Analysis of sprite events during small-scale winter thunderstorms in northern Europe

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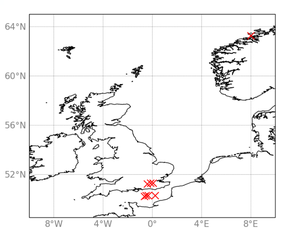
1. Introduction

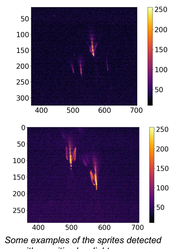
- Lightning occurrence throughout Europe is at a minimum in winter and mostly confined around the coastlines of the Mediterranean (Arnone et al., 2020).
- Limited extent and low flash-rate winter thunderstorms at higher latitudes are nevertheless found to produce intense CG strokes that may result in short-lived optical phenomena above thunderstorms in the region between the stratosphere and the lower ionosphere that are collectively referred to as transient luminous events (TLEs).
- We analysed recent examples of sprite events reported in Europe at latitudes larger than about 49N, focusing on parent strokes properties and storm system characteristics.

2. Data

- Optical observations mostly conducted by the UK Meteor Network, with sensitive low-light cameras covering most of UK and surrounding areas.
- 8 sprites selected in the period 2016/2019 during the winter months (Oct/Mar).



Location of the 8 positive sprite-producing CG strokes (red crosses), distributed over the sea and the coastline.

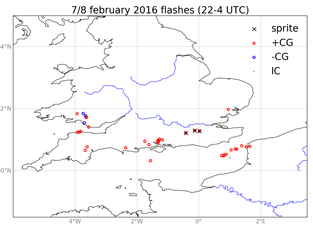


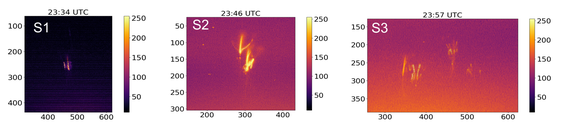
Some examples of the sprites detected with sensitive low-light cameras (Courtesy: UKMON, Nemetode.org)

- Lightning data from Météorage/GLD360 used to identify +CG parent strokes and relative peak currents.
- Wideband ELF/VLF electromagnetic and displacement current measurements used for further characterization of the associated signals
- The characteristics of the thunderstorm, as the cloud top temperature (CTT), radar reflectivity and the meteorological context, are considered in order to better understand the conditions leading to the observed events.

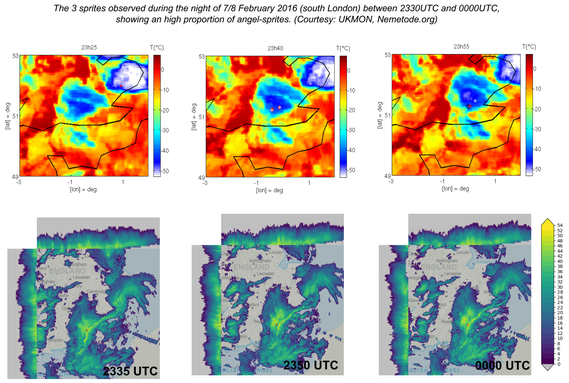
3. 7/8 Feb 2016 case study (3 sprites)

- Atmospheric instability activated by polar maritime air mass, during its passage over the British Isles.
- Cloud system developed around 2200UTC on the SW peninsula of England and triggered a limited number of CG strokes (all positive) in the following 2 hours period.
- Very low IC activity, mostly around 2300UT (~30 min before sprites)
- Sprite-parent CG strokes located at about 30 km from the cold core of the cell (~ -50°C)



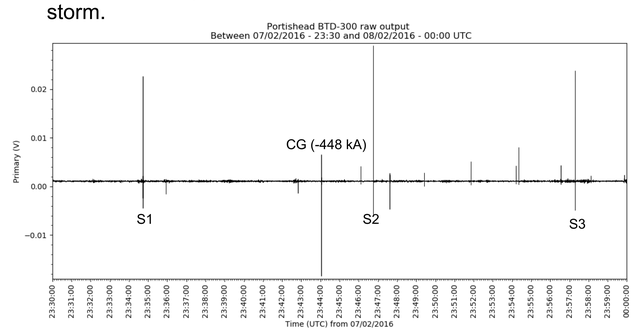


The 3 sprites observed during the night of 7/8 February 2016 (south London) between 2330UTC and 0000UTC, showing an high proportion of angel-sprites. (Courtesy: UKMON, Nemetode.org)



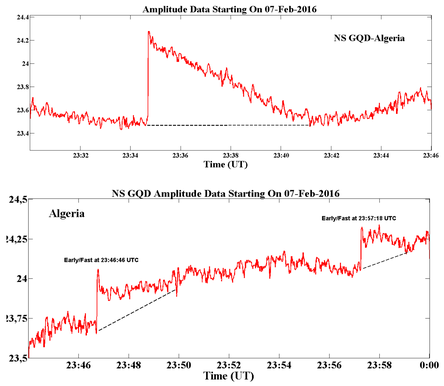
Meteosat cloud top temperature (CTT) maps and Met Office radar reflectivity (dBZ). The sprite CG+ (red + detected for 3 cases) and the IC strokes (white circles) are located about 30 km south of the coldest (convective) core ~ -50°C, for the three cases. The sprite locations trail behind an high radar reflectivity elongated band and it could indicate the direction of positive charge advected from the convective core.

- Large amplitude current spikes associated with the high peak current sprite-producing strokes, detected on a displacement current sensor (Bennett, 2013) located about 180 km from the storm.



Primary antenna raw data output of a BTD300 thunderstorm detector installed in Portishead (51.485 N, 2.756 W), operating at frequencies 1-45 Hz. The current spikes related to the sprite parent +CG strokes are clearly distinguishable (S1, S2 and S3). Interestingly, no other strokes occurred in the same storm in a 10 min period interval around each event, suggesting a relation to the charging conditions in the cloud system. Additional signals visible in the plot are associated to other active storm systems; in particular the negative spike around 2344UTC is caused by a large negative CG (-448 kA).

- The 3 sprites led to changes in the electron density of the lower ionosphere, affecting sub-ionospherically propagating VLF radio transmitters.



- Induced perturbations were detected from Algiers, with respect to GQD transmitter in UK (NaitAmor et al., 2017).

Early/Fast VLF signal perturbations observed in coincidence with the 3 sprites from Algiers. The geometry of transmitter-receiver path is shown in the map.

4. Overall properties

- Very large peak current values (median 306 kA) and extremely low flash rates and flash densities (less than 0.05 fl km^{-2})
- Average CMC and iCMC values: 845 (204) C km
- Complex morphology, mostly angel sprites

List of sprite-parent +CGs

Date	Time (UTC)	Lat	Lon	I_{pk} (kA)	iCMC (C km)	CMC (C km)
2016-02-07	23:34:44.643	51.236	-0.4016	318	189	747
2016-02-07	23:46:46.499	51.2839	-0.1238	370	252	691
2016-02-07	23:57:18.319	51.2748	0.0528	265	311	851
2018-10-21	22:57:33.960	63.2706	7.9945	163	258	1749
2019-03-05	00:46:22.444	50.2191	-0.6525	389	172	990
2019-03-05	00:55:53.250	50.2815	-0.4982	318	127	829
2019-03-05	01:02:25.575	50.2723	-0.3532	370	174	1307
2019-03-05	04:05:28.801	50.2706	0.2164	281	219	839

5. Conclusions

- We presented evidences of TLEs triggered by strong isolated CG strokes during near-zero flash-rate winter storms in areas of northern Europe, reportedly known as hotspots for superbolt lightning (Holzworth, 2019).
- Polar/arctic maritime air mass produces favourable conditions for the occurrence of such powerful strokes and eventually related TLEs.
- Sprite morphology observed reveals indications on the electric field at mesospheric altitude and streamers development (Malagon-Romero et al., 2020).

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