 4:39 UTC, (c) 4:55 UTC, and (d) 5:12 UTC. The locations and polarities of NLDN stroke reports are shown with a '+' for positive strokes and an 'x' for negative strokes. Only negative NLDN reports with $|I_p|$ > 10 kA and positive NLDN reports with $I_p$ > 20 kA are shown. The NLDN reports that were correlated with video strokes are circled in white, the camera location is indicated by a star, and the maximum azimuthal extent of the NLDN reports are shown by the solid lines.

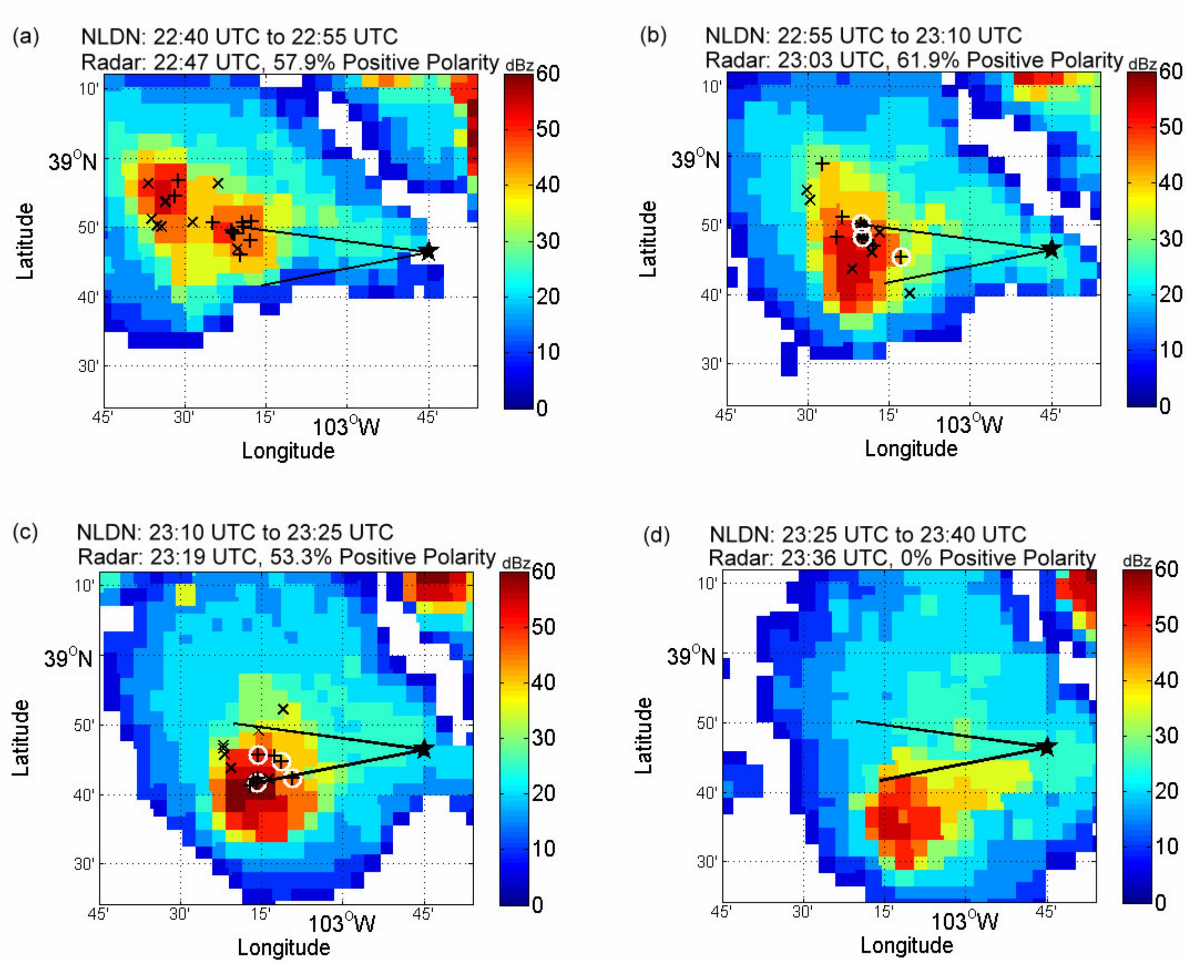


Figure 2. The same as Figure 1, except for July 4, 2005 and the times of the radar scans are (a) 22:47 UTC, (b) 23:03 UTC, (c) 23:19 UTC, and (d) 23:36 UTC.

Prior studies have shown that a large fraction of positive flashes can occur during the mature and dissipating stages of thunderstorms (Fuquay, 1982; Seimon, 1993; MacGorman and Burgess, 1994; Carey and Rutledge, 1998; Lang et al, 2004), and that the dominant polarity can change as the storm evolves with time (Seimon, 1993; MacGorman and Burgess, 1994). Therefore, the dominant polarity of our sessions could be biased if the recording session covered only a portion of the storm life-cycle. In order to investigate this possibility, frequency histograms of the NLDN stroke reports, after filtering out all reports with a low-amplitude $|I_p|$, were plotted for all single-cell storms starting one hour before the session started, and going to one hour after the session ended. The single-cell storms for the negative dominated sessions showed a clear tendency for negative strokes to dominate before, during (between the dotted lines), and after the video recording session, but only 1 out of 4 of the single-cell storms for sessions that were dominated by positive strokes on video showed a clear tendency for positive strokes to dominate for the entire the video recording session. The other 3 positive-dominated sessions had a period that was dominated by positive CG's, but this period was preceded by a period that was dominated by negative CG's. Figure 3 shows the 5-minute CG stroke rates of the large negative and positive NLDN reports before, during (between the

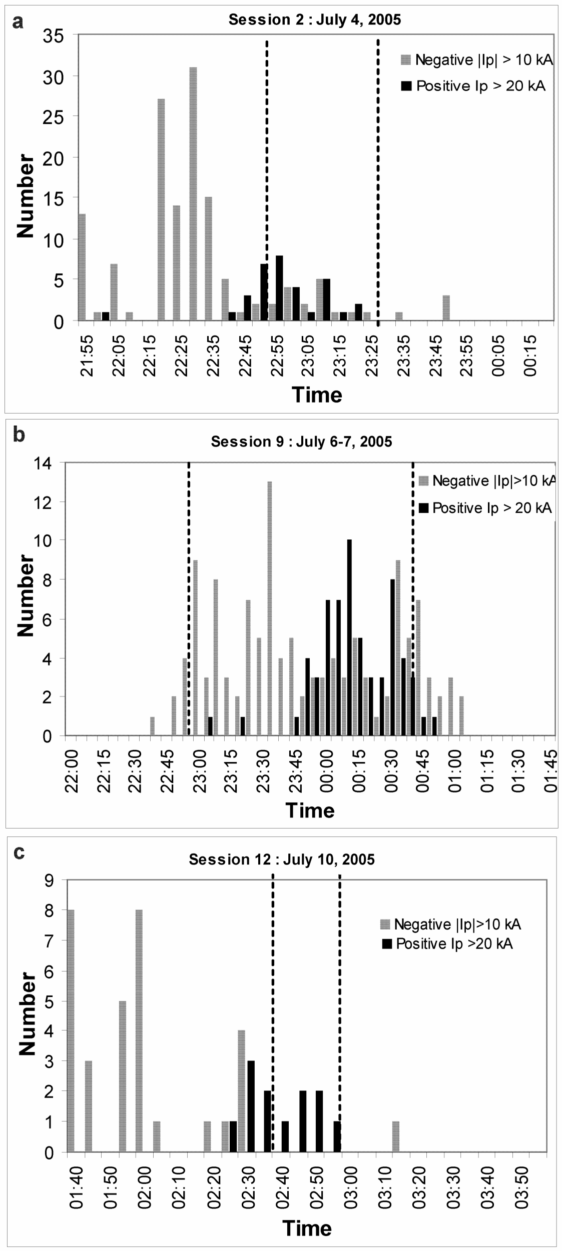


Figure 3. Distribution of the occurrence and polarity of all NLDN stroke reports in three positive-dominated sessions during single-cell storms starting one hour before the recording session began to one hour after the recording session ended for a) session 2, b) session 9, and c) session 12. Note: Only negative NLDN reports with $|I_p|$ > 10 kA and positive reports with $I_p$ > 20 kA have been included in these plots.

dotted lines), and after the latter 3 sessions. A negative-dominated period occurred toward the beginning of these storms when the storms were less organized on radar, and this period was followed by a positive-dominated period that occurred when the composite reflectivity reached a maximum.

### 3.2 *Multiple-cell Thunderstorms*

There were 8 video recording sessions of multiple-cell storms: 2 were dominated by negative strokes and 6 were dominated by positive strokes. A session was defined in terms of the recording interval at each camera location, and only 3 different multiple-cell storms were recorded during these 8 sessions. Figure 6 shows distributions of the large negative and positive NLDN stroke reports in 3 multiple-cell storm complexes. Here, the NLDN reports start one hour before the start of the first recording session and end one hour after the last recording session ended. The spatial domain for the NLDN reports covered the entire multiple-cell storm, and remained constant for the entire time period. Because of the large spatial domain, there were a few flashes that occurred in small storms that passed through the domain that were not part of the multiple-cell storm of interest. These NLDN reports are a very small fraction of the total. Note that the dominant polarity of the recording session does not always agree with the dominant polarity of the NLDN reports. This occurs because even though negative NLDN reports dominate the multiple-cell storms most of the time, there are still small regions within the larger storm complex that are dominated by positive strokes. For example, video session 5 recorded primarily negative polarity strokes and session 6 recorded primarily positive strokes. However the larger storm during both of these sessions was dominated by negative NLDN reports (see Figure 4b). Therefore, while our video sessions accurately represented the polarity of flashes occurring in the localized region of where the camera was pointing, they did not accurately represent the dominant polarity of flashes in the larger storm.

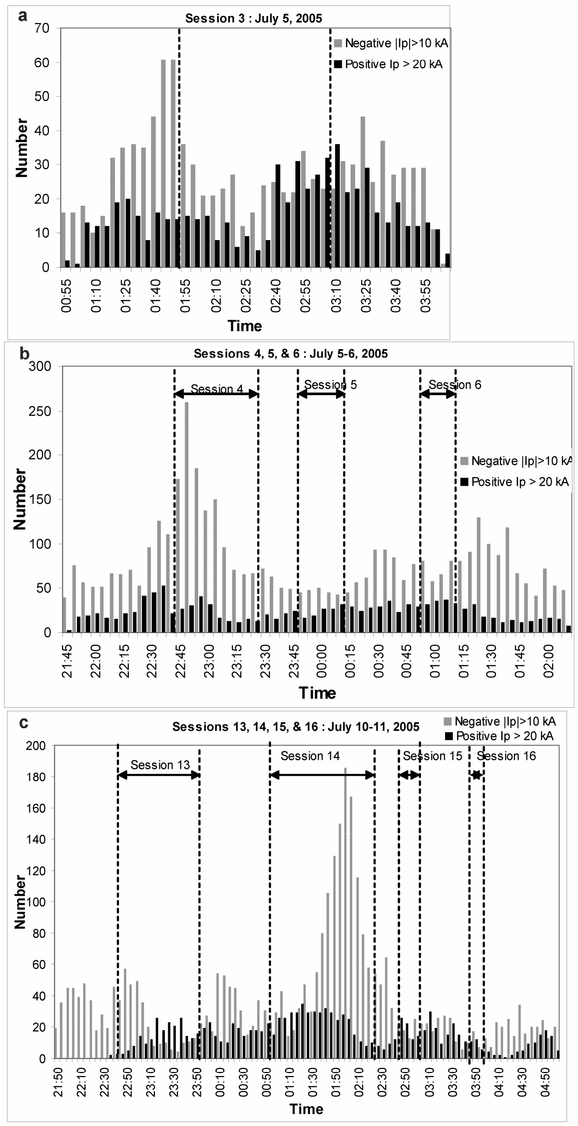


Figure 4. Distributions of the occurrence and polarity of all NLDN stroke reports in three multiple-cell storms from one hour before the recording sessions started to one hour after the recording sessions ended for a) session 3, b) sessions 4, 5, and 6,, and c) session 13, 14, 15, and 16. Only negative reports with $|I_p|$ > 10 kA and positive reports with an $I_p$ > 20 kA have been included in these plots.

Figures 7a and 7b show 15-minute periods of NLDN stroke locations and the associated (mid-period) composite radar reflectivity taken from successive 1 hour intervals during video recording sessions 5 and 6, respectively. In Figure 5a, it is clear that the eastern portion of the storm (i.e. near the camera location for session 5) is dominated by large, negative reports, but regions in the western portion of the storm have a much higher fraction of large, positive reports. For session 6 (Figure 5b), one of the positive regions of the storm is being recorded on video, and the negative-dominated portion of the storm recorded during session 5 has moved further to the east. Since we recorded just small regions of these large multiple-cell storms, we clearly tended to obtain lightning of only one polarity. Thus, in multiple-cell storms, our video recording sessions do not accurately represent all the CG strokes that occurred, but are representative of just the local region that was recorded on video.

## 4. Conclusions

Spatial relationships between the radar reflectivity and lightning were carried out for both single-cell storms and multiple-cell storms. For the single-cell storms, the dominant polarity during a video recording session was representative of the storm polarity during that session, but was not always representative of the dominant storm polarity before and/or after the recording session. During multiple-cell storms, we were only able to record small portions of the larger storms, and therefore, tended to only record just one polarity. In both cases, the positive CG lightning recorded on video was occurring within, or near, a convective core on radar.

Single-cell storms tended to produce one polarity of CG strokes at a time. In 3 of the 4 single-cell storms that contained a period dominated by positive polarity, that polarity was preceded by a period of negative polarity (see Figure 13). The positive dominated periods occurred during the time of maximum composite reflectivity on radar. Seimon (1993) and MacGorman and Burgess (1994) found 11 storms where the dominant polarity switched from positive to negative sometime during the mature stage. Although these storms did not produce a long period of negative-dominated strokes before the period dominated by positive strokes (as in our study), several of the storms began with a period of infrequent negative CG strokes. These negative CG strokes occurred when the storms were weaker and less organized.

Multiple-cell storms tended to be dominated by negative strokes most of the time, but had small regions within the larger storm complex that were dominated by positive strokes. The broad spatial patterns of negative and positive strokes in multiple-cell storms were similar to the patterns described by Stolzenburg (1990).

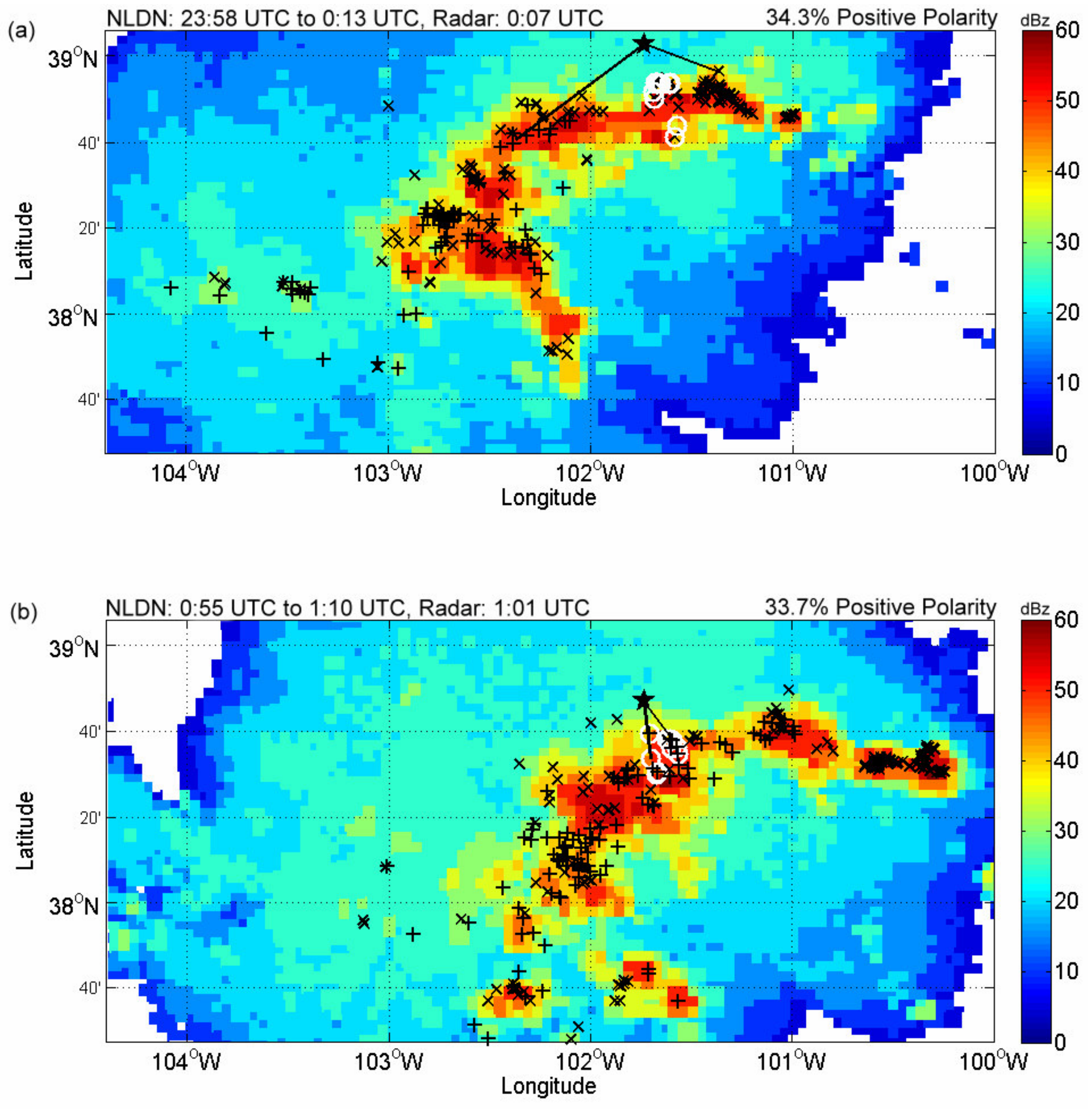


Figure 5. The same as Figure 2, except for a multiple-cell thunderstorm on July 5-6, 2005 for (a) session 5 at 0:07 UTC, and (b) session 6 at 1:01 UTC.

**ACKNOWLEDGEMENTS**

This work has been supported in part by the NASA Kennedy Space Center, Grant NNK06EB55G, and Vaisala Thunderstorm, Tucson, AZ. We also thank John Cramer of
Vaisala Thunderstorm for NLDN data processing.

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