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# Study of the relationship between Sprites and lightning from the associated storms

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**Abstract**

**Sprites are emissions of light in the medium and high atmosphere associated with thunderstorms and cloud-to-ground lightning. The lightning of the Sprite associated storms of seven days with high activity of Sprites over Midwest USA, recorded from Yucca Ridge, Colorado, were studied. The Sprite associated storms had different percentages of positive cloud-to-ground lightning (7-17%), indicating that a high percentage of positive cloud-to-ground flashes is not a necessary condition to sprites occurrence. Most Sprites were associated with positive cloud-to-ground lightning with average peak current higher than the same value for the storm's total lightning population. There were more Sprites associated with 40-50 kA positive lightning than with any other range of peak current. A small number of Sprites seemed to be associated with negative cloud-to-ground lightning. The total negative current stayed high during the Sprites' period. The existence of a significant number of Sprites without the parent positive lightning suggests that some other unknown process, more complex than the one related to a single CG flash, would be part of the Sprites' generation mechanism, not very well understood yet.**

## INTRODUCTION

Since last century, there have been reports of brief optical emissions above thunderstorms. Before Franz et al. (1990) recorded the first low light level television images of these events, they were nothing but fairy tales. Nowadays there are scientific campaigns all over the world in order to record and investigate these new phenomena. Sprites are mesospheric/D region events associated with positive cloud-to-ground lightning flashes. They are brief (< 16 ms) luminous structures extending from 50-90 km altitude, possessing lateral dimensions of 5-30 km (Sentman at al., 1995). Sprites are predominantly red in color and all emission is found to be of the first positive bands of $N_2$ (Mende et al., 1995). They usually occur above large thunderstorm systems in association with positive cloud-to-ground (+CG) lightning, concentrating over a relatively small area called "sprite generating cell" (Lyons, 1996).
Sprites associated with storms over Mid-West USA were recorded between 9 and 29 of July 1996, during the Sprites96 Campaign. The observation site was located in Yucca Ridge, near Ft. Collins, CO (40.4$^o$ N, 105.1$^o$ W, 1,600 m). Sprites were recorded using an Isocon camera with ~22$^o$ field of view, fitted with a 665 nm red interference filter to obtain images of sprites in the $N_2$ first positive emission, with time resolution of 50 fields/sec (Armstrong et al., 1998). National Lightning Detection Network (NLDN) data, from seven days with high Sprites' activity, were analyzed. This work presents the results obtained during the study of the relationship between sprites and lightning from the associated storms, during Sprites96 Campaign.

## DATA SET

The analyzed days were: 6 (188), 7 (189), 11 (193), 19 (201), 21 (203), 22 (204) e 24 (206) of July 1996. Lightning data of each storm was isolated, for the period from 0-14 UT (16-8 LT), covering the "beginning" of the storm and its night period. The analysis of storm's average peak current, total peak current and CG number in 5-min intervals was performed to positive and negative flashes separately. Five-min intervals were chosen because it is approximately the relaxation time of the atmosphere, around 10-km height, due to lightning occurrence. Considering that the positive charge center would be around this altitude, the existence of some cumulative effect in the sprites generation mechanism due to +CG was investigated. Parameters as peak current distribution and polarity percentages were also analyzed.
Positive and negative sprites associated CG candidates, were identified using the time and spatial criteria described in São Sabbas (1999). The same parameters evaluated to storm's +/-CGs population were analyzed. The behavior of the curves obtained to positive and negative sprites associated CGs were compared to each other and to the curves obtained to storm's flashes.
Table 1 shows the observation period (camera "turned on/off"), the period in which sprites were recorded (sprites period), these periods duration and the total number of sprites recorded each night. In day 189 the end of sprites period (08:35 UT) was assumed as end of observation period (08:35 ? UT) because the last information was not available.
TABLE 1 – SPRITES RELATED DATA

| Day | Observation period (UT) | Duration | Sprites period (UT) | Duration | Number of Sprites |
|---|---|---|---|---|---|
| 188 | 04:54 – 08:20 | 3 h 26 min | 05:03 – 07:37 | 2 h 34 min | 36 |
| 189 | 03:49 – 08:35 ? | 4 h 46 min ? | 03:57 – 08:35 | 4 h 22 min | 88 |

| | | | | | |
|---|---|---|---|---|---|
| 193 | 03:55 – 08:50 | 4 h 55 min | 06:59 – 08:31 | 1 h 32 min | 38 |
| 201 | 03:30 – 08:28 | 4 h 58 min | 04:12 – 07:17 | 3 h 5 min | 83 |
| 203 | 03:34 – 10:10 | 6 h 44 min | 06:40 – 10:07 | 3 h 27 min | 212 |
| 204 | 03:23 – 08:41 | 5 h 4 min | 04:22 – 08:29 | 4 h 7 min | 84 |
| 206 | 03:32 – 08:56 | 5 h 24 min | 03:36 – 08:56 | 5 h 20 min | 205 |

**RESULTS**

Positive and negative sprites associated CG candidates were identified. These two groups of candidates had completely different behaviors. The 5-min average peak current of -CG candidates had low values oscillating around the -CG storm average, which stayed between 20-30 kA. On the other hand, the +CG candidates had high 5-min average peak current, oscillating between 50-140 kA, while the +CG storm's average was between 20-60 kA, supporting the suggestion that sprites associated +CG have high peak current (Lyons, 1996).

An unexpected result came from the analyses of the peak current percentage distribution of sprites associated +CG candidates (Fig. 1). There were more sprites associated with +CG that had peak current around 40-50 kA than with +CG with other peak current values (the last column is the sum of all +CG with peak current greater than 100 kA). This result could be interpreted as peak current range of 40-50 kA being the most produced in the storm. Looking at the percentage distribution of the peak current of storm's +CG (Fig. 2), one can see that this curve is centered at 10-20 kA peak current range, meaning that +CG with 40-50 kA were not majority in the storm. The curve in Figure 1 would only be explained by the present sprites theories if, through some unknown mechanism, it were the curve of +CG lightning with continuous current. It also suggests that some other completely unknown process may be occurring.

The -CG candidates and storm's -CG curves are quite similar; both are centered at 10-20 kA (not shown).

Figure 1 also shows that approximately 6% of the sprites were associated with +CG that had very low peak current, less than 20 kA, indicating that sprites may and do occur associated with +CG with any peak current value.

Most of sprites, 65%, were associated with a positive cloud-to ground flash candidate, supporting previous studies (Lyons, 1996). However 31% of sprites had candidates of both polarities, that is, just 34% of the sprites were only associated with positive flashes. 11% of the sprites were only associated with a negative candidate, and 24% of sprites were not associated with any CG, positive or negative.

Up to now, sprites have been considered associated with a single +CG lightning, no association with -CG has been made. The 11% of sprites associated with -CG and the 24% without an associated CG could be interpreted as sprites associated with undetected +CG flashes. It would suggest that the NLDN has lower detection efficiency than the 80-90% estimated value (Cummins et al., 1998). On the other hand, considering that sprites are really associated with -CG, these flashes should have some physical property not analyzed yet or not measured by the NLDN, such as continuous current, that would be important in the sprite generation process. The existence of 35% of sprites without a +CG associated candidate may also be another indication that sprites are the result of a more complex process than the one related to an unique CG flash.

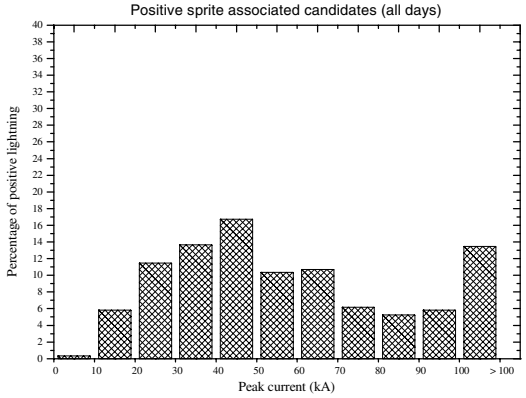


Figure 1. Percentage distribution of the peak current of +CG sprites associated candidates.

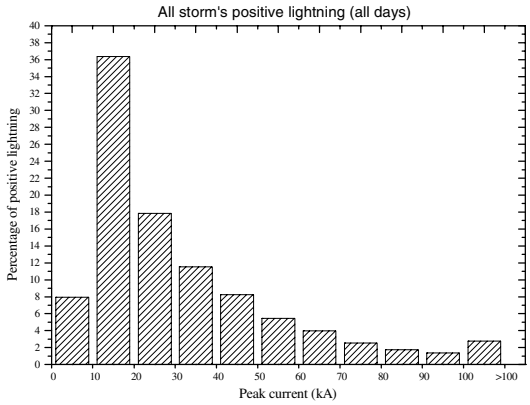


Figure 2. Percentage distribution of the peak current of storm's +CG.

In order to investigate the existence of a cumulative effect in the +CG flashes occurrence that would affect the sprites producing mechanism, a correlation study between the time distribution of total 5-min positive peak current and number of sprites (in 5-min intervals) was made. The same analysis was performed to -CG, and a conclusive correlation was not found, even though there was the tendency of sprites occur during the period of high total positive peak current (Fig. 3). Sprites also tended to occur during periods of high

rates of positive and negative CG lightning. Not finding a conclusive cumulative effect in the whole storm lightning behavior doesn't exclude the possibility of the existence of this effect at the vicinity of the sprites occurrence region.

It seems to exist a relationship between the beginning of the sprites occurrence and a growth in the rate of occurrence of storm's +CG with high peak current (above 50 kA). Day 203 is the only day that the observation period started before the lightning activity (Fig. 4); therefore, it was assumed that the beginning of the sprites occurrence was recorded. In all other days, lightning were already occurring when the camera was turned on, and sprites started to be recorded minutes after the camera was pointed to the sprites associated storms, except in day 193 (Table 1). In day 203 sprites started to be recorded after a continuous growth in the occurrence rate of storm's high peak current +CG, indicating that it can play an important role to the beginning of sprites activity. All other days had similar growths and peaks in the occurrence rate of storm's high peak current +CG before the beginning of the observation period (not shown).

Surprisingly, sprites occurred over storms with different percentages of positive cloud-to-ground lightning. The percentage of +CG varied from 7 to 17%, indicating that a high percentage of +CG is not a necessary condition to sprites occurrence. High percentage of +CG doesn't guarantee a high number of sprites too. Days 203 and 206 had the largest number of sprites (212 and 205, see Table 1) and the percentages of +CGs of these days were 17 and 9% respectively.

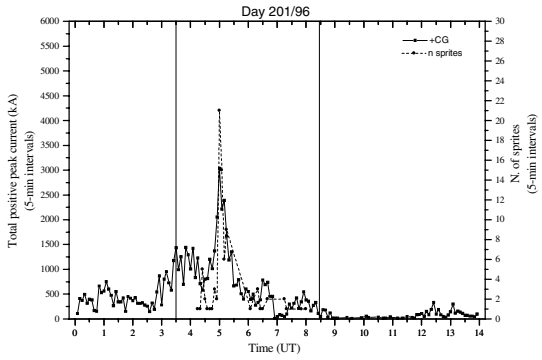


Figure 3. Time distribution of the total +CG peak current in 5-min intervals and number of sprites in 5-min intervals, day 201/96.

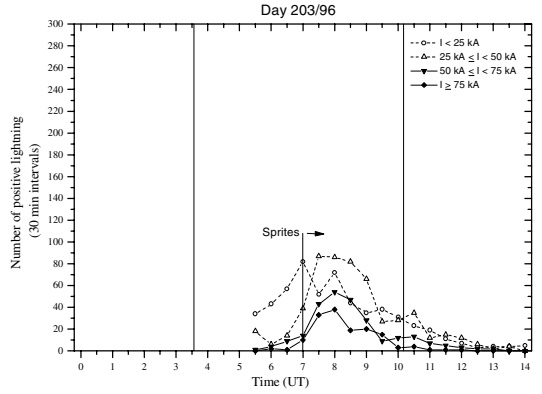


Figure 4. Time distribution of the number of positive lightning in 30-min intervals, for different peak current ranges, day 203/96.

conclusions

The lightning characteristics from 7 days of high sprites activity in Midwest USA, recorded from Yucca Ridge between 4 and 29 of July 1996, during Sprites96, were analyzed and the relationship between sprites and lightning from the associated storm was investigated.

The average of parent +CG candidate peak current was higher than the average of all +CG of the storm in all 7 days, supporting the suggestion that sprites are associated with high peak current +CG flashes. However, approximately 6% of the sprites were associated with +CGs with peak current less than 20 kA and there were more sprites associated with +CGs with peak current around 40-50 kA than with any other peak current values. Most +CGs of the storm had peak current around 10-20 kA.

There was 65% of sprites associated with +CG lightning, 34% were only associated with +CGs and 31% were also associated with -CGs. There was 11% of sprites only associated with -CG and 24% not associated with any CG, neither positive nor negative, suggesting that or the NLDN has a lower detection efficiency than estimated, or sprites are result of a more complex process than the one related to one positive cloud-to-ground lightning.

In order to make a preliminary investigation of a possible cumulative effect in the +CG flashes occurrence that would have implications in the sprites generation process, a correlation study between the total 5-min peak current of all +CG of the storm and the 5-min sprites occurrence rate was performed. There was the tendency of sprites occur during periods of high total 5-min peak current but, the cumulative effect was not conclusively found to the whole storm's +CGs behavior. However, it doesn't exclude the possibility of its existence in a smaller region at the vicinity of the sprites producing region of the storm.

Sprites had the tendency to occur during period of high positive and negative CGs occurrence rates.

Storms with low percentages of positive CG did developed sprites, indicating that a high percentage of +CG is not a necessary condition to sprites occurrence.

It seems to exist a relationship between the beginning of the sprites occurrence period and a growth in the high peak current +CGs occurrence rate, whereas it occurred in the only day that the beginning of the sprites period was recorded and similar peaks occurred before the observation period in all other days.

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