Concurrent Upward Lightning Flashes from Two Towers

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Abstract  Upward lightning flashes initiated simultaneously from two towers separated by a distance of 3420 m were analyzed in detail based on high-speed camera images and S-band Doppler radar echo intensity. Both discharges lasted more than 250 ms and were self-initiated from the towers in the form of upward positive leaders with a time difference of less than 4 ms. Abundant recoil leaders occurred transiently in the remnant channel sections during the development of the upward lightning. The number of recoil leaders over the lower tower was greater than over the higher tower. When the concurrent upward flashes occurred, the radar echo intensity in the area of the towers was no more than 45 dBZ and the towers were separately located beneath two echo centers with low altitudes of 2–3 km.

Keywords: tower, upward lightning, leader, discharge

1 Introduction

Upward lightning usually initiates from tall structures or natural high points, and has gained growing concern in recent years with the increased requirement to protect large buildings and windmills all over the world against lightning (Miki et al., 2005). Generally, upward lightning is observed to initiate singly from a tall structure (usually the tallest out of those in the vicinity), sometimes accompanied by preceding nearby discharges (Takagi et al., 2006; Zhou et al., 2012). Some observations have revealed that two or more tall structures located not far from each other may sometimes initiate upward flashes simultaneously in certain situations (Berger et al., 1966; Miyake et al., 1990; Suzuki et al., 1992). Rakov and Uman (2003) suggested that such multiple upward flashes are triggered by identical in-cloud discharge, of which the horizontal extent would significantly affect the number of, and the distances between, the structures involved.

Wang et al. (2008) inferred that, under a favourable thunderstorm, an object-initiated upward discharge may trigger another upward discharge with opposite polarity from a nearby tall object. Lu et al. (2009) confirmed this inference by observing two associated tower-initiated upward flashes 375 m apart, with the first one being of positive polarity and the second one of negative polarity. Recently, Warner (2012) observed simultaneous upward flashes from four towers triggered by a positive cloud-to-ground (CG) flash, as the negative breakdown following the return stroke propagated horizontally. In this paper, we present an analysis of simultaneous upward lightning flashes (both were self-initiated) from two towers, on the basis of high-speed camera observations and radar echo detection.

2 Observation and data description

The concurrent upward lightning flashes studied in this paper initiated from a 325-m meteorology tower and a 112-m old television tower in Beijing, with a horizontal distance of 3420 m between them, as shown in Fig. 1. A fastcam SA1 high-speed camera, operated at 10000 fps with a spatial resolution of 960×528 pixels, was located on the 9th floor (about 30 m aboveground) of Institute of Atmospheric Physics (IAP) 40# building, 910 m away from the meteorology tower and 4320 m away from the old television tower. A single pixel of the high-speed images is equivalent to an area of 1.25×1.25 m² at the distance of the meteorology tower, and 5.9×5.9 m² at the distance of the old television tower. An S-band Doppler radar monitoring the development of the thunderstorm was located 20.3 km southeast of the towers. The radar routinely completes a volume scan every 6 minutes.

3 Analysis and results

3.1 General characteristics

The multiple lightning from the two towers occurred at 0602:05 UTC 27 September 2012. Figure 2 shows the time-integrated high-speed camera image starting from the leader inception until the end of the lightning. Abundant recoil leaders appeared during the development of both upward leaders from these two towers, indicating that both were of positive polarity, which was also supported by the measured atmospheric electric field. The lightning lowered negative charge from cloud to ground, without any subsequent dart leader-return strokes after the current cutoff of the initial continuous currents at both towers. Since the lightning occurred in the daytime with relatively strong background light and the upward leaders exhibited weak luminosity in the very initial stage, it was
not possible to determine the exact start time of both upward leaders, with the initiation order of them being unknown. Nevertheless, based on the channel lengths when the leaders were distinguishable, the time difference between the initiations of these two upward positive leaders was estimated to be within \( \pm 4 \) ms under an assumption of a 2D propagation speed of about \( 10^5 \) m s\(^{-1}\) of both leaders (Jiang et al., 2013). By checking the electric field data, this multiple tower lightning was found to be self-initiated, without any preceding occurrence of CG or inter-cloud (IC) lightning flashes in the nearby area, and it did not induce any adjacent discharge processes.

Lu et al. (2009) observed that a tower-initiated flash with an upward positive leader triggered another tower-initiated flash with a negative upward leader. The horizontal distance between the towers was 375 m in their study, which was much closer than the distance involved in this paper. The discharge with the triggering leader lasted about 130 ms and the triggered one with the opposite polarity lasted only 14 ms. However, the durations of both discharges in this paper were longer than 250 ms. In Lu et al. (2009), the initiation of the triggered leader lagged 45.8 ms behind the triggering leader—considerably longer than in the present study. Since the upward leaders in this study were of the same polarity, there would have been no triggering relationship between them, for the occurrence of an upward leader may theoretically weaken the ambient electric field, and, consequently, produce a negative effect on the initiation of another leader with the same polarity. This is consistent with the relatively short time difference studied here. As in Warner (2012), four upward leaders in response to the approaching negative breakdown of a +CG flash were also found to be of the same polarity, which initiated almost simultaneously. It is worth noting that their case was other-triggered, while the multiple lightning in this study was self-initiated. In the dataset of Warner et al. (2012), the longest time difference between the first and last leader was 10.2 ms.

### 3.2 Recoil leaders

As shown in Fig. 2, abundant recoil leaders occurred during the lightning development. These recoil leaders transiently started in the remnant channel sections (with the luminosity below the lower detection limit of the optical observation), which were generated by the upward leader and propagated toward the trunk channel flowing with continuous current. Most of the recoil leaders died out before reaching the trunk channel and exhibited very short durations, while some of them succeeded in the junction and continued to propagate down through the already luminous channel. Figure 3 shows the evolution of a recoil leader during the lightning discharge of the old television tower. The recoil leader first appeared at 0 ms, and extended to the right, toward the main channel with a faint luminosity that indicated a continuous current. At 0.2 ms, the recoil leader had connected to the main channel, and then it continued to propagate downward, during which period the upper extremity of the leader channel exhibited a reduced luminosity. The downward portion of the leader reached the tower tip between 0.3 ms and 0.4 ms, and induced a reflection that traversed back through the channel to the upper extremity. The reflection wave finally realized an outward channel extension, as shown in Fig. 3f. Different from the observation of Warner et al. (2012) showing a bidirectional development of the recoil leader (Fig. 6 in Warner et al. 2012), the image frames in this study demonstrated a unidirectional propagation, and the tailing end of the leader channel exhibited a weakening luminosity before the reflection at the tower tip.
Figure 3  Evolution of a recoil leader initiated in the channel remnant. The recoil leader propagated toward the main discharge channel and succeeded in the connection. It continued to develop downward and induced a reflection when reaching the tower tip.

Figure 4a shows the frequency of recoil leaders during the period of upward lightning, with the number of recoil leaders having been counted every 5 ms. Twenty nine and 317 recoil leaders occurring in the discharge channels of the meteorology tower and the old television tower, respectively, were captured with the high-speed camera. The recoil leaders firstly occurred at about 10 ms after the initiation of the lightning, exhibiting an increasing frequency as the lightning developed, and reached the frequency peak of 26 recoil leaders per 5 ms at about 75 ms. It is interesting that although the lightning discharges from both towers initiated almost simultaneously, their associated recoil leaders were not similar, with the recoil leaders over the old television tower being greater than those over the meteorology tower. The reason for this phenomenon is not clear. It may be partly due to the lightning channels of the meteorology tower not being totally captured, as it was nearer to the camera. It also seems logical to attribute such a result to the different tower heights, as the meteorology tower is two times higher than the old television tower. Nevertheless, no concrete evidence has been found to support this inference.

The recoil leader shown in Fig. 3 lasted more than 0.6 ms, which is a considerably long duration among the recoil leaders in this flash. Most of the time, the recoil leaders were only captured by one to two frames, indicating they were short in duration (within 0.3 ms, theoretically). Figure 4b shows the numbers of recoil leaders with different durations. For simplicity, the duration of 0.1 ms was considered to correspond to those recoil leaders captured by only one frame (the camera was operated at a speed of 10 000 fps), and so forth. Although such an approximation is not sufficiently precise, the figure nevertheless roughly demonstrates an exponential declining trend in recoil leader occurrence versus duration.

Figure 4  Statistical characteristics of recoil leaders: (a) occurrence frequency during the period of lightning, counted every 5 ms; (b) histogram of recoil leaders with different durations.
3.3 Radar reflectivity

A thunderstorm’s evolution and the associated charge structure may exert important effects on the lightning activity (Qie et al., 2005). Figure 5 shows a vertical cross section of the radar echo reflectivity when the concurrent upward lightning flashes occurred. The area of the towers was controlled by the thundercloud with a radar echo intensity of no more than 45 dBZ, indicating non-severe convective activity at that moment. Overall, two strong radar echo centers of the whole thunder system were both located more than 50 km away from the towers, with a maximum intensity of 60 dBZ. Although the radar echo over the tower area was not very strong, and the associated thundercloud covering the towers exhibited inactive lightning activities, tower-initiated lightning was relatively frequent. Besides the concurrent flashes studied in this paper, five other upward lightning flashes initiated from the meteorology tower during a short period of about 20 minutes. As shown in Fig. 5, the height of the strong radar echo center was only about 2–3 km. Consequently, as the cloud was carrying some negative charge, the associated charge center may also have been relatively low. This could have been the cause of the upward lightning from the towers without any preceding nearby lightning discharge.

It is generally considered that a tower with an effective height of lower than 100 m only involve downward lightning; and as tower height increases, the probability of initiating upward lightning increases, by up to 100% if the tower is taller than 500 m (Rakov and Uman, 2003). Based on this understanding, the old television tower, with its height of 112 m, would barely initiate upward lightning. The observations in this study indicated that the charge structure of the thunderstorm with its radar echo reflectivity center being very low is conducive to the occurrence of upward lightning from towers or grounded tall structures. As indicated in Fig. 5, the towers were separately underneath the two radar echo centers, which were not far from each other, and the region above the old television tower exhibited a larger area of relatively strong echo intensity than above the meteorology tower. This may be a possible reason for the large disparity in the number of recoil leaders over these two towers.

4 Conclusion

Concurrent upward lightning flashes from two neighboring towers with a horizontal distance of 3420 m between them were captured by a high-speed camera with a time resolution of 100 µs. Both discharges were of negative polarity and initiated from the towers with upward positive leaders. There was no preceding lightning activity before their occurrence, and their durations were both longer than 250 ms, without any dart leader-return stroke sequences after the current cutoff of the initial stage. Abundant recoil leaders, captured mostly by only one to two frames, were observed during the development of the upward lightning at both towers, although the recoil leaders over the lower tower were greater in number than that those over the higher tower. The highest occurrence frequency of recoil leaders was 26 per 5 ms at about 75 ms after the initiation of the upward lightning. The convective activity was not severe when the simultaneous tower flashes occurred, with the radar echo intensity in the area being no more than 45 dBZ. The radar echo centers over the two towers both involved extremely low altitudes of 2–3 km.

Different from multiple negative upward lightning from towers generally triggered by nearby discharge activities (especially +CG), the concurrent upward lightning flashes studied in this paper were self-initiated, and there was no triggering relationship between the two upward discharges since they were of the same polarity. It is rational to consider that the charge structure of the associated thundercloud played an important role in the occurrence of these multiple upward flashes. Although the old television tower is two times lower than the meteorology tower, the sufficiently low charge centers of the cloud ultimately resulted in the upward lightning with multiple strike points.

Figure 5  Vertical cross section of radar echo reflectivity when the concurrent upward lightning flashes occurred.
Acknowledgements. This research was supported by the National Basic Research Program of China (Grant No. 2014CB441405) and the National Natural Science Foundation of China (Grant No. 41375012).

References


