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TALL STRUCTURE LIGHTNING INDUCED BY SPRITE-PRODUCING DISCHARGES

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ABSTRACT: The large and rapid charge transfer of some +CGs can initiate upward positive leaders from tall structures while simultaneously initiating downward positive streamers below the base of the ionosphere in the form of sprites. Structures with >400 m height have a significantly enhanced probability of launching upward positive leaders, the presence of which is readily detected later if a dart leader propagates down the channel to ground, generating a −CG return stroke. Such tall structures can be repeatedly struck if, as often happens, sprite-producing +CGs repeatedly occur.

INTRODUCTION

Sprites are luminous electrical discharges which initiate near the base of the nighttime ionosphere at ≃75 km altitude [*Stanley et al.*, 1999; *McHarg et al.*, 2002] and propagate primarily downward under the influence of a strong quasi-electrostatic electric field from a lightning discharge below 8 km altitude [*Stanley*, 2000]. The lightning discharges which produce sprites are primarily positive cloud-to-grounds (+CGs) with unusually large charge moment changes (charge transfer times height) [*Boccippio et al.*, 1995; *Reising et al.*, 1996; *Cummer and Inan*, 1997; *Bell et al.*, 1998; *Reising et al.*, 1999; *Huang et al.*, 1999; *Cummer and Stanley*, 1999; *Stanley et al.*, 2000; *Cummer and Fullekrug*, 2001; *Hu et al.*, 2002]. The charge moment change associated with sprite initiation has been observed to be as low as 120 C·km, but is more typically >600 C·km [*Hu et al.*, 2002]; ∼30 times more than the ≃22 C·km of a typical −CG stroke [*Brook et al.*, 1962]. Analysis of the charge structure of sprite-producing flashes [*Stanley*, 2000] and parent storms [*Williams*, 1998; *Marshall et al.*, 2001] indicates that charge transfer, not height, is entirely responsible for the larger charge moments relative to average −CGs.

It has been known for over six decades that upward lightning can initiate from tall structures [*McEachron*, 1939]. This phenomena can be understood as resulting from the combined effects of electric field intensification at the top of a tall structure along with an applied field which changes faster than what the shielding corona layer can compensate for [*Brook et al.*, 1961; *Aleksandrov et al.*, 2001]. One serious consequence of the large and rapid charge transfers of sprite-producing discharges is that they may readily spawn upward leaders from tall structures. In this paper, we will show a couple of sprite-producing discharges which apparently produced upward lightning from the top of a tall tower. We will also show statistical data indicating that there are several other probable examples of upward lightning following +CG occurrence.

EXPERIMENT

On June 22, 1997, several sprites were observed above a small mesoscale convective system (MCS) near the Kennedy Space Center (KSC), Florida in association with horizontally extensive +CG discharges [*Stanley*, 2000]. CG locations were obtained from the National Lightning Detection Network [*Cummins et al.*, 1998] while the 3-dimensional discharge development was mapped with the KSC Lightning Detection and Ranging (LDAR) instrument [*Boccippio et al.*, 2001]. The CG locations will be compared with that of tall structures.

Sensors of the Los Alamos Sferic Array (LASA) [*Smith et al.*, 2002] have been operational in Florida since early 1999. Recorded LASA sferic waveforms can be post-processed to determine type, polarity, and source location. The location accuracy is <2 km [*Smith et al.*, 2002] in central Florida. Several months of LASA −CG locations over central Florida will be compared with that of tall structures.

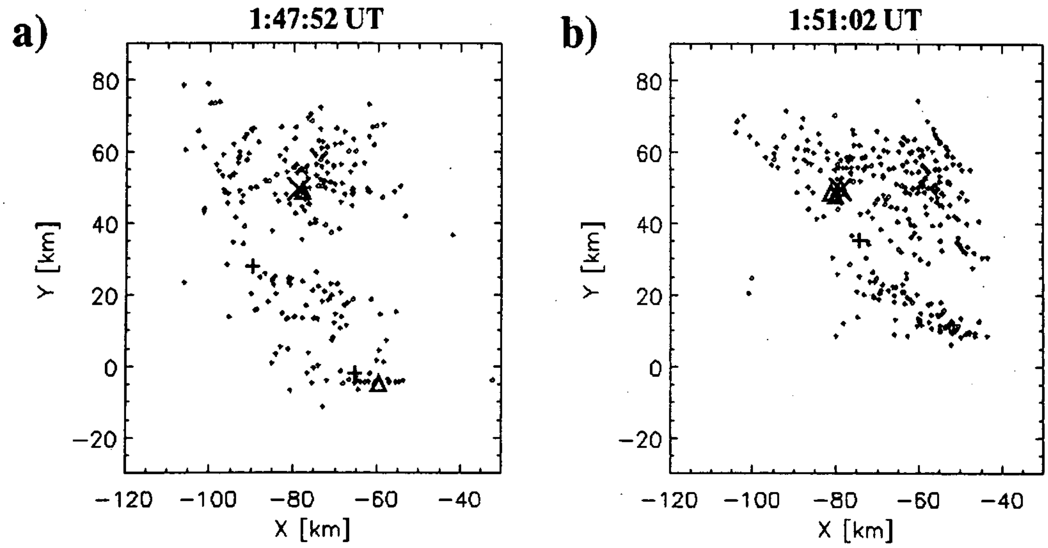

Figure 1: **a)** The 1:47:52 UT sprite-producing discharge with –CG stroke (△), +CG stroke (+), tower (**X**), and LDAR source (∘) locations indicated. One of the –CG locations coincides with that of a 457 m tower. **b)** The 1:51:02 UT sprite-producer. All three of the –CG stroke locations coincide with the same tower as before.

SPRITE-PRODUCING DISCHARGES ON JUNE 22, 1997

At KSC on June 22, 1997, sprites were observed at close range (<100 km) above a compact MCS near Orlando, Florida. A detailed analysis of the MCS, discharges, and sprites was presented by *Stanley* [2000]. Here, we focus on the CGs associated with a couple of the sprite-producing discharges.

Figure 1a shows the horizontal extent of the MCS's second sprite-producing discharge at 1:47:52 UT overlaid on CG and tower locations. The axis units correspond to cartesian coordinates in kilometers relative to the observation site at KSC. The flash originated from a convective storm core in the lower right, produced a 32 kA –CG at 1:47:51.476 UT, and then propagated into the stratiform region to the north-northwest (up and a bit left). It is also possible that the –CG originated from a separate flash immediately prior to that which propagated into the stratiform region. A +CG was indicated less than a second later near this –CG, though the weak 10 kA peak current suggests that it might have actually been an intracloud [*Cummins et al.*, 1998]. An 84 kA +CG was produced at 1:47:52.711 UT and was coincident with the sudden appearance of sprites above the discharge. Unfortunately, no charge moment estimate could be obtained for this +CG due to the lack of static electric field data.

At 1:47:53.750 UT, a 49 kA –CG was indicated by the NLDN below the horizontally extensive discharge in the stratiform region of the MCS while the discharge was still active. Curiously, this was the first –CG of the MCS to occur in the stratiform region instead of the convective region. What is particularly interesting about the –CG location is that it coincides with a 457 m tall tower.

The next sprite-producing discharge at 1:51:02 UT (Figure 1b) progressed in similar fashion from a convective core into the stratiform region to the northwest. A 61 kA +CG at 1:51:02.762 UT was coincident with the appearance of sprites in video. Electric field data obtained at KSC indicated that the +CG had a charge moment change of ≃390 C·km in 4 ms. This +CG was followed >300 ms later by multiple –CG strokes at 3.068 s (38 kA), 3.111 s (34 kA), and 3.196 s (22 kA). All of these –CG stroke locations coincided with the same 457 m tower as before. It is likely that the sudden and rapid removal of charge by the +CG was sufficient to launch an upward positive leader from the tower and that this led to the lowering of negative charge in the form of subsequent return strokes. This inferred sequence of development is very similar to that documented for ordinary triggered lightning [*Wang et al.*, 1999].

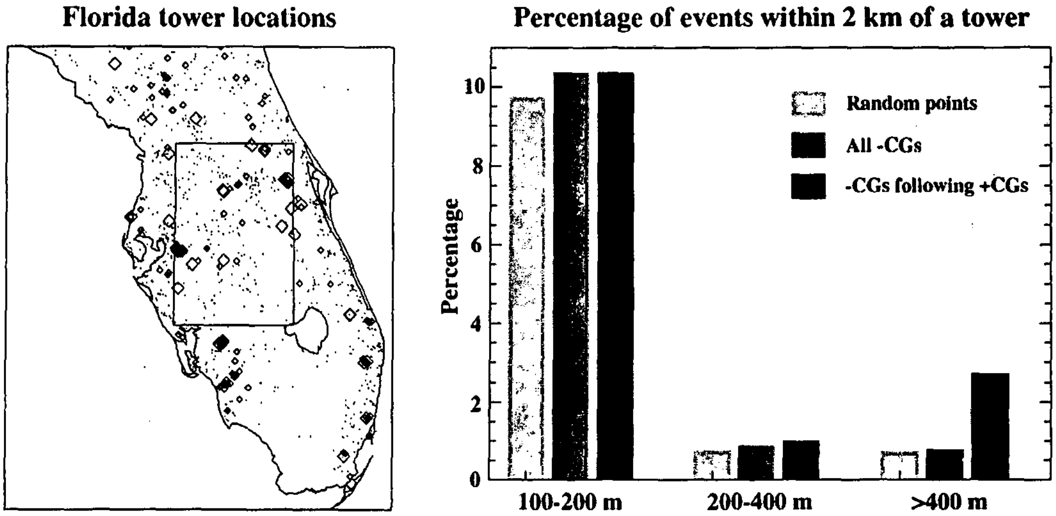

Figure 2: **a)** The locations of 100-200 m (·), 200-400 m (⋄), and >400 m (◇) tall structures in Florida. Only CGs within the box region were analyzed. **b)** The percentages of events which were located within 2 km of a tall structure within a height range. A >3-fold enhancement is clearly evident for post +CG −CGs near >400 m tall structures

LASA DATA FOR SUMMER OF 2001 AND 2002

A square region over central Florida, 27-29° N, 82.3-81.0° W, was chosen for this study. The peak lightning months of June-August were analyzed for the years 2001 and 2002. A total of 240,037 −CGs and 4,007 +CGs were identified by LASA within this region and time period. The +CGs were then used to locate possible -CGs which were spawned in a similar fashion to those described in the previous section. A total of 405 distinct −CGs followed within 1 second of a +CG and were within 40 km of the +CG.

Figure 2a shows the distribution of 100-200 m, 200-400 m, and >400 m tall structures in Florida and the region of interest. A random distribution of 50,000 points was generated within the region and the percentage of these points within 2 km (the LASA CG location error) of each of the three structure height ranges was calculated. These percentages were also calculated for all −CGs as well as the −CGs following +CGs. The results are shown in Figure 2b.

The percentage of −CGs correlated with tower positions is slightly higher than for a random point distribution for all structure heights. The significance of this is not clear though, since it might be due to a variation in the −CG density caused by a land-sea breeze convergence more than due to a logical enhanced strike probability on tall structures. What is clear from Figure 2b is that the −CGs which follow +CGs do not show a statistically enhanced probability of striking structures less than 400 m tall, but do show a more than three fold enhanced probability of striking >400 m tall structures. We speculate that this indicates a subset of +CGs with large charge moments are spawning upward lightning from the tallest towers.

DISCUSSION

We have used the occurrence of −CGs to locate probable upward lightning events associated with tall structures. However, upward positive leaders can be launched from tall structures without producing −CGs in much the same way as triggered lightning has been documented to often produce only a continuing current without subsequent return strokes. Thus, it is likely that the occurrence of upward lightning is more common than indicated in this study.

While it is well known that tall structures can more readily attract lightning, a particularly insidious quality of large charge moment +CGs is that they draw charge from a large horizontal region and often repeat. Thus, a tall tower can be repeatedly struck under these conditions, as was shown in Figure 1.

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