Statistical Studies of the Relations Between Sprites, Lightning and Thunderstorm Precipitation During the Eurosprite Campaigns

Oscar van der Velde[1], Serge Soula[1], Torsten Neubert[2]

[1] *Laboratoire d'Aérologie, UMR 5560, Université Paul Sabatier, Toulouse, France, oscarvdvelde@yahoo.com*
[2] *Danish National Space Center, Copenhagen, Denmark*

I. INTRODUCTION

The Eurosprite campaigns of 2003-2006, as part of the EU-funded CAL project, cameras in the Pyrenees and the Massif Central in France recorded more than 250 sprites mostly during nights of long-lived thunderstorms. Sprites have been documented over mesoscale convective systems in the later stages of their lives, when a large area of more or less stratiform precipitation has formed adjacent to convective cells (e.g. Lyons, 1996), but studies quantifying storm and lightning conditions related to sprites have remained scarce. We present results of a statistical study of sprite observations over France, involving 1) precipitation conditions associated with lightning strokes causing sprites, and those not associated with sprites; and 2) the morphology of sprites in relation to their causative +CG's peak current, delay and precipitation characteristics. The purpose is to quantify relations between precipitation, lightning and visual characteristics of sprites.

II. DATA AND METHODS

The dataset consists of 7 cases of nocturnal sprite-producing mesoscale convective systems (MCS), with 145 sprites. We used 5-minute radar reflectivity composites over France, Météorage lightning detection data (TOA/DF system), Meteosat cloud top temperatures and the image database of sprites and their times of occurrence. Radar data availability limits the analysis to include only events occurring over France. A more limited set of data is used for the sprite morphology analysis.

Within circles with radii of 5 and 10 km, radar reflectivity (in dBZ), average precipitation rate and cloud top temperatures were automatically summarized for every CG stroke. Radar pixels with a reflectivity lower than 9 dBZ ('dry') in the circle have been excluded.

Next, lightning strokes during a period of sprite occurrence were grouped into three basic classes: strokes not related to sprites (+, -), strokes occurring shortest (and <250 ms) before a sprite (triggering stroke, ST+), and accessory strokes that appeared very close to the sprite in time and space (S+, S-). This latter category occurred usually within 1 second before or after the sprite and in areas with sparse lightning activity, giving the appearance that they are part of the same lightning flash, taking into account the possibility of "spider lightning" flashes (e.g. Mazur et al., 1998) connecting these strokes. The categories of one-stroke flashes (0+, S0+), first strokes of sequences (1+,S1+) and any subsequent stroke (2+, S2+) are grouped by a assuming a leader speed of 10^4-10^6 m/s.

Sprites have often been classified subjectively as carrot sprites, columniform sprites, jellyfish, angels or other terms. We measured photogrammetrically the length of the different features of sprites to avoid most subjectivity: sprite body (the bright center), lower and upper streamers (branches), and the number of most representative elements. The triggering +CG distance is used as a proxy for sprite distance in the length calculations. The delay of a sprite to its causative +CG was determined from time-stamped video fields, lasting 20 ms. For two nights images were recorded with only 40 ms accuracy (progressive scan camera). The delays used here are relative to the start of the video field containing the sprite, thus, a minimum delay.

III. RESULTS

A selection of the various results is presented here. Peak currents of all +CG and first strokes of –CG lightning are compared to precipitation intensity (Figure 1) and uniformity. For +CGs, large peak currents (>100 kA) occur only in weak to moderate precipitation (<15 mm/hr) while high precipitation rates only produce weaker peak current +CGs. For –CGs the distribution shows a gradually increasing amount of large peak currents with decreasing precipitation rates. Uniformity shows a similar distribution.

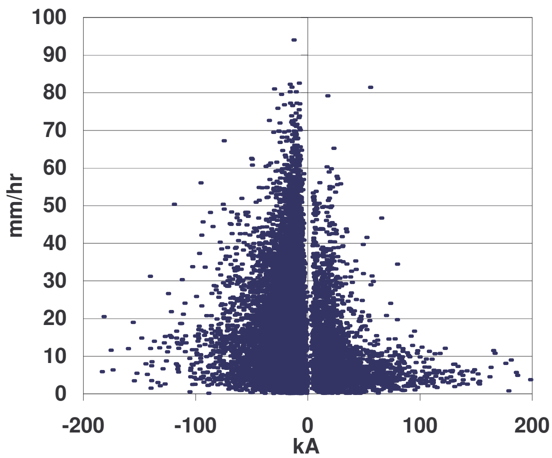

FIG 1. Peak current versus average precipitation rate over a 10 km circle around a stroke.

An example of the stroke classification results is shown below in Figure 2 for the case of 21 July 2003. Maximum reflectivity around a stroke clearly shows differences between normal +CG strokes (high, large variability) and those triggering sprites (lower), and accessory sprite-flash strokes (lowest). It appears that there is a preference for triggering strokes to strike near maxima adjacent to stratiform precipitation. Furthermore, there is a tendency that first strokes of a sequence strike near more intense precipitation, indicating a front-to-rear propagation of spider lightning in this leading line-trailing stratiform MCS. This is also suggested by the uniformity of precipitation (5-10 km average precipitation difference, not shown). In general, despite the distinctive tendencies, there is a quite large overlap of precipitation characteristics and peak currents between all classes, especially when joining the data of all cases. For peak currents, the 25th percentile value for triggering +CG falls together with the 75th percentile value of unrelated +CGs (37 kA) while the median values were 58 kA and 23 kA, respectively (averages: 68 and 30 kA). This is consistent with Lyons [1996]. We did not have charge moment change values available for all CGs, which should be more discriminating (Cummer and Lyons, 2005).

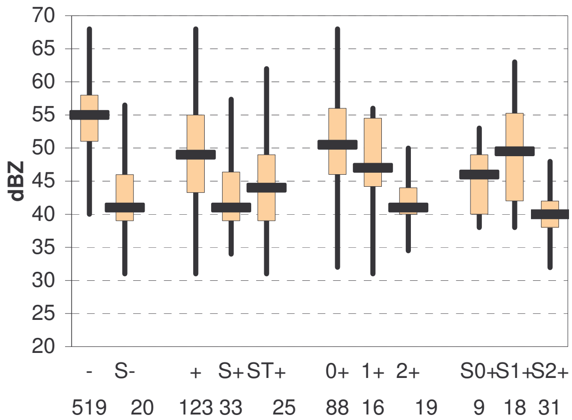

FIG 2. Boxplots for maximum reflectivity within 10 km radius around a stroke for 21 July 2003. The number of events in each group are indicated at the bottom.

Interesting distributions are found for sprite shape attributes. A strong apparent relation is found between the number of elements and the minimum delay to the triggering +CG stroke (Figure 3), with more than 6 elements only occurring with very short minimum delays (which can be negative if the +CG occurs after the frame onset). In contrast, half of the single-element sprites occur with delays of 50 - 215 ms, and these long-delayed sprites rarely contained more than 3 elements. Unlike Adachi et al. (2004), we found no relation between peak current and number of elements.

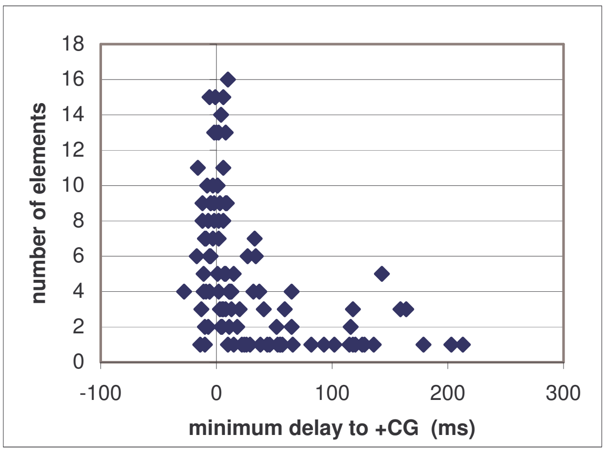

FIG 3. Number of main sprite elements and delay

Figure 4 shows that small sprites are usually short-delayed, but sprites taller than 30-35 km can be delayed anywhere between zero and more than 200 ms. This is mostly due to longer upper branches (figure not shown).

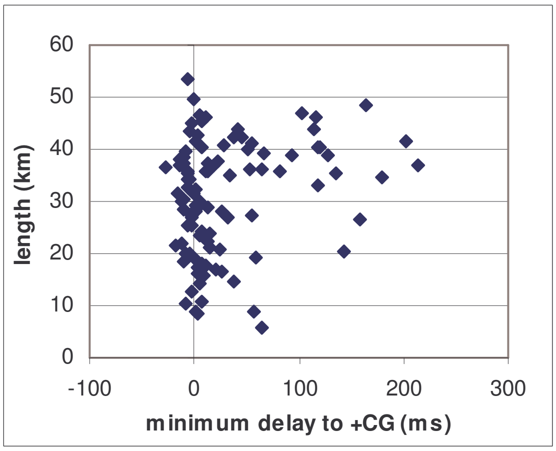

FIG 4. Total vertical sprite length and delay

Even though triggering lightning positions are not necessarily close to the position of sprites, in our data there seems to be a relation between the element count and uniformity of precipitation (graph not shown) near the triggering stroke. Sprites consisting of 6 or more elements only appear with the triggering stroke in very uniform precipitation with 5-10 km circle differences <2 mm/hr, while the +CGs causing sprites with fewer elements may also occur in less uniform precipitation and higher maximum reflectivities, closer to convective regions.

IV. SUMMARY

Sprite-related +CG strokes occur in weaker reflectivity areas than non-sprite +CGs, although there is overlap. The triggering stroke often occurs in less stratiform precipitation than accessory strokes. First strokes of inferred large horizontal flashes in a ‘leading line – trailing stratiform’ MCS tend to occur near higher radar reflectivity than subsequent strokes, suggesting propagation from convective into stratiform precipitation area. High peak current +CGs (and to a lesser extent –CGs) are limited to areas of weak to moderate, uniform precipitation. Sprites consisting of many elements are shorter delayed and generally have smaller top branches (if any), with a parent +CG in very stratiform precipitation, while tall single-element sprites tend to be significantly delayed with a parent +CG in less stratiform precipitation. A forthcoming paper will discuss the complete results.

V. REFERENCES

Adachi, T., H. Fukunishi, Y. Takahashi, and M. Sato, 2004: Roles of the EMP and QE field in the generation of columniform sprites, Geophys. Res. Lett., 31, L04107.

Cummer, S. A., and W. A. Lyons, 2005: Implications of lightning charge moment changes for sprite initiation, *J. Geophys. Res.*, 110, A04304.

Lyons, W. A., 1996: Sprite observations above the U.S. High Plains in relation to their parent thunderstorm systems, *J. Geophys. Res.*, 101(D23), 29,641–29,652.

Mazur, V., X.-M. Shao, P. R. Krehbiel, 1998: “Spider” lightning in intracloud and positive cloud-to-ground flashes, *J. Geophys. Res.*, 103 (D16), 19811-19822.