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# Multi-Instrumental Observation of an Upward Cloud-To-Air Discharge Above a Mediterranean Storm

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# Geophysical Research Letters®



## RESEARCH LETTER

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### Key Points:

- An upward discharge embedded in a lightning flash is identified as a negative leader up to 14.2 km topped with streamers up to 17.2 km
- The upward leader is followed by Current Moment peaks and channel rebrightening connected to the negative charge of a positive dipole
- It has the opposite characteristics to the blue starter and common ones with triggering conditions of gigantic jets

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## Multi-Instrumental Observation of an Upward Cloud-To-Air Discharge Above a Mediterranean Storm

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**Abstract** On the night of 1 November 2022, a luminous discharge was produced above a storm over the northwestern Mediterranean Sea. An unprecedented set of optical and electrical data makes it possible to characterize this event. It is embedded in a lightning flash which starts with a positive discharge producing a high-power very high frequency (VHF) source at 6 km followed by VHF sources at 10 and 4 km within the cloud. The luminous event above the cloud is identified as a negative leader emerging from the cloud and reaching 14.2 km, topped with streamers up to about 17.2 km, and followed by channel rebrightening phases connected to the negative charge of a positive dipole. It is preceded by a convective surge and a production of positive flashes within the same storm region. Its polarity and its triggering conditions show similarities with those of gigantic jets.

**Plain Language Summary** Several pictures and one video of a luminous discharge above a storm over Mediterranean Sea allow us to determine its structure and the associated altitudes. Data from different lightning location systems show that it was embedded within a lightning flash, including an initial positive stroke, followed by substantial intracloud activity between two levels within the cloud, 4 and 10 km. The upward discharge corresponds with a negative leader developing up to 14.2 km altitude, long streamers at its top up to 17.2 km and three brightening of the leader channel connected with the main negative charge of the cloud. It was produced 10 min after the main convective surge of the storm. Finally, the whole discharge resembles the beginning of a gigantic jet in terms of negative polarity and conditions of production.

## 1. Introduction

On the night of 1 November 2022, several weather photographers obtained remarkable photos showing a jet-like phenomenon with long blue filaments above a Mediterranean storm. The question of identifying this luminous discharge was raised on social networks and by some expert scientists in altitude discharges. Indeed, the classification of the Transient Luminous Event (TLE), established by Lyons (2006) and others, include different upward discharges, especially blue jets (BJs) and gigantic jets (GJs) which emerge from the cloud top and propagate up to about 40 km and the ionosphere, respectively. Lyons et al. (2003) talked about another type of discharge rising from cumulonimbus tops that may be a true “cloud-to-stratosphere” lightning or simply another manifestation of the BJ.

Wescott et al. (1995) reported observations of several tens of BJs they characterized as narrow cones of blue light above a hail-bearing thunderstorm in Arkansas during the summer 1994. Then, Wescott et al. (1996) showed observations of another type of discharge above small areas of the same storm producing negative CG flashes: they called them “blue starters,” different from BJs by the altitude reached (up to 25 km). More recently, a blue starter photographed above a thunderstorm in west-central New Mexico was reported by Edens (2011). A Lightning Mapping Array (LMA) allowed the author to characterize the parent storm with a normal charge structure polarity and the blue starter as a positive discharge (positive charge carried upwards) initiating between the upper positive charge and a negative screening charge layer and propagating as a bidirectional discharge with downward negative and upward positive leaders. The three-channel positive leader emerged from the cloud top at 15.2 km and was topped by diffuse blue streamer zones up to 17 km with a gradual transition between leader and streamer. The author noted the difference with negative leaders at similar altitudes, which show a more abrupt transition between leader and streamer. Edens et al. (2014) analyzed a negative leader associated with an upward

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cloud-to-air discharge photographed on 20 August 2010, also in south-central New Mexico. They estimated the leader steps at more than 200 m, that is, an order of magnitude longer than those usually found at sea level.

The first observation of GJ was analyzed by Pasko et al. (2002). Since that date, several studies allowed to better characterize this TLE mainly produced by thunderstorms in tropical regions and over ocean (e.g., Chen et al., 2008; Peng et al., 2018; Soula et al., 2011; Su et al., 2003; van der Velde et al., 2019). However, it is possible to see such events in different conditions (van der Velde et al. (2010) with a GJ produced by a winter thunderstorm over the Mediterranean Sea [41.8°N]; Boggs et al. (2022) with a GJ observed in Southwest Oklahoma [35°N]). For an overwhelming majority of cases, the GJs are of negative polarity, connecting the main negative charge of the cloud to the ionosphere, and start with intracloud (IC) or positive CG discharge processes (Cummer et al., 2009; Krehbiel et al., 2008; Lu et al., 2011; Soula et al., 2011; van der Velde et al., 2019). The GJs emerge from a cloud with a weaker positive charge above the negative charge (Boggs et al., 2018; Krehbiel et al., 2008; Rioussat et al., 2010) and evolves first as a stepwise phase before accelerating in a continuous jump up to the ionosphere (van der Velde et al., 2019).

We analyze in the present study the discharge mentioned at the beginning of the introduction. The storm developed over the Mediterranean Sea at about 100 km from the coastline in southeastern France. Figure 1a displays the storm location at 21:25 UTC when the discharge was recorded. The geostationary satellite Meteosat recorded minimum values of the cloud top temperatures (CTTs) at approximately  $-60^{\circ}\text{C}$  and the tropopause height was estimated around 12 km, according to a radio sounding 150 km away at 00:00 UTC on 2 November 2022.

## 2. Observations

### 2.1. Optical Observation of the Luminous Event

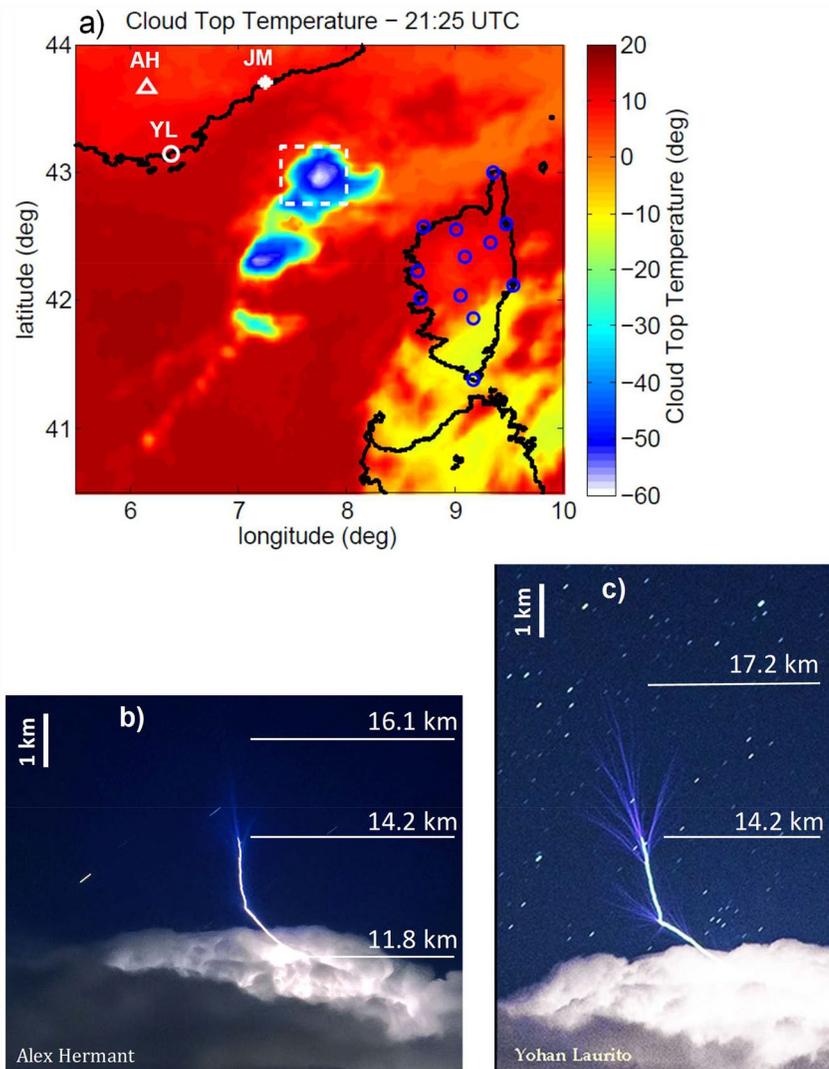
The pictures in Figure 1 were obtained by two storm chasers: (a) Alex Hermant (AH) at  $124^{\circ}$  of azimuth and a 30-s exposure using a Nikon D850 equipped with a 50 mm focal length and F5.6 aperture lens; (b) Yohan Laurito (YL) at  $103^{\circ}$  of azimuth and a 13-s exposure using a Nikon D780 equipped with a 50 mm focal length and F1.8G aperture lens. The two lines of sight provide the location of the discharge by triangulation and finally the distances, 140 km for AH and 100 km for YL. The analysis with “sky chart” allows us to determine the elevation of different parts of the discharge. The combination of distance and elevation shows that the bright channel emerges from the cloud at about 11.8 km and reaches a height of 14.2 km. From different parts (the cloud top around the channel, the channel top and bend) blue filaments are clearly visible, especially in Figure 1c up to 17.2 km altitude. The luminous aspect seems to correspond with an upward leader with long streamers in its intermediate steps.

In order to analyze the electrical characteristics of the luminous event, we have determined its time in UTC. The method successfully used for GJ analysis in Soula et al. (2011) consists in resetting the camera clock by recognizing common flashes with the French lightning location system Météorage (Schulz et al., 2016) for 10 min encompassing the time window of two successive videos obtained by AH during the storm and including several flashes. We obtain 21:20 UTC for the recording time of the luminous event picture. A unique flash is found in the Météorage database during the 30-s exposure time of the picture: it is composed of a 25-kA discharge classified as CG stroke by the Météorage system, followed by four IC pulses between 21:19:42.474 and 21:19:42.852 UTC.

### 2.2. LMA Data Associated With the Luminous Event

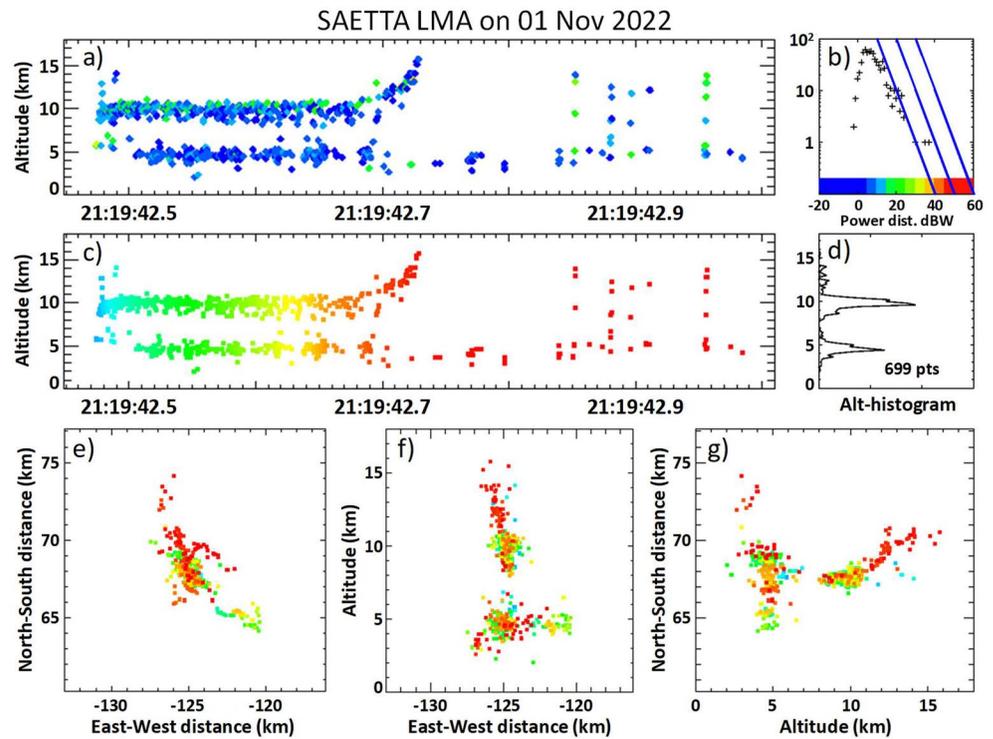
The flash associated with the luminous upward discharge is documented by the LMA system Suivi de l'Activité Electrique Tridimensionnelle Totale de l'Atmosphère (SAETTA) which includes 12 stations installed in Corsica at about 150 km from the storm (Figure 1a and Coquillat et al., 2019). SAETTA provides valuable insights into the electrical configuration of the cloud by examining the vertical distribution of very high frequency (VHF) source density and the power with which the VHF sources are detected (Coquillat et al., 2022). Indeed, the negative leader, characterized by discontinuous propagation, induces rapid fluctuations in electrical current over time, leading to the generation of powerful VHF waves. On the other hand, the positive leader propagates continuously, and the weaker VHF sources emitted along its path are primarily attributed to negative recoil leaders.

Figure 2 presents the VHF sources recorded during the flash on several graphs with a color code relating to the power of VHF sources (panel a) or relating to the time (panels c, e, f, and g). SAETTA detected a total of



**Figure 1.** (a) The storm and the observation sites: cloud top temperature with the colored scale (the white dashed frame shows the thunderstorm cell which produced the discharge); the camera locations with a white triangle labeled AH for Alex Hermant (picture in panel (b)), a white circle labeled YL for Yohan Laurito (picture in panel (c)) and a white star labeled JM for Jean Mortini (video). The blue circles indicate the Lightning Mapping Array stations of Suivi de l'Activité Electrique Tridimensionnelle Totale de l'Atmosphère in Corsica. The altitudes of the upward leader and blue streamers in panels (b) and (c) are calculated using the distance and the elevation obtained with the software Skychart.

699 VHF sources (with  $\chi^2 \leq 0.5$  and by at least six stations), between 21:19:42.474 and 21:19:42.956 UTC. On panel a, we see a high-power VHF source (yellow color) detected between 5 and 6 km at the initiation stage of the flash. Then, VHF sources are rapidly produced around 10 km, also around 4 km a little later (21:19:42.500 UTC). A large majority of the VHF sources are produced in the first half of the sequence, globally distributed around about 4 and 10 km, with a greater number and stronger powers (green color) at 10 km. Panel d confirms this distribution of the VHF sources according to the altitude, which indicates the polarity of the leaders involved, negative at 10 km and positive at 4 km, and therefore a positively (negatively) charged area at 10 km (4 km). At 21:19:42.73 UTC, VHF sources are detected up to an altitude of about 16 km with a faster and faster upward propagation, which means they could be produced above the leader channel, within the streamer zone of the discharge. The VHF sources are less numerous and at variable altitude in the second half of the sequence and some of high power are detected almost simultaneously between 4 and 14 km at specific times, for example, at 21:19:42.850 and 21:19:42.955 UTC. Panels (e, f, and g) give an idea of the horizontal extent of the lightning flash: approximately 10 km (south-north) by 7 km (west-east) for the lower negative charge, and much less for the upper positive charge.

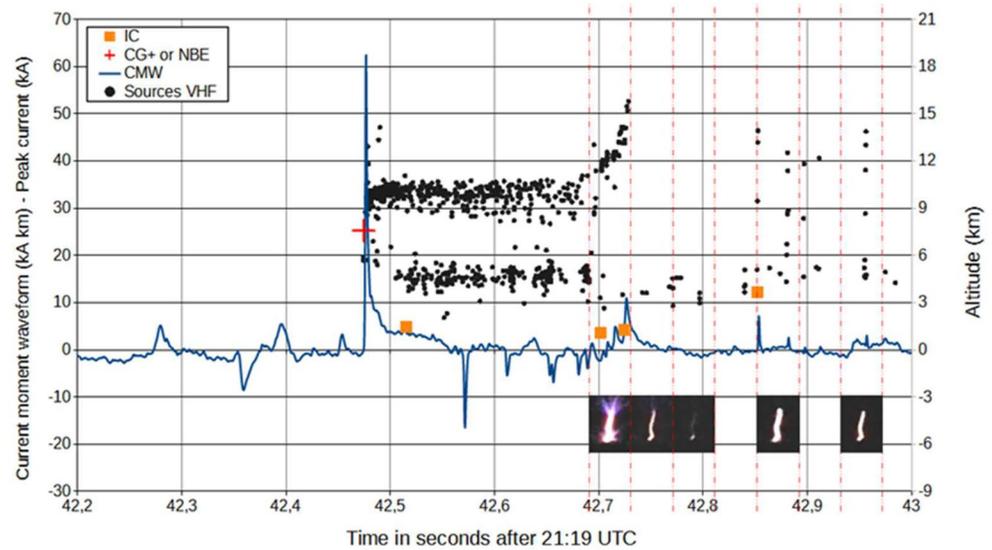


**Figure 2.** The Suivi de l'Activité Electrique Tridimensionnelle Totale de l'Atmosphère network's Lightning Mapping Array data presented in several panels: (a) Time-altitude distribution of very high frequency (VHF) sources colored according to the power; (b) distribution of VHF sources versus their power; (c) time-altitude distribution of VHF sources colored according to the time; (d) distribution of VHF sources versus altitude; (e) horizontal representation of VHF sources; (f) altitude versus east-west distance distribution of VHF sources; (g) altitude vs. north-south distance distribution of VHF sources; the color of the dots in panels (e, f, and g) represents the time of the VHF according to the scale in panel (c).

### 2.3. Chronology of the Luminous Event

Figure 3 displays the chronology of all optical and electrical/electromagnetic information recorded during the flash. In addition to the VHF sources recorded by SAETTA, it includes the current moment waveform (CMW) obtained from measurements of an extremely low frequency (ELF) receiver system in the Bieszczady mountains in Poland (49.2°N and 22.5°E), 1,345 km apart the storm. The ELF system measures the magnetic field component of electromagnetic waves with two antennas oriented to north-south and east-west directions, respectively, in the frequency range 0.02 Hz–1.1 kHz. The methodology to reconstruct both CMW and charge moment change (CMC) is described in Mlynarczyk et al. (2015). Figure 3 includes also the peak current of the five detections by Météorage in LF range during the flash. We obtained a video of the event recorded by the photographer Jean Mortini (JM in Figure 1a) in Nice (France). We plot in Figure 3 the most relevant frames processed from the video imagery at a rate of 25 frames per second (40 ms time windows).

In the following, the time is in second after 21:19 UTC. The flash initiation at 42.474 s coincides with a +25-kA stroke from Météorage, a peak at 62 kA km in the CMW and a high-power VHF source. This early discharge in the flash, followed by a significant concentration of VHF sources at altitudes around 10 km, is consistent with an NBE (narrow bipolar event) (Lu et al., 2011; Rison et al., 2016). An IC pulse with a low positive peak current (5 kA) is recorded at 42.515 s by Météorage and VHF sources are then detected at 4 km, which shows the negative cloud charge contribution to IC discharge processes. Between 42.55 s and about 42.68 s, the CMW exhibits peaks in negative values without any detection by Météorage. The ELF signals measured by two orthogonal antennas show that these discharges occurred in a different location (the angle of arrival differs by nearly 45°). VHF sources are detected at 4 km around 42.69 s and then, mainly at 10 km and higher and higher during about 40 ms, reaching the level of 15.8 km at 42.73 s simultaneously to a positive peak in the CMW and a detection by Météorage classified as a positive IC pulse. Simultaneously, a bright channel is visible above the cloud in the video, while its luminosity decreases and completely disappears after two more frames, that is, about 100 ms



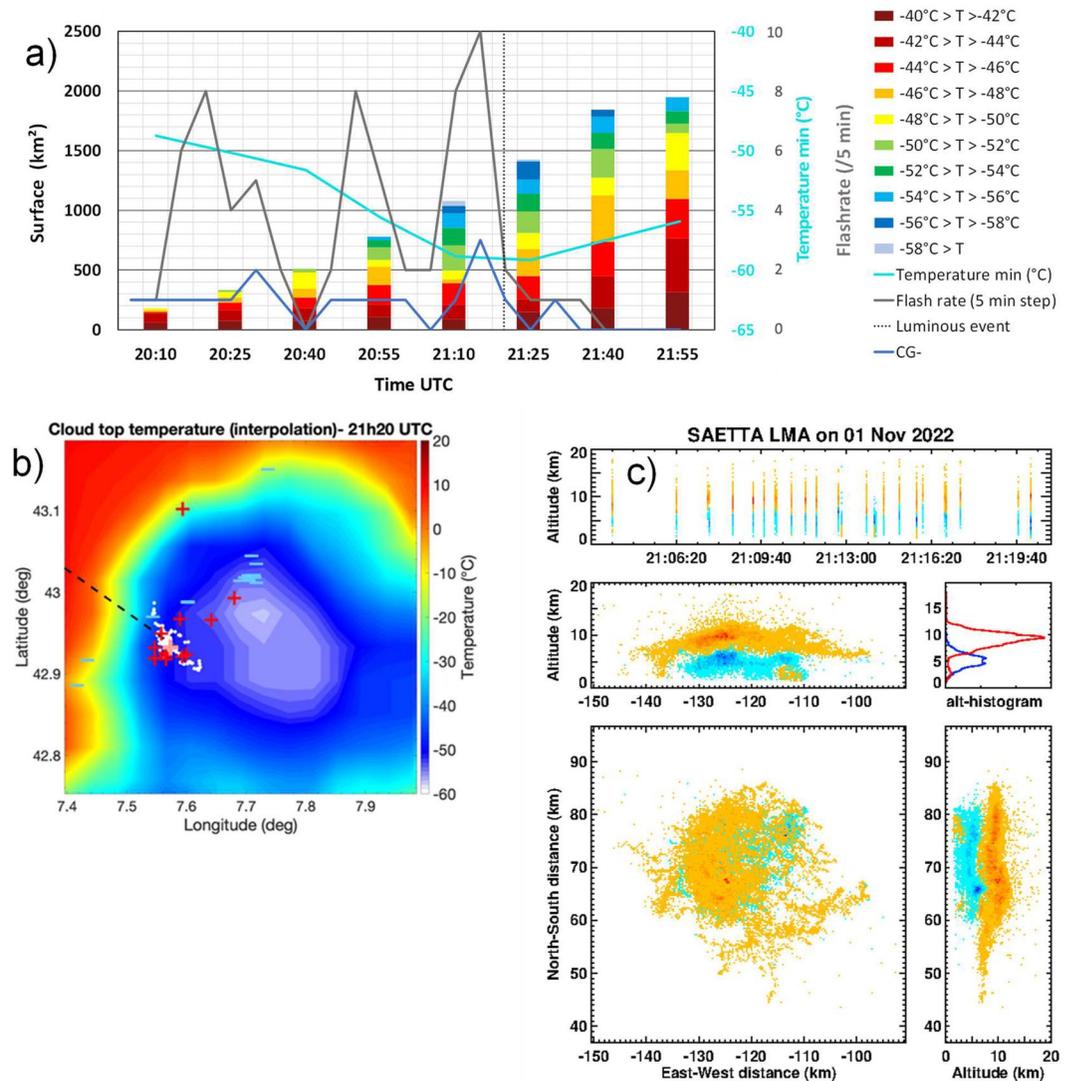
**Figure 3.** Combination of optical and electrical information during the luminous event: time series of the current moment waveform issued from extremely low frequency radiations (blue curve, in kA km), the altitude of very high frequency sources from Suivi de l'Activité Electrique Tridimensionnelle Totale de l'Atmosphère (black dots), the peak current (in kA) of narrow bipolar event pulse (red plus) and intracloud (IC) pulses (orange squares) from Météorage, and the images from a video (red bars represent the exposure duration and time of the images).

later. The power and the density of the VHF sources before the CMW peak and the positive polarity of this peak suggest a leader and a stroke which carries negative charge upwards. Then, two other small positive CMW peaks occur at 42.85 and 42.95 s, the first one simultaneously to a positive IC pulse from Météorage. These two CMW peaks correspond with leader channel rebrightening in the video imagery, the first a little more luminous than the second.

#### 2.4. Convective and Electrical Context of the Luminous Event

The thunderstorm which produced the luminous event is analyzed in terms of CTT thanks to the thermic infrared channel of the Spinning Enhanced Visible and InfraRed Imager (SEVIRI) radiometer on board the Meteosat Second Generation (MSG; Aminou et al., 1997). Figure 4a shows the time series of several parameters to characterize the storm activity between 20:05 and 22:10 UTC:  $T_m$  the minimum of CTT;  $A(\tau_1, \tau_2)$  the fractional areas of cloud top with the CTT between  $\tau_1$  and  $\tau_2$ ; FR the total flash rate from LMA and the CG-flash rate from Météorage. The storm activity starts around 20:10 UTC with a weak convection characterized by CTT around  $-49^\circ\text{C}$  and mainly IC flashes. Then, the convection intensifies until 21:10 UTC with  $T_m$  decreasing first by  $1.5^\circ\text{C}$  every 15 min and then by  $3.5^\circ\text{C}$ . The peak of convection occurs at 21:10 UTC, with the largest area  $A(-58)$  (CTT  $< -58^\circ\text{C}$ ) covering approximately  $45\text{ km}^2$ , and a maximum FR at 10 flashes per 5 min at 21:15 UTC, including a large majority of CG+/IC+ flashes (close to 80%). Finally,  $T_m$  reaches its minimum ( $-59.2^\circ\text{C}$ ) at 21:25 UTC although the coldest area  $A(-58)$  decreases to  $15\text{ km}^2$  and FR decreases to 1 flash per 5 min. After 21:25 UTC, the convection gradually decreases with very few flashes and a spreading cloud, which indicates the storm dissipation. The flash rate exhibits three cycles, peaking at 20:20, 20:50, and 21:15 UTC, respectively. The third cycle appears the most significant, it is associated with the peak of convection and precedes the luminous event by 5–10 min. FR is about two flashes per 5 min when the luminous event occurs.

Figure 4b plots several elements superimposed to the CTT interpolated at 21:20 UTC: the line of sight of the luminous event from AH location, the VHF sources associated with the luminous event at 21:19:42 UTC, the CG strokes (including strong IC+ discharges) detected by Météorage during 10 min before it. The flash matches with the line of sight in a cloud region at about 15 km west-southwest of the cloud top. There is a significant accumulation of positive discharges in this cloud region within the 10 min preceding the luminous event. There are  $-CG$  strokes at different locations, especially a few km to the north of the coldest cloud top. Figure 4c displays the 20-min electrical structure (positive and negative regions in orange and blue, respectively) of the convective



**Figure 4.** (a) Evolution of cloud top areas  $A(\tau_1, \tau_2)$  in km<sup>2</sup> and with temperature intervals of 2°C (stacked colored histograms), lightning flash rate FR per 5 min (black curve), CG-flash rate (blue curve) and minimum cloud top temperature (CTT)  $T_m$  (sky blue curve). The luminous event time is indicated by the black dotted line. (b) CTT interpolated at 21:20 UTC (color scale), location of the very high frequency (VHF) sources associated with the flash of the luminous event (white dots), discharges from Météorage between 21:10 and 21:20 (red plus for positive, pink plus for the positive discharge associated with the luminous event at 21:19:42.474 and blue minus for -CG), line of sight of AH picture (black dashed line). (c) 20 min of Suivi de l'Activité Electrique Tridimensionnelle Totale de l'Atmosphère VHF sources before the luminous event presented in several panels and colored according to the polarity of the charge region (blue for negative, orange/red for positive): (top) time-altitude distribution, (middle left) altitude versus east-west distance distribution, (middle right) distribution of VHF sources versus altitude, (bottom left) horizontal representation, and (bottom right) altitude versus north-south distance distribution.

cell, deduced from the LMA system observations including 22 flashes. The positive dipole is well visible over the whole storm throughout this period. The first panel shows a gap of 137 s without any flash before the luminous event at 21:19:42 UT. The vertical distribution of the VHF sources (middle right panel) indicates a more pronounced difference between the density of VHF sources in the positive region (red curve) and the negative one (blue curve) than in panel d of Figure 2. It means the flash at 21:19:42 UT exhibits a specific discharge scheme with a bigger contribution of the negative region compared to the other flashes of the period. Furthermore, the extent of the upper positive charge is much larger than that in Figure 2 deduced from the flash of the luminous. We note the maximum of VHF source density is located at about (-125 km; 68 km) which is also the location of the upward discharge at 21:19:42 UTC.

### 3. Discussion

The emergence of the luminous event above the cloud and its terminal altitude could make us think about a blue starter. However, it differs in polarity since blue starters and jets are characterized by positive charge carried upwards and associated with negative CG flashes (Edens, 2011; Suzuki et al., 2012). Our luminous event shares similarities with a description made in Lyons et al. (2003), for upward discharges which appear bright, white to yellow in color, relatively straight, with finer-scale streamer-like filaments at the top. A similar cloud-to-air discharge was studied by Edens et al. (2014), although exhibiting shorter blue streamers. This flash had a negative polarity and was on the margins of the convective core. The authors stated that it could have similarities with a “bolt-from-the-blue,” referring to a flash striking several kilometers away from a thunderstorm and occurring, as the GJs, in a context of a charge imbalance between the depleted positive upper charge and the main negative charge (Krehbiel et al., 2008). The GJs emerge from the cloud top as negative leaders and propagate faster and faster up to the ionosphere (Soula et al., 2011; van der Velde et al., 2019).

The event reported in this study starts in the same conditions of charge imbalance according to the large proportion of flashes involving the upper positive charge before it. A detailed analysis of these flashes shows structures relatively homogeneous with a significant horizontal development in the upper positive region. On the contrary, the upward discharge remains confined in a relatively narrow space corresponding to the maximum of the VHF source density within this positive region, at the end of a convective pulse, which agrees with Boggs et al. (2018). This supports the idea that an upward discharge can develop when the upper positive charge is weakened, either by previous flashes or by strong storm top divergence and turbulence (Boggs et al., 2018). The upward discharge emerges from the cloud top as a GJ and stops a few kilometers above, producing VHF radiation up to within the streamer zone. The vertical speed of the leader in the present study is around  $500 \text{ km s}^{-1}$  in its upper part, whereas it is from 400 to  $2,000 \text{ km s}^{-1}$  for a GJ (Soula et al., 2011). The terminal speed of our leader is therefore in the speed range of the lower part of a GJ. The rebrightening phases of the present discharge visible in the video imagery and the CMW, seem to be similar to those commonly observed at the end of the GJs, called “final leader” in van der Velde et al. (2019). Thus, the present discharge has the greatest number of points in common with the GJs.

By integrating the CMW to obtain the CMC, the impact of the first discharge (NBE) shows a CMC of 448 C km, including the continuing current. During its initial 40 ms, it produces a CMC of 346 C km, which is equivalent to a charge transfer of 50 C for an NBE.

### 4. Summary

During the night of 1 November 2022, an upward luminous discharge was observed by several photographers above the cloud top of a storm over Mediterranean Sea, 90 km south-southeast of Nice (France). The analysis of two pictures and one video shows it emerges from the cloud top at 11.8 km altitude, develops upwards under the shape of a bright channel up to 14.2 km and blue filaments up to 17.2 km, and produces three bright illuminations of the channel in less than 0.3 s.

The lightning flash associated with this luminous event is documented by several systems in different frequency ranges. It lasts 482 ms according to the VHF sources detected by the LMA and is produced in a positive dipole structure with the upper positive pole around 10 km and the negative one between 4 and 5 km. It starts with a discharge classified as a positive stroke and producing powerful VHF sources, that resembles to an NBE. VHF sources are produced within both charge regions of the positive dipole during about 200 ms, but within a very narrow part of the upper positive region. Then, a negative leader develops upwards up to 14.2 km, with streamers up to 17.2 km producing VHF sources up to 15.8 km, a positive peak of CMW and the first luminous brightening of the channel. The VHF sources show the connection between the brightening stages of the channel and the lower negative charge, while two of them are classified as positive IC pulses by Météorage. The storm context is characterized by a high proportion of positive flashes within the region of the upward discharge, which suggests a weakened positive charge.

The remarkable set of optical and electrical data on this case of discharge shows it differs from the blue starters already documented, by its polarity and its triggering conditions. On the other hand, it starts under the same conditions as a GJ and ends after a few kilometers of ascent above the cloud, which makes one think to a jet starter.

## Data Availability Statement

The data files used in this work and the description file are available online via Zenodo on (Hausknost et al., 2023).

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## References

- Aminou, D. M. A., Jacquet, B., & Pasternak, F. (1997). Characteristics of the Meteosat Second Generation (MSG) radiometer/imager: SEVIRI. In *Proceedings of SPIE 3221, Sensors, Systems, and Next-Generation Satellites*. <https://doi.org/10.1117/12.298084>
- Boggs, L. D., Liu, N., Rioussset, J. A., Shi, F., Lazarus, S., Splitt, M., & K. Rassoul, H. (2018). Thunderstorm charge structures producing gigantic jets. *Scientific Reports*, 8(1), 18085. <https://doi.org/10.1038/s41598-018-36309-z>
- Boggs, L. D., Mach, D., Bruning, E., Liu, N., van der Velde, O. A., Montanya, J., et al. (2022). Upward propagation of gigantic jets revealed by 3D radio and optical mapping. *Science Advances*, 8(31), eabl8731. <https://doi.org/10.1126/sciadv.abl8731>
- Chen, A. B., Kuo, C. L., Lee, Y. J., Su, H. T., Hsu, R. R., Chern, J. L., et al. (2008). Global distributions and occurrence rates of transient luminous events. *Journal of Geophysical Research*, 113(A8), A08306. <https://doi.org/10.1029/2008JA013101>
- Coquillat, S., Defer, E., de Guibert, P., Lambert, D., Pinty, J.-P., Pont, V., et al. (2019). SAETTA: High-resolution 3-D mapping of the total lightning activity in the Mediterranean Basin over Corsica, with a focus on a mesoscale convective system event. *Atmospheric Measurement Techniques*, 12(11), 5765–5790. <https://doi.org/10.5194/amt-12-5765-2019>
- Coquillat, S., Pont, V., Lambert, D., Houel, R., Pardé, M., Kreitz, M., et al. (2022). Six years of electrified convection over the island of Corsica monitored by SAETTA: General trends and anomalously electrified thunderstorms during African dust south flow events. *Atmospheric Research*, 275, 106227. <https://doi.org/10.1016/j.atmosres.2022.106227>
- Cummer, S. A., Li, J., Han, F., Lu, G., Jaugey, N., Lyons, W. A., & Nelson, T. E. (2009). Quantification of the troposphere-to-ionosphere charge transfer in a gigantic jet. *Nature Geoscience*, 2(9), 617–620. <https://doi.org/10.1038/NNGEO607>
- Edens, H. E. (2011). Photographic and lightning mapping observations of a blue starter over a New Mexico thunderstorm. *Geophysical Research Letters*, 38(17), L17804. <https://doi.org/10.1029/2011GL048543>
- Edens, H. E., Eack, K. B., Rison, W., & Hunyady, S. J. (2014). Photographic observations of streamers and steps in a cloud-to-air negative leader. *Geophysical Research Letters*, 41(4), 1336–1342. <https://doi.org/10.1002/2013GL059180>
- Hausknost, G., Ventre, A., Soula, S., Coquillat, S., Mlynarczyk, J., & Hermant, A. (2023). Multi-instrumental observation of an upward cloud-to-air discharge above a Mediterranean storm [Dataset]. <https://doi.org/10.5281/zenodo.8369472>
- Krehbiel, P., Rioussset, J., Pasko, V., Thomas, R. J., Rison, W., Stanley, M. A., & Edens, H. E. (2008). Upward electrical discharges from thunderstorms. *Nature Geoscience*, 1(4), 233–237. <https://doi.org/10.1038/ngeo162>
- Lu, G., Cummer, S. A., Lyons, W. A., Krehbiel, P. R., Li, J., Rison, W., et al. (2011). Lightning development associated with two negative gigantic jets. *Geophysical Research Letters*, 38(12), L12801. <https://doi.org/10.1029/2011GL047662>
- Lyons, W. A. (2006). The meteorology of transient luminous events. An introduction and overview. In M. Fullekrug, E. A. Mareev, & M. J. Rycroft (Eds.), *NATO Advanced Study Institute on Sprites, Elves and Intense Lightning Discharges* (pp. 19–56). Springer.
- Lyons, W. A., Nelson, T. E., Armstrong, R. A., Pasko, V. P., & Stanley, M. A. (2003). Upward electrical discharges from thunderstorm tops. *Bulletin of the American Meteorological Society*, 84(4), 445–454. <https://doi.org/10.1175/BAMS-84-4-445>
- Mlynarczyk, J., Bór, J., Kulak, A., Popek, M., & Kubisz, J. (2015). An unusual sequence of sprites followed by a secondary TLE: An analysis of ELF radio measurements and optical observations. *Journal of Geophysical Research: Space Physics*, 120(3), 2241–2254. <https://doi.org/10.1002/2014JA020780>
- Pasko, V. P., Stanley, M. A., Mathews, J. D., Inan, U. S., & Wood, T. G. (2002). Electrical discharge from a thundercloud top to the lower ionosphere. *Nature*, 416(6877), 152–154. <https://doi.org/10.1038/416152a>
- Peng, K.-M., Hsu, R.-R., Chang, W.-Y., Su, H.-T., Chen, A. B.-C., Chou, J.-K., et al. (2018). Triangulation and coupling of gigantic jets near the lower ionosphere altitudes. *Journal of Geophysical Research: Space Physics*, 123(8), 6904–6916. <https://doi.org/10.1029/2018JA025624>
- Rioussset, J. A., Pasko, V. P., Krehbiel, P. R., Rison, W., & Stanley, M. A. (2010). Modeling of thundercloud screening charges: Implications for blue and gigantic jets. *Journal of Geophysical Research*, 115(A1), A00E10. <https://doi.org/10.1029/2009JA014286>
- Rison, W., Krehbiel, P. R., Stock, M. G., Edens, H. E., Shao, X. M., Thomas, R. J., et al. (2016). Observations of narrow bipolar events reveal how lightning is initiated in thunderstorms. *Nature Communications*, 7(1), 10721. <https://doi.org/10.1038/ncomms10721>
- Schulz, W., Diendorfer, G., Pedeboy, S., & Poelman, D. R. (2016). The European Lightning Location System EUCLID—Part 1: Performance analysis and validation. *Natural Hazards and Earth System Sciences*, 16(2), 595–605. <https://doi.org/10.5194/nhess-16-595-2016>
- Soula, S., van der Velde, O., Montanya, J., Huet, P., Barthe, C., & Bór, J. (2011). Gigantic jets produced by an isolated tropical thunderstorm near Réunion Island. *Journal of Geophysical Research*, 116(D19), D19103. <https://doi.org/10.1029/2010JD015581>
- Su, H., Hsu, R., Chen, A., Wang, Y. C., Hsiao, W. S., Lai, W. C., et al. (2003). Gigantic jets between a thundercloud and the ionosphere. *Nature*, 423(6943), 974–976. <https://doi.org/10.1038/nature01759>
- Suzuki, T., Hayakawa, M., Hobara, Y., & Kusunoki, K. (2012). First detection of summer blue jets and starters over Northern Kanto area of Japan: Lightning activity. *Journal of Geophysical Research*, 117(A7), A07307. <https://doi.org/10.1029/2011JA017366>
- van der Velde, O. A., Bór, J., Li, J., Cummer, S. A., Arnone, E., Zanotti, F., et al. (2010). Multi instrumental observations of a positive gigantic jet produced by a winter thunderstorm in Europe. *Journal of Geophysical Research*, 115, D24301. <https://doi.org/10.1029/2010JD014442>
- van der Velde, O. A., Montanya, J., López, J. A., & Cummer, S. A. (2019). Gigantic jet discharges evolve stepwise through the middle atmosphere. *Nature Communications*, 10(1), 4350. <https://doi.org/10.1038/s41467-019-12261-y>
- Wescott, E. M., Sentman, D., Osborne, D., Hampton, D., & Heavner, M. (1995). Preliminary results from the Sprites94 aircraft campaign: 2. Blue jets. *Geophysical Research Letters*, 22(10), 1209–1212. <https://doi.org/10.1029/95gl00582>
- Wescott, E. M., Sentman, D. D., Heavner, M. J., Hampton, D. L., Osborne, D. L., & Vaughan, O. H., Jr. (1996). Blue starters: Brief upward discharges from an intense Arkansas thunderstorm. *Geophysical Research Letters*, 23(16), 2153–2156. <https://doi.org/10.1029/96gl01969>