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Gravity Waves, Meteor Trails and Asymmetries in Elves

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ABSTRACT: From June 2008 to March 2011 more than 400 elves have been recorded by cameras in southern France and northeastern Spain. A considerable fraction of elves are not as uniform as predicted by theory. We demonstrate examples and analyses of events displaying an asymmetrical distribution of luminosity in elves, gravity wave patterns, and even elves not recognizeable as a ring, and a distinct meteor trail. Emissions were enhanced by the meteoric dust deposition. The observations imply that the conditions in the lower ionosphere significantly influence the luminosity output. Furthermore, certain elves were accompanied by unusual electromagnetic signals, and we discuss the symmetry of their polarity, meteorology and land/sea differences.

1. INTRODUCTION

Elves are transient optical emissions in the shape of rings at the base of the ionosphere resulting from electron heating by strong electromagnetic pulses from cloud-to-ground (CG) lightning flashes of any polarity. The most prominent aspects of elves (shape, expansion speed, altitude) have already been modelled succesfully [e.g. *Barrington-Leigh et al.* 2001]. While low light camera systems have poor temporal resolution, spatial features are better resolved than by photometers, although the weaker elves are often missed due to their long image integration time. In this paper we report on a significant number of elves observed by cameras in which structure is clearly present. The presence of structure in the mesosphere in the form of gravity wave patterns and meteor dust has been speculated to be important for providing streamer seeds of sprites and has been investigated by several authors. Particularly, *Moudry et al.* [2003] showed examples of mesospheric structure visible in sprite halos. A global climatology by *Chen et al.* [2008] of transient luminous events (TLE) observed from space showed elves to be very frequent over the oceans, especially the warmer parts, while sprites are more common over land. As we report in the following, camera-detectable elves tend to be primarily a late autumn and winter phenomenon in southwestern Europe (over sea), while only very few are detected over summer mesoscale convective systems (over land) which produce sprites. One of our aims is to find out the reasons for their occurrence

2. METHODS

2.1 Data

Elve images were mainly obtained with a Watec 902H2U camera located in Sant Vicenç de Castellet, Spain (41.67°N, 1.86°E, 190m), in almost all cases with a 12mm f/0.8 lens, occasionally with a wide angle converter. UFOCapture software was used for detecting events, using the most sensitive thresholds possible with respect to the image noise level. A mean pixel value image was calculated from the video clips excluding the event frame.

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This image was subtracted from the event frame to remove the background sky (which may have luminosity gradients or clouds) and multiplied by 3 for contrast. The mean image was used to fit stars in order to find elevation angle of elve centers. Combined with the distance to their detected CG flash, altitudes of elves are found with an error margin of ±2 km. CG flashes were detected by the LINET time-of-arrival lightning detection network. The number of elves used in this study is 416, obtained between June 2008 and February 2011. Of these, 219 had CG flashes detected by the lightning detection system (note that lightning data east of 5°E and north of 45°N have not been available yet for study). Not all of these elves had visible centers (holes) due to clouds: of 154 elves the altitude could be determined.

3. RESULTS

3.1 Elve locations

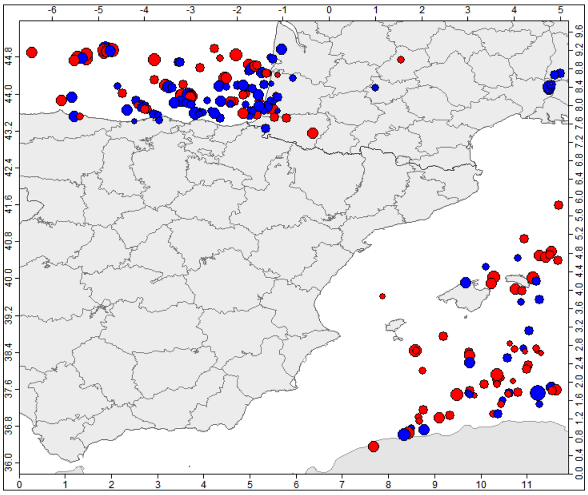


Figure 1. Locations of detected CG flashes which produced observed elves south of 45°N and west of 5°E. Red: positive, blue; negative. The size scales with peak current.

Figure 1 shows that the majority of elves occur over the Bay of Biscay and deeper over the Mediterranean Sea. During the winter half year, cold airmasses over warm sea water provides a source of convective available potential energy for thunderstorms (as opposed to the cold land). During summer, storms prefer land, sometimes pass over sea, but hardly produce elves. Several tracks of elve-producing cells can be noticed over the Bay of Biscay. A lack of elves is apparent over the Balearic Sea. However, there are often storms in this area, typically during the first night after the entry of a cold front into the Mediterranean in autumn. Those tend to be very active cells with high cloud flash rates. This type of convection tends to be unfavorable for elve-producing CGs (perhaps for the same reasons as for summer storms). Elves tend to occur mostly during the subsequent one or two nights, when multiple smaller cells occur. Interesting also is that elve CGs also are produced over land (southwestern France) as the storms move onshore. It is therefore more likely that the meteorological regime and cloud characteristics are responsible for high elve rates, rather than e.g. conductivity of sea water, which might be a factor in attaining such high peak currents. While not shown, sprites are much less frequent than elves over the Bay of Biscay than they are over the Mediterranean, and are produced both west and east of the Balearic islands.

3.2 Elve-producing lightning

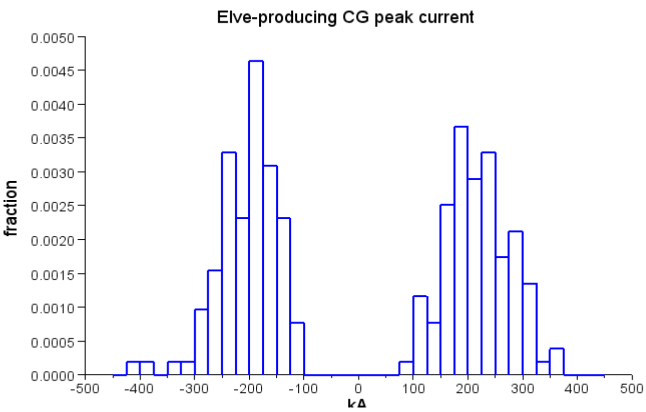


Figure 2. Peak current of elve-CGs reported by the LINET lightning detection system.

Figure 1 and Figure 2 show that elves are produced by CG flashes of both polarities in almost equal proportions. However, verification by a broadband receiver of the University of Bath (UK) proved that many winter elve -CGs were in reality +CGs. Both lightning detection systems had this problem. It even occurred that the polarity has changed after reprocessing of the data, or that this time the detection is finally listed, or removed from the listing. The peak currents reported ranged approximately between 100 to 400 kilo-Ampères (kA), however, such large values have never been verified against real current measurements, and the brightest elves are not necessarily produced by the highest peak current CGs. Elves are still produced by <100 kA CGs, but their luminosity tends to be below the camera noise level. This was confirmed by our high-speed observations of Mediterranean sprites [*Montanyà et al.* 2010] in which the recordings showed simultaneous elves not observed by the conventional camera. Our distribution is shifted towards higher peak currents than in the cases by *Newsome and Inan* [2010] who used photometers.

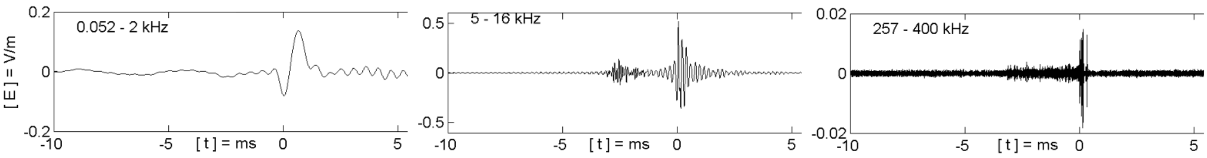


Figure 3. Waveforms in different frequency ranges of an elve-producing CG flash, 022807 UT, 20 August 2010, over southeastern France, recorded by the University of Bath radio receiver, about 1000 km away.

Figure 3 is an example of elve-producing flash accompanied by remarkably strong very low frequency and medium frequency sferics from in-cloud leaders in addition to the electromagnetic pulse (at t=0) itself.

3.3 Elve altitude

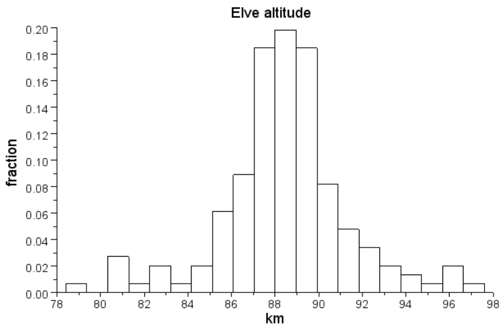


Figure 4. The altitude of elves measured from center elevation angle and CG location.

Given the uncertainties of CG location and elevation readout, the resulting distribution is remarkably concentrated between 87 and 90 km (mean 88.5 km, standard deviation 2.9 km). For a group of elves which occurred on 20 August 2010 over France, the altitude was found to be higher: 93.9 km (standard deviation 2.6 km).

3.4 Elve structure

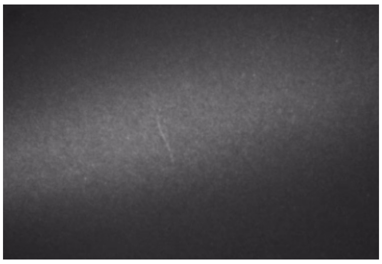
Figure 5. First row: elves with asymmetrical luminosity, offset from CG flash. Second row: gravity waves and shallow holes. Third row: sharp billows, also visible in its background (right). Last row: elves completely dominated by mesospheric background structure (plus a halo in right image). Bottom: high-speed camera image of a meteor trail illuminated during an elve.

Asymmetric elves or elves without holes were predicted by simulations of non-vertical lightning currents [*Marshall et al.* 2010].

Gravity waves (GW) are frequently observed in elves, although usually not as pronounced as in these examples. Watec averaged images can reveal GW patterns, but the match with those in the elve is not exact, probably because of differences in altitude and emission species.

4. CONCLUSIONS

We presented observations of the structured appearance of elves, their parent lightning flashes and meteorological aspects. These are currently being subjected to deeper analysis.



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