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Multi-instrumental analysis of large sprite events and of their producing storm in southwestern France

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ABSTRACT: During the night of 01-02 September, 2009, several TLEs including 3 halos and 16 distinct sprites were observed above a storm in north-western Mediterranean Sea with a camera at Pic du Midi (42.93° N, 0.14° E, 2877 m). Some of the sprites were especially large with vertical and horizontal extension estimated at about 70 km and 80 km, respectively. The TLE sequence lasted about one hour during a storm which developed 9 hours earlier over northern Spain in a very unstable atmosphere (CAPE at about 2000 J kg^{-1}). The storm was characterized by a very circular shape and a size of about 250×250 km^2 (cloud top temperature lower than -30°C) when the TLEs were produced (0209-0307 UT). The cloud to ground (CG) flash rate was large (45 min^{-1}) one hour before the first TLE was detected and very low (< 5 min^{-1}) during the TLE production. Over the 16 sprite events, 14 parent flashes were identified and their average peak current was 87 kA, while the associated charge moment changes which could be determined, ranged from 424 to 2088 C km. Most parent flashes were clearly located in the stratiform area of the storm and were into line with the lines of sight of the TLEs. For some parent flashes which were located closer to the convective area, the TLEs lines of sight were slightly shifted and remained over the stratiform area. Different ELF/LF radiations produced during the luminous events have been analyzed. A specific signature with long duration signal (> 5 ms) was observed for the electric field in ELF range in the cases of the very large sprites. Data from a VLF receiver shows the association between large sprites and early VLF signal perturbations.

1. INTRODUCTION

From several years and in the frame of Eurosprite program, several campaigns for TLEs observations are organized in southern Europe. Numerous sprites and other TLEs have been observed with video cameras above thunderclouds which regularly develop during the summer months from the beginning of May to mid-September [Soula et al., 2009; Neubert et al., 2008]. The typical characteristics of TLEs determined in other regions of the world are observed in the cases detected above storms in southern and Central France, along the Mediterranean coastline and above sea for the fall season. Case studies allow distinguishing some relationships between sprite type and delay of production after the parent CG flash [van der Velde et al., 2006] and specificities of the lightning activity associated with sprite production and CG flash sequences [Soula et al., 2010].

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In the present study, the occurrences and characteristics of TLEs detected above a storm, are analyzed and associated to data about the cloud structure, the lightning flash activity, and the ELF/VLF radiations. The camera system (Watec 902H with a 12mm f/0.8 lens and a FOV of 31°) was located at the Pic du Midi (42.93° N, 0.14° E, 2877 m altitude). The cloud top temperatures are provided by the Meteosat satellite from EUMETSAT based on radiometer data in the thermal infrared band (IR) at 10.5 - 12.5 µm. Data from the French meteorological radar network ARAMIS (24 C-band and S-band Doppler radars) provide the description of the structure of the storms. CG lightning flash characteristics (time of occurrence, location, polarity, peak current) are issued from two complementary detection systems (Meteorage and Linet). Charge moment change (CMC) values are determined from ELF signals recorded at the Széchenyi Isván Geophysical Observatory near Nagycenk, Hungary (NCK; 47.62ºN, 16.72ºE) (Sátori et al., 1996). Broadband LF radiations are provided by two antennas, one in France at 500 km of distance and one in Bath (GB) at 1280 km of distance.

2. CASE STUDY: STORM ON SEPTEMBER 2, 2009

2.1. ***Storm activity***

The storm developed northern Spain during the evening and moved eastward during the night in Gulf of Lion, as illustrated in Figure 1a-b with the cloud top temperature issued from infrared radiometer (10.5/12.5 µm) of the Meteosat Second Generation (MSG). Figure 1c displays the CG lightning flash density issued from Meteorage data. Most of CG flashes are observed to have been produced when the storm was located over sea in the Gulf of Lion. The CG flash density maximum is 2 km^{-2} within this area, where the storm was located during the occurrence of the TLEs observed from Pic du Midi (42.93° N, 0.14° E, 2877 m altitude) of which the location is indicated by a circle in Figure 1b. The locations of the 14 parent flashes of TLEs (triangle in Figure 1c) are all over sea.

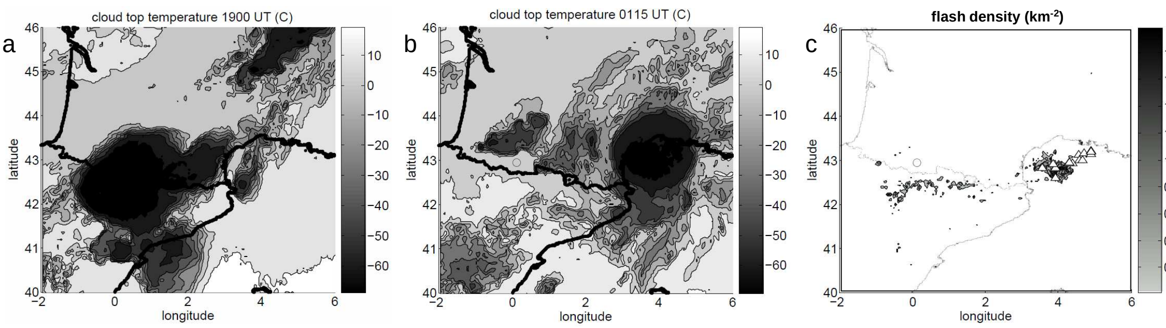

Figure 1. Cloud top temperature issued from MSG satellite: (a) at 1900 UT on September 1, (b) at 0115 UT on September 2. (c) CG lightning flash density over the whole storm lifetime averaged in 5 km × 5 km pixels. The triangles indicate the location of the sprite-parent flashes and the circle indicates the camera location.

Figure 2a displays the time series of the area of the cloud for several intervals of its top temperature (histograms) and that of the minimum value of the cloud top temperature (line). The storm development clearly exhibits two periods with a maximum of the total area (around 2100 and 0300 UT) preceded by minima of the cloud top temperature (around 1800 and 0030 UT). The value of the temperature is about -71°C for both minima observed. Figure 2b displays the rates (histograms) and the average peak currents (lines) for CG lightning flashes of both polarities, and for the same period. The maximum values of the CG flash rate are relatively well synchronous to the minima of the cloud top temperature (around 1815 UT and 0100 UT) and precede largely the cloud extension. The second period of CG lightning activity is much stronger with a maximum rate close to 45 min^{-1} (~ 18 min^{-1} for the first period), although the size of the cloud is lower. The CG flashes produced during this storm period when the storm is over sea lead to the largest densities as shown in Figure 1c. After the CG flash rate reach the maximum at 0110 UT, it decreases rapidly for both polarities and some CG flashes remain until 0310 UT with a significant increase of the average peak current of positive the CG flashes.

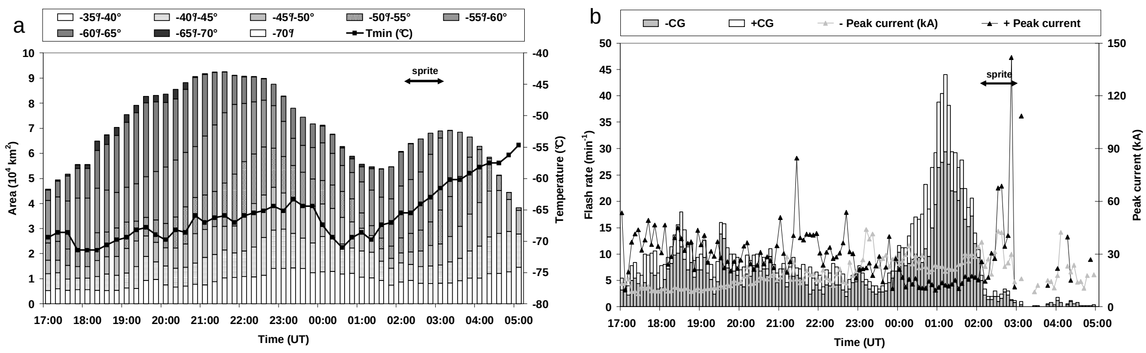

Figure 2. Time series of: (a) minimum temperature of the cloud top and cloud area for several ranges of cloud top temperatures. (b) rate and average peak current for both polarities of CG lightning flashes.

2.2. ***Conditions of production and characteristics of sprites***

The period of sprite production (0209-0307 UT) is short in comparison to the whole storm lifetime (5 hours during night conditions). During this period, the CG flash rate is low, the cloud area increases (especially that with a top temperature between -60°C and -45°C), and the average peak current for positive CG flashes is large. Nine video events were triggered including 16 sprite events, each one associated with a positive CG flash detected. Five sprite events are multiple with 2 or 3 sprites separated of a few tens of second. Three sprite of carrot-type are associated with a halo, a majority of cases are carrot-type and most of them have multiple elements. The sprite images in Figure 3 display three video frames of sprite including halo, carrot and column sprites. Most of the parent CG flashes are located out of the main CG flash area as indicated in Figure 1c, i.e. when the storm was in the most eastern part of the area it covered. The distance of observation ranges from 280 km to 390 km. The parent CG flashes of the sprites in Figure 3 have peak currents and CMC of 153 kA (left), 216 kA and 1678 C km (middle), and 86 kA and 2088 C km (right). Both sprites at left and right sides of Figure 3 exhibit an exceptional size estimated at about 70 km vertically (altitude from 30 km to 100 km) and 80 km horizontally.

Figure 3. Three frames (20 ms of resolution) from two different sprite events at 0233 and 0307 UT, including large carrots (left), halo with carrot and column (middle), and large carrots (right).

2.3. ***ELF signals associated with sprites***

LF broadband signals have been recorded for all parent CG flashes. Figure 4 shows two examples of electric field radiated from two parent flashes of sprites recorded in one video. The characteristics of the parent flash of the large sprite are a large CMC (2088 C km), a relatively high peak current (85 kA), a signal in the ULF range with two peaks separated by a few ms which is very different from the signal associated with the parent CG flash of the sprite with halo in frame 1. The latter has a CMC of 1678 C km and a peak current of 216 kA. A signal in LF band has been recorded before the large sprite (more than 100 ms) and classified as intracloud source (IC).

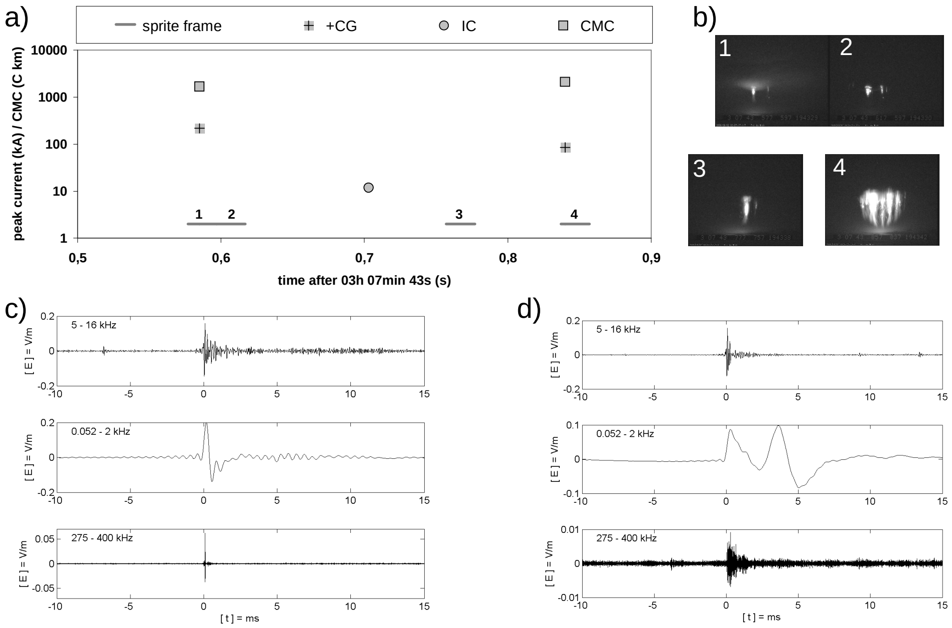

Figure 4. Sprite event at 03h 07min 47s. a) Peak current and CMC values of the CG flashes associated with the sprite event (2 +CG parent flashes) versus time. b) 4 frames from the video imagery at the times indicated in a). c) Amplitude of the electric field radiated after the +CG flash parent of the sprite in frame 1 (t=0 is the flash occurrence). d) Same as c) for the +CG flash parent of the sprite in frame 4.

3. CONCLUSIONS

Large sprites have been observed during the end of the lifetime of a storm when it was over sea and after a very high CG lightning flash rate. The size of the largest events is about 70 km vertically and 80 km horizontally. The cloud top has very cold temperature (~ -70°C) and therefore probably a large level of altitude, especially during the maximums of the lightning activity. The CMC values determined for a few parent flashes are strong, especially for the parent flash of the largest sprite, which is consistent with a high altitude of the charge or a complex discharge process (continuous current or long distance intracloud process).

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