Observations of Western Mediterranean TLE: LS8000 Intracloud Lightning and High-Speed Video

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1. INTRODUCTION

Transient luminous events (TLE) are electrical phenomena occurring between the ionosphere and the tops of thunderstorms. First discovered in 1989, the family of TLE now consists of different members: sprites, sprite halos, elves, jets, gigantic jets, trolls, and palm trees. Of these phenomena, only sprites are easily and regularly observed by sensitive cameras, and their global occurrence matches well with that of thunderstorms (Chen et al., 2008). Sprites occur at altitudes between 40 and 90 km in the mesosphere (Sentman et al., 1995) a few milliseconds to tens of milliseconds after intense positive cloud-to-ground flashes (+CG) (Boccippio et al., 1995) which can have continuing currents lasting for several hundred milliseconds so that large amounts of charge can be drained from the cloud. The most common thunderstorm systems to produce such +CG are mesoscale convective systems (MCS) and marine winter thunderstorms. In response to the charge removal that follows a +CG, a transient electric field develops between the cloud and the ionosphere which can be large enough for initiation of streamers. The exact conditions for initiation, and the morphological appearance of sprites, could also depend on pre-existing mesospheric ion density variations and radiated electric fields from (horizontal) lightning channels. Underlying lightning discharge processes are currently investigated by means of 2D and 3D time-of-arrival or interferometer lightning mapping systems, while high-speed cameras are used to gain insight in the development of sprites at fine temporal scales.

During the period July-December 2008, a low-light camera network registered about 600 TLE (sprites and elves) over the northwestern Mediterranean area. A number of events occurred over northeastern Spain within the area of detection of our intracloud lightning detection system (XDDE). The 2007/2008 upgrade of the SAFIR interferometric system to CP/LS8000 allows better detection efficiency of sprite-related lightning processes and offers in the best cases reasonably detailed horizontal lightning patterns under the optically determined direction of sprites, as shown by an example in the following section.

We also obtained the first high-speed video recordings of sprites and elves over the northwestern Mediterranean Sea. Observations were carried out with a Phantom V7.3 monochrome high speed camera attached to an image intensifier and a 50mm or 85mm f/1.4 lens. Each frame was time stamped within 1 micro-second resolution provided by a GPS receiver. From three nights of observation during December 2008 and January 2009 a total of 14 sprites and 19 elves were recorded at frame rates from 6688 to 15037 frames per second.

II. PRESENTATION OF RESEARCH

Two topics are presented: the development of horizontal lightning in association with sprite-triggering +CG flashes on 6-7 August 2008, and winter high-speed video observations of sprite, halo and elve development.

For the first topic, the XDDE interferometrically located lightning sources of a thunderstorm producing 17 sprites were run through a 6-point moving average to obtain the average location, direction and speed of propagation of lightning channels from the noisy raw data. The data was then plotted in space and time per sprite-producing flash with colors according to the period before +CG, between +CG and sprite, and after the sprite (figure 1).

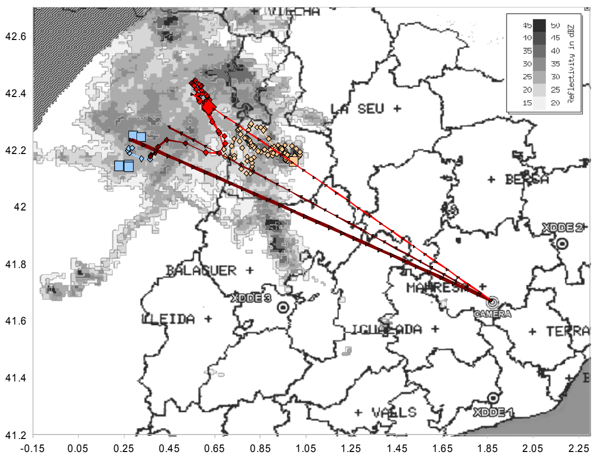

FIG. 1: Average source locations of the lightning flash that triggered the sprite of 21:24:40 UTC, as detected by the XDDE and LINET lightning detection systems in northeastern Spain. The background is the radar reflectivity image of 21:24 UTC. Lines indicate the great circle paths from the camera to the sprite features with triangles spaced every 5 km as an indication of horizontal scale. Large markers indicate LINET detections. Colors of all items correspond to the time evolution as indicated in Figure 2.

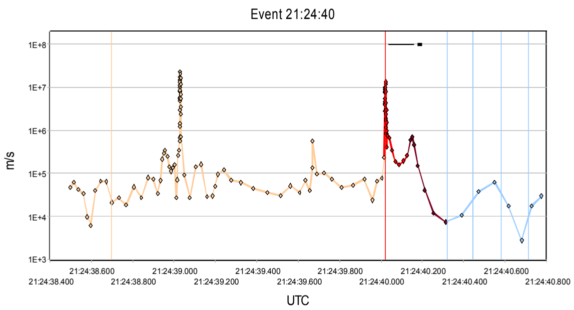

FIG. 2: Partial traject speed between average source locations and times, of the lightning flash that triggered the sprite of 21:24:40 UTC. Vertical lines indicate the times of LINET detections (sprite-triggering +CG red). The dark red color indicates the period of increased in-cloud activity preceding the delayed carrot sprite. Sprite frame times are indicated with black bars at the top.

The case shows initial lightning activity near the convective cores followed by the sprite-triggering +CG, which was accompanied by a burst of sources and a hardly visible sprite. The delayed carrot sprite occurred during a secondary burst of sources with higher apparent average propagation speed and the sprite location seems to match very well with the simultaneous lightning activity, which occurred inside the stratiform precipitation region of the MCS. Rearward propagation of spider lightning flashes was also described for example by Ely et al., 2008. Several more examples will be discussed.

The second part of this study, which we only summarize here, is an analysis of the differences in automatically computed flash characteristics (duration, size, propagation speed) between CGs of different peak current ranges and CGs that produced sprites. Sprite-producing flashes are shown to have significantly more sources than any other class of discharges (median 68 sources, versus 10 sources for other +CG), and propagate deeper into the stratiform region than other flashes.

The second topic is a demonstration of our first high-speed video recordings of sprites, elves and halos. The fine temporal resolution allows to study the complex behavior of streamer development and offers the opportunity to analyze the lighting-sprite causal relations whenever the sprites occur within the XDDE network. In winter 2008-2009 sprites were recorded over the Mediterranean Sea. Many elves were recorded by a normal frame rate low-light camera, but the high-speed camera recorded also weaker elves not seen by the normal camera. The example in Figure 3 is a stack of images showing the attraction of streamers to a pre-existing column sprite, lwhich may be explained by induction effects in a relatively conductive streamer channel. Upon collision, a slight repelling motion is visible.

III. RESULTS AND CONCLUSIONS

The location and horizontal size of sprites can be well explained by the temporal and spatial development of the lightning path. The majority of sprite-producing discharges started directly at the rear side of developing convective cores, either the +CG, or preceding negative breakdown (10^5 m s^{-1}). The +CG started a burst of VHF sources during which the sprite develops. Delayed carrot sprites developed after a secondary, smaller burst and were well collocated with the burst. The second part of the analysis concentrated on the metrics of +CG flashes sorted by peak current, and sprite-producing flashes, and showed that sprites are indeed produced by the largest, longest lasting discharges with particularly large line-perpendicular dimensions (42 km median compared to 16 km for +CG >30 kA). This study may well be first to describe such large horizontal flashes in European storms.

Additionally, we show the first high-speed video recordings of sprites and elves over European winter storms. Streamer velocities, elves, a case of a “bouncing sprite” and the relation between sprite duration and underlying lightning duration are discussed.

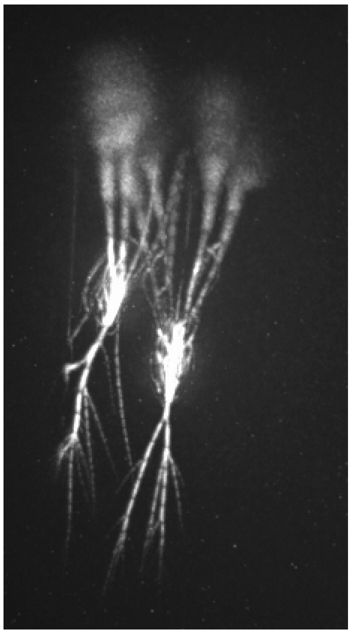

FIG. 3: A carrot sprite of which the downward positive streamers are attracted to a previously formed columniform streamer channel.

IV. AKNOWLEDGMENTS

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V. REFERENCES

Boccippio, D. J., E. R. Williams, S. J. Heckman, W. A. Lyons, I. T. Baker, and R. Boldi, Sprites, ELF transients, and positive ground strokes, *Science,* 269, 1088, 1995.

Chen, A. B., et al. (2008), Global distributions and occurrence rates of transient luminous events, *J. Geophys. Res.*, 113, A08306, doi:10.1029/2008JA013101.

Ely B. L., R. E. Orville, L. D. Carey, C. L. Hodapp (2008), Evolution of the total lightning structure in a leading-line, trailing-stratiform mesoscale convective system over Houston, Texas, J. Geophys. Res., 113, D08114, doi:10.1029/2007JD008445.

Sentman, D. D., E. M. Wescott, D. L. Osborne, D. L. Hampton, and M. J. Heavner (1995), Preliminary results from the Sprites94 aircraft campaign: 1. Red sprites, Geophys. Res. Lett., 22(10), 1205–1208.