Using a short-range quasi-electrostatic thunderstorm detector for lightning safety and research

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Abstract

Lightning detection is fundamental for nowcasting of severe weather and increased risks for aviation and civil infrastructures, associated with thunderstorms. Monitoring of lightning activity and atmospheric electric field variability around a site, using an innovative quasi-electrostatic sensor is described. The present sensor is especially useful for sites where the continuous check and interpretation of rain radar or satellite images is impractical, and internet may not be available. In addition, it offers a low-cost, user-friendly interface and maintenance-free complementary method for well-established lightning detection networks, to increase the performance around a limited specific area, including the harsh marine environments of offshore installations. The further potential to detect short quasi-static current transients from remote lightning located up to 1,000 km away from the sensor is also investigated. These strokes exhibit large peak currents and often large impulse charge moment change (iCMC) values and are usually associated with transient luminous events (TLE) in the upper atmosphere above thunderclouds. Future work will prove if the observed signature can be successfully used to estimate the regional rate of TLE-producing strokes, with the major advantage that this method does not require the clear skies and dark nights necessary for ground-based optical detection.

1. Method

The BTD-300 sensor uses a system of 3 co-located stainless steel passive antennas of approximately 0.1 m^2. Each antenna generates a displacement current, flowing from the surface of the conductor to the ground, in response to the rate of change of the local electric field, which is measured using an electrometer current amplifier, embedded within the supporting PTFE insulator.

The signal measured is suitably digitized and filtered to remove the DC currents and the minute-scale variability associated with the passage of charged clouds and to supress the RF components above 200 Hz. It is then sampled continuously at 100 Hz to resolve the total electric field change from distant lightning flashes.

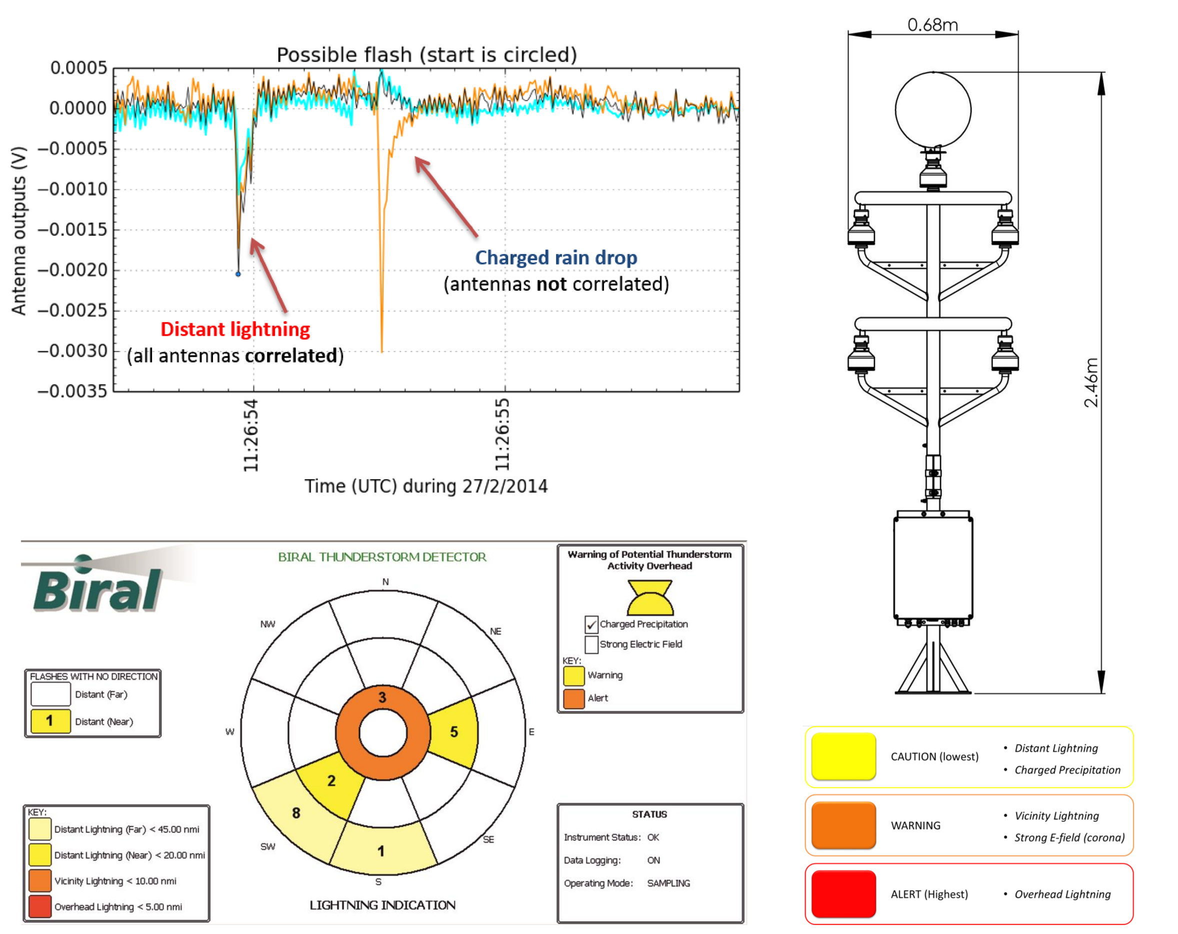

Figure 1. Left: BTD diagram and size; right: an example of the BTD interface output, providing multiple warning on local thunderstorm activity, within a 90 km range. The location of a flash is determined by estimating both the distance, using the inverse cube dependence of the electrostatic component, and the azimuth, by polling an additional LF magnetic direction finder installed on the BTD.

Lightning flashes are not the only source of transient changes in the atmospheric electric field. Charged particles, fast moving near and/or impacting the detector surface, such as charged hydrometeors and wind blown ions, produce also large and rapid changes to the electric field.

The BTD-300 separates lightning flash signals from non-lightning sources by a unique method which compares the signal characteristics on the three antennas. Due to the special geometry of the detector and antennas, only lightning produces the correct combination of relative signal amplitudes and antennas correlation compared with local, non-lightning sources of electric field change.

2. An unusual sprite-producing storm in UK

2.1 Storm characteristics

The night of 26-27 May 2017 was warm and moist, following on from warm temperatures which had occurred earlier in that day. The storm over Cornwall and SW UK originated from strong convection on a trough line, ahead of an occluded front. The Met Office radar-derived rainfall rates for 00:30 UTC, when the storm was close to its peak over Cornwall, were particularly intense, greater than 32 mm/hour and likely to produce flash flooding.

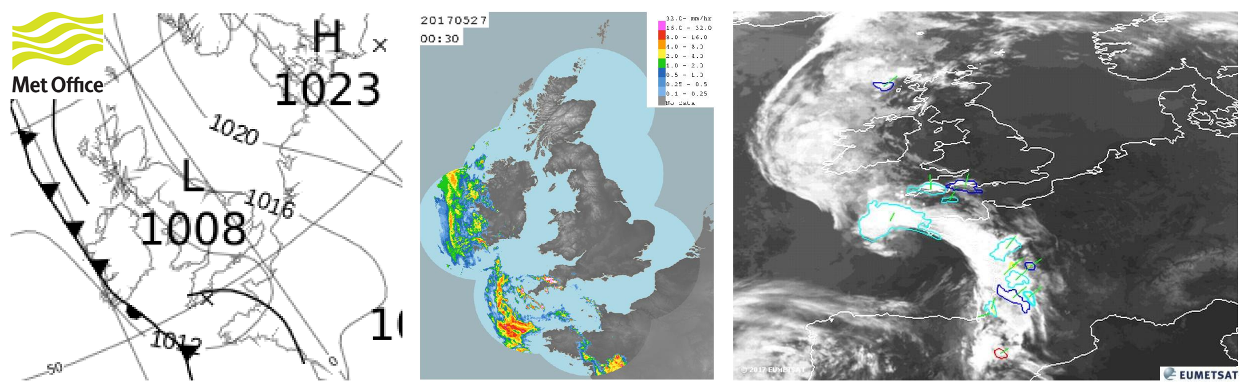

Figure 2. Left: the synoptic chart issued by the Met Office at 00UTC on the 27th May 2017, shows the trough line over Cornwall. The resulting storm produced heavy rainfall and an intense lightning activity. Right: the Metcheck Thunderstorm Tracker Satellite showing the developing storm over Cornwall *(Source: metcheck.com, accessed on 21th March 2019)*

2.2 Lightning activity

Data from the Météorage lightning network suggest that the flashes started around 23 UTC. The peak lightning activity was between 00 and 0130 UTC on the 27th May, after which the storm moved northwards into Wales and gradually dissipated. It is possible that the progress of the storm northwards over the steep slopes of the moors, present on the South West peninsula, caused the updrafts to grow stronger and the storm to intensify. During the peak lightning activity, 23 sprites were also captured by one of the UKMON cameras located in Wiltshire, nearly 200 km away from the storm.

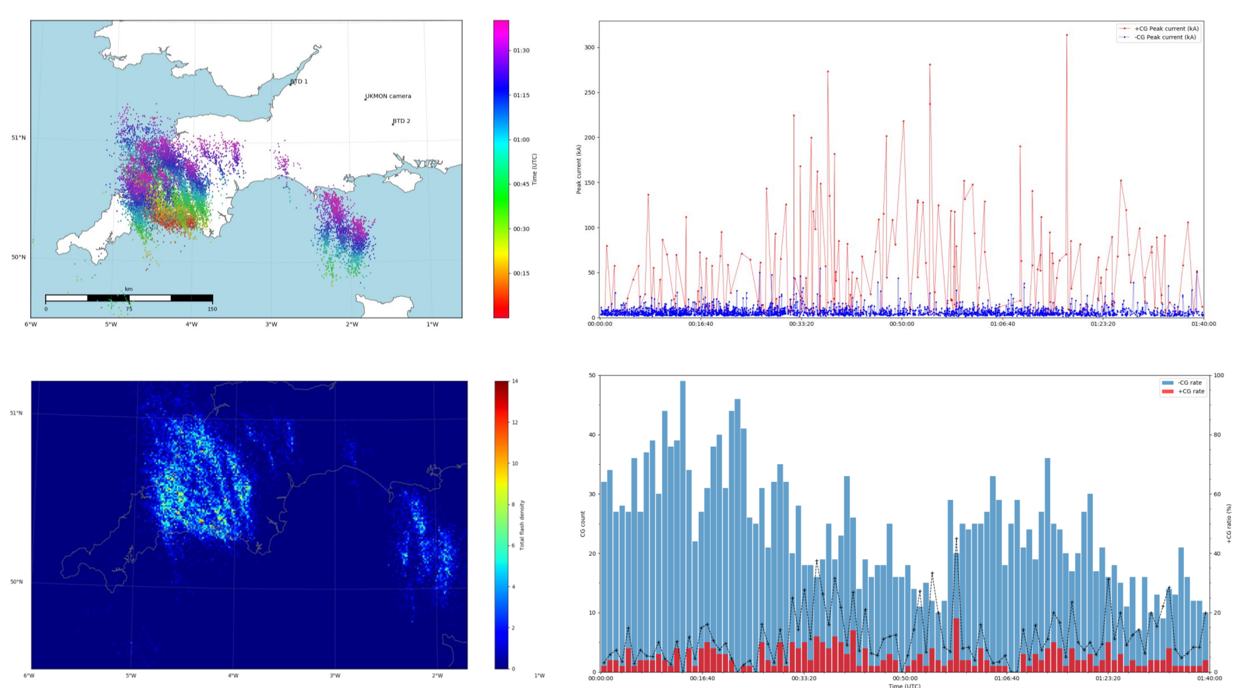

Figure 3. Right: time series of peak current (top) and rate for both polarities CG strokes, including the +CG ratio trendline (bottom). Left: total lightning activity evolution during the interval 00:00 to 01:40 UT (top) and total flash density (km^{-2}) (bottom)

2.3 Quasi-static currents measurement

Two identical BTD-300 were operating simultaneously during the storm at different sites. Focusing on the recordings of the distant +/-CG strokes, we found that the BTD responds to the large peak current and/or iCMC values exhibiting a rapid onset of the antenna displacement current. In particular, the signals coincident on both the detectors are biased towards values exceeding 80 kA for positive strokes. 18 out of the 23 sprite parent strokes (median +165 kA) were unambiguously detected. The only two strokes undetected produced faint single column sprites, characterised by a similar iCMC of about 120 Ckm. Long delayed sprites typically induce more complex features in the BTD quasi-static current signature, than just a single transient spike likely related to the return stroke.

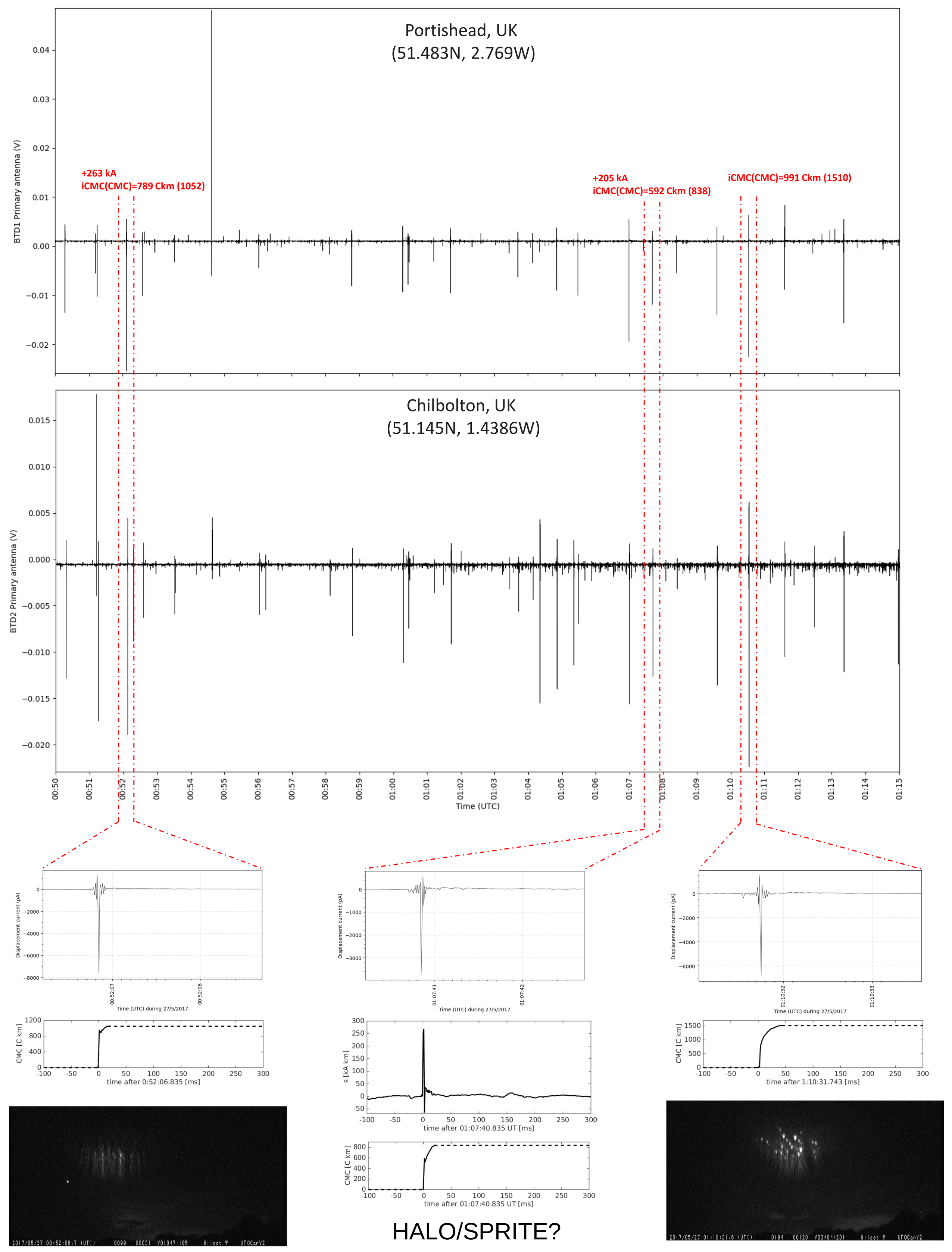

Figure 4. From the top: a sample of the quasi-static current recordings from the BTD1 (Portishead) and the BTD2 (Chilbolton) during the Cornwall storm (time frame 0050-0115 UT). The plots are zoomed into two BTD transient onsets associated with sprite-producing strokes. The CMC plots shown are based on the ELF data from the Hylaty station in Poland [Kulak et al., 2014]. The current moment waveforms and the charge moment changes were calculated using the method presented by Mlynarczyk et al. [2015]. In the same time frame, a similar transient was caused by another +CG, above the iCMC threshold for halo and sprite initiation. Is that a unique signature of a TLE-related stroke?

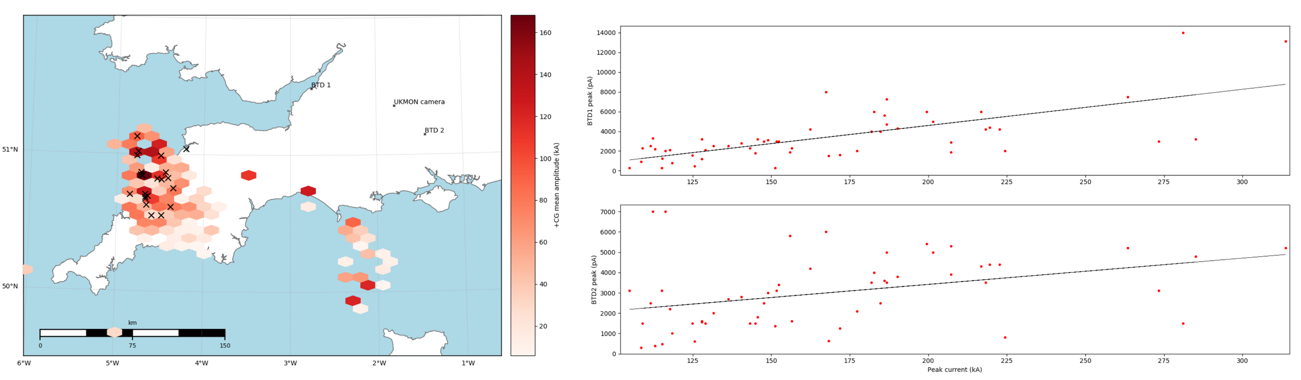

Figure 5. Sprite-associate strokes locations and +CG mean amplitude distribution, respect to the BTDs and the UKMON camera (left). Quasi-static current peak amplitude correlation to +CG peak current for coincident transients related to sources above 100 kA (right).

3. BTD signature of elves over Europe

The almost one-to-one correspondence found between the large amplitude quasi-static current transients and distant optical elves, up to more than 1.000 km away from the BTD sensors, suggests a further link to TLE and extremely large peak current strokes (i.e. when the CMC is below the threshold for halos/sprites initiation). The following example shows the case of a large storm across the Netherlands on the 10/11 April 2018 which produced several powerful strokes and subsequent elves, as observed by an amateur observer in France. In a later stage of the storm, the occurrence of elves is inferred indirectly from the BTD measurements and the step-like LORE events on a VLF transmission path.

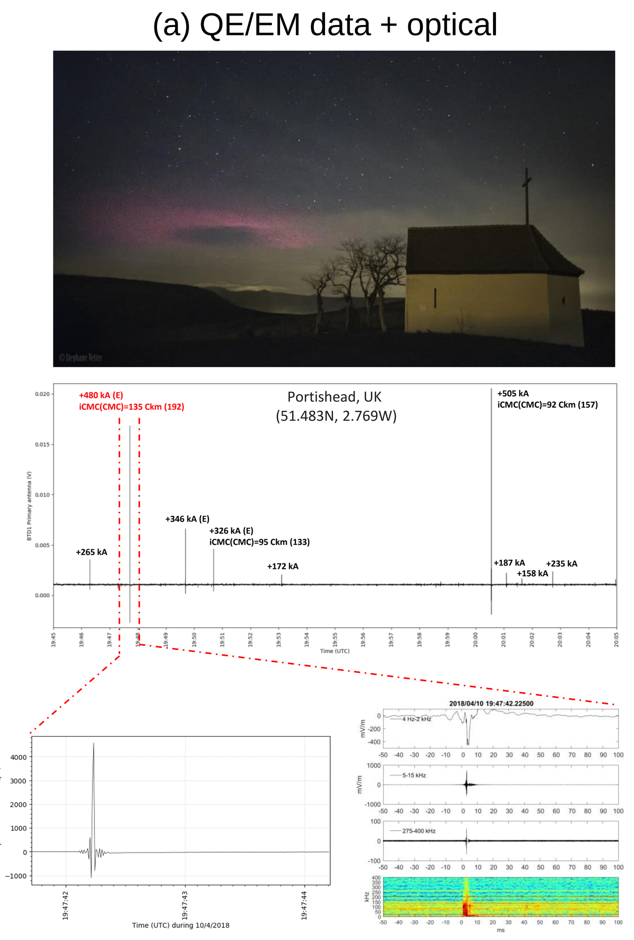

Figure 6. BTD signatures of large strokes, some of which are known to have produced optical elves. The elf in the picture above, captured by Stephane Vetter, was caused by a +480 kA CG, which triggered a rapid current transient on the two BTD sensors. The broadband radio waveform of this event was recorded from the Bath Uni sensor is also reported (right).

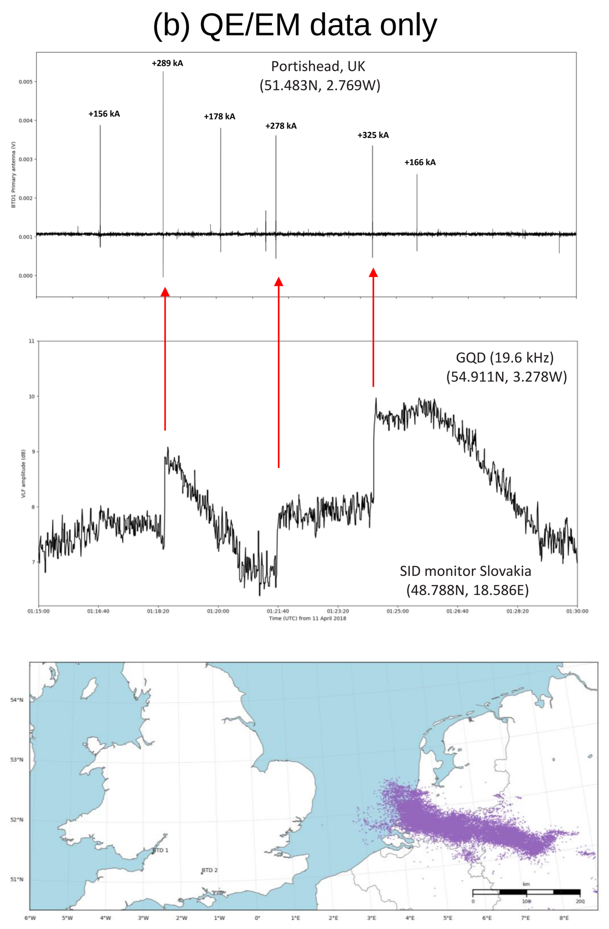

Figure 7. The BTD primary antenna output during the interval 01:15 to 01:30 UT. Some of the transient spikes were coincident with typical VLF perturbations associated with elves, as recorded from a SID monitor in Slovakia.

4. Conclusions and future work

- ✓ Innovative and unique single site sensor for nowcasting of hazards related to thunderstorms around a specific area.
- ✓ Further capability to detect transient signals originating from powerful lightning strokes located hundreds of kilometres away, offering a potentially new complementary method for TLE research.
- ✓ Quasi-static current onsets appear as a clear signature of remote CG strokes producing electron density enhancements and quasi-electrostatic heating at mesospheric altitudes.
- ✓ Planned fieldwork in southern France during the summer 2019, supported by hi-res imaging of TLE and electromagnetic simulations, will assess if the observed signatures could be used to evaluate the European regional rate of TLE-producing strokes by means of a BTD mini-array.
- ✓ Release of a BTD upgraded version for research purposes.

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