On the relation between the red sprites and the transients in the ELF band

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Abstract: Under favourable conditions sprites appear above large storms. Long continuing current in tens of ms in the parent +CG stroke radiates electromagnetic energy also in the Schumann resonance (SR) band. Optical and Extremely Low Frequency (ELF) observations at the Astronomical and Geophysical Observatory (AGO) near Modra are analyzed to find these two effects associated with +CG discharges. Since April 2007 dozens of sprites have been captured by automated all-sky TV system at AGO. A majority (77%) of the optical transient events are accompanied with the transients in the SR band. No ELF counterparts are found for 23% of the captured sprites. Our observations are compared with similar observations in Sopron and Nagycenk (NCK). Example of the optical frames, the associated ELF time plot and the Fourier as well as dynamic spectrum are presented for one of the events simultaneously observed at AGO and NCK.

Key words: electromagnetic field, ELF, lightning, sprites, Schumann resonances

1. Introduction

Sprites are transient luminous events observed over large active storms at a height between 40 and 90 km. Observations show that the duration of sprites is only some tens of ms. Usually they are orange or red and of the form of carrots or columns (compare Fig. 1). Sprites were first discovered during tests of a low-light television camera in Minnesota in 1989. Since then it has become clear that these mesospheric luminous events occur worldwide. Airborne and ground campaigns revealed that meteorological conditions prevalent on summer nights over the High Plains in USA may be the most conducive to sprites in the world *(Lyons et al., 2000)*.

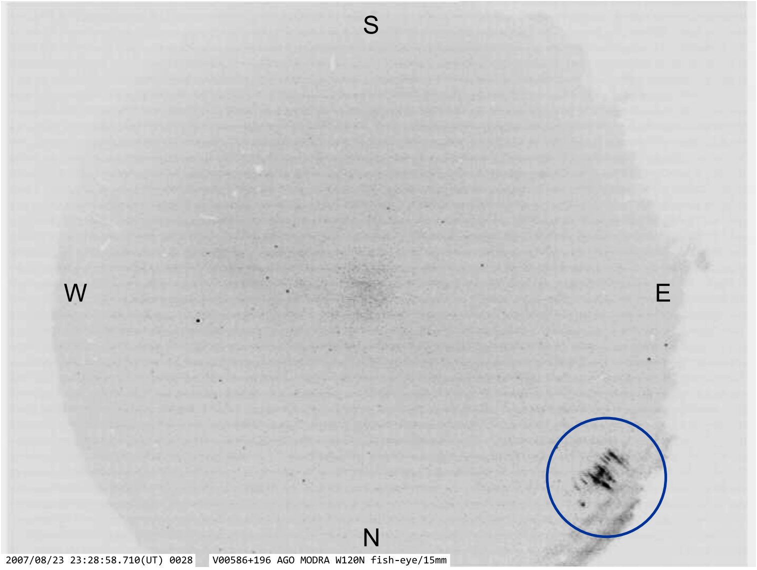

Fig. 1. Negative image of sprite captured by the all-sky TV system on August 23, 2007 at 23:28:58.710. West is on the left, north in the bottom, the sprite itself is in the NE direction marked by a circle.

Sprites are recorded above large mesoscale convective systems (MCS) and they are usually associated with a positive cloud-to-ground (+CG) lightning discharge which neutralizes large amounts of charge from cloud but as a consequence generates an electric field in the mesosphere which drives the electric breakdown causing sprites. This parent +CG lightning discharge produces powerful electromagnetic bursts dominantly in the very low frequency (VLF: 3–30 kHz) band. Part of the energy is radiated also in the extremely low frequency (ELF: 3–300 Hz) band. Long continuing current of tens of ms in the +CG discharge generates a transient in the lower part of ELF, i.e. in the Schumann resonance band.

Most lightning strokes are inter-cloud. About 40% of all strokes is cloud-to-ground and most of these are negative, bringing negative charge to ground. Only about 10–20% of the strokes to ground are positive. The reason for these positive flashes is not yet fully understood but their occurrence is in relation with the form of the clouds (expansion of the cloud into the form of anvil) and the size of the storms (large MCS).

Sprites are occasionally observed above smaller storms (in Europe). Often these convective strokes generate many +CGs but few of them produce sprites, the ratio of +CGs that produce sprites is often as low as 1:100 *(Lyons et al., 2003)*.

Sprites are not exclusively associated with high peak currents of the strokes. *Greenberg et al. (2009)* studied 15 sprites and found that their causative +CGs discharges had peak current intensities from +8 to 130 kA whereas their charge moment changes (CMCs) ranged from 500 to 3500 C.km.

In this paper, our Schumann resonance data are analyzed with the aim to find ELF counterparts to the sprites observed at the Astronomical and Geophysical Observatory (AGO) near Modra in 2007 and in May 2008. Sprite observations are shortly described in Section 2, the ELF observations in Section 3. One event of a sprite accompanied with the ELF transient is illustrated in Section 4.

2. Sprite observations

An Automated all-sky TV system and UFO capture real time detection software was installed at AGO near Modra (western Slovakia) on April 1, 2007. The TV system consists of Fish-eye Canon 2.4/15mm objective, 2° Mullard image intensifier, Meopta 1.9/16mm lens, Watec 120N camera, and has the field view $170° \times 140°$. The resolution is 720×540 (15 arcmin/pixel). The entire system operates autonomously. The original and the main aim of the system is detection of moving objects in the sky, namely meteors. Soon after its installation it became clear that it is capable to detect also sprites.

Since April 2007, when the system was installed, till September 2008, altogether 68 sprites were observed at AGO, see Table 1. The early observations were compared with similar observations in Sopron, Hungary, 92 km away from AGO. 24 sprites in period July 21–August 10, 2007 were simultaneously captured at AGO and in Sopron what enabled the evaluation of their distances by triangulation method *(Bór et al., 2008)*. Distances between 150 and 400 km were found. 18 sprites between August 22, 2007 and May 31, 2008, arranged in Table 2, are used for the present study.

Table 1. Sprites optically observed at AGO from April 2007 to August 2008 by Automated all-sky TV system

Date	Number of sprites
2007 July 19	2
2007 July 21	15
2007 July 22	4
2007 July 23	1
2007 August 10	4
2007 August 22	3
2007 August 23	9
2007 August 24	2
2008 May 15	1
2008 May 31	4
2008 July 11	3
2008 July 29	2
2008 July 30	1
2008 August 7	17
Total	68

Table 2. Set of selected sprites observed at AGO and their ELF counterparts found at AGO and NCK measurements

No	Date	Time of spite at AGO	ELF at AGO	ELF at NCK
1	2007 August 22	20:08:19.882	yes	no data
2	2007 August 22	20:31:03.545	no	no
3	2007 August 22	20:35:21.061	yes	no data
4	2007 August 23	23:27:00.556	no	no
5	2007 August 23	23:28:58.710	yes	yes
6	2007 August 23	23:31:02.710	yes	yes
7	2007 August 23	23:38:04.272	yes	yes
8	2007 August 23	23:38:55.244	no	no
9	2007 August 23	23:40:49.682	yes	yes
10	2007 August 23	23:45:59.760	data gap	yes
11	2007 August 23	23:48:13.807	yes	yes
12	2007 August 23	23:51:42.924	data gap	yes
13	2007 August 24	00:05:58.857	no	no
14	2007 August 24	00:11:39.538	yes	yes
15	2008 May 31	22:29:26.358	yes	yes
16	2008 May 31	22:39:48.123	yes	yes
17	2008 May 31	22:45:41.998	yes	yes
18	2008 May 31	22:50:52.279	data gap	yes

3. Measurement of the electric field component of SR at AGO Modra

The vertical electric component in Schumann resonance frequency (ELF) band has been recorded at AGO near Modra since October 2001. The measuring equipment consists of a ball antenna on a 5 m high insulating mast, and the preamplifier located at the antenna base. The 50 Hz analog filter and three-channel 16 bit ADC follow. Details are given in *Kostecký et al. (2000)*. Since October 2006, the raw time series data have been collected every 6 minutes for 327.68 seconds (which is 65536 samples taken with 200 Hz sampling frequency). Though the measurements are practically continuous, there are 32.32 s time gaps between two consecutive data sequences.

4. Case study of the August 23, 2007 23:28:58.710 sprite

One of the captured sprites occurred on August 23, 2007 at 23:28:58.710 in north-east direction from our observatory. In fact, a cluster of columns can be seen in Fig. 1. An electromagnetic transient was found in Schumann resonance data, namely in the electric field data measured at AGO, with the time accuracy 77 ms.

Measurements of the magnetic field components of SR at AGO have not been completed yet. Fortunately, our colleagues from Sopron provided their data from Nagycenk (NCK) and the transient is clear in all three components of the field – see Fig. 2. The wave form of the electric component is typical for the so-called Q-burst. When the receiver is not phase inverting, as in our case, then the parent lightning polarity is opposite to the polarity of the first pulse in the electric component of the transient recording. Thus, the shown polarity represents a positive parent lightning (+CG).

Fourier amplitude spectrum of 512 samples (2.56 s) of the electric component record containing the transient revealed the first 5 Schumann resonance modes. They are depicted in Fig. 3.

Time-frequency analysis of a 4 s interval around transient was performed to show that the transient is of natural origin and its spectrum shows resonance frequencies of the Earth–ionosphere cavity. Such analysis using Morlet wavelet with parameter 14 was found the most suitable to reveal individual frequencies near the Schumann eigenfrequencies at about 8, 14, 20,

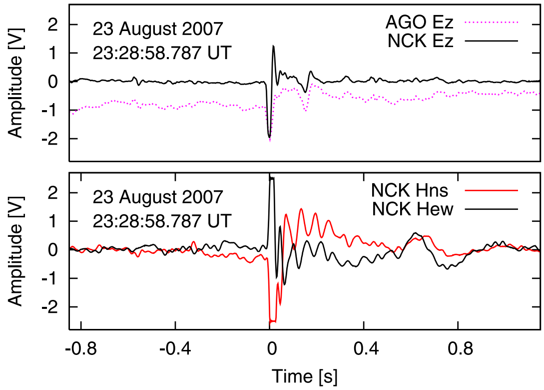

Fig. 2. Two-second record of the electric field component data (E_z) (above) containing the transient on August 23, 2007 at 23:28:58.787 in data from both AGO and NCK. The same transient in the two magnetic field components (H_{ns} and H_{ew}) in data from NCK is shown on the graph below. The waveforms are typical for the so-called Q-bursts associated with a positive parent lightning (+CG).

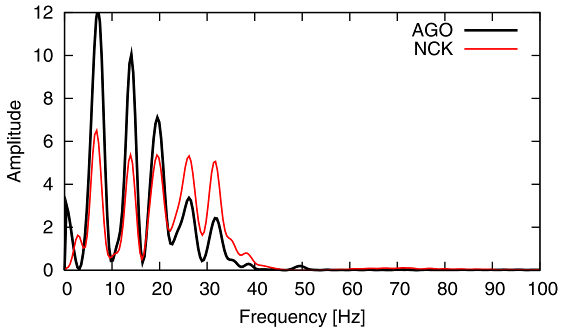

Fig. 3. Short-time Fourier amplitude spectrum of the transient electric component. The first 5 Schumann resonance modes are clearly developed.

26 and 32 Hz. Strong lightning discharges, which manifest themselves as Q-burst-type transients, usually excite higher modes in the Earth–ionosphere cavity unlike a non-coherent superposition of electromagnetic waves radiated by random lightning discharges known as the background SR. Exactly, the spectrum of the background around the transient, see Fig. 4, possesses much weaker spectral lines. A thin line at around 8 Hz, which is present in the whole time window, is the fundamental mode of the background.

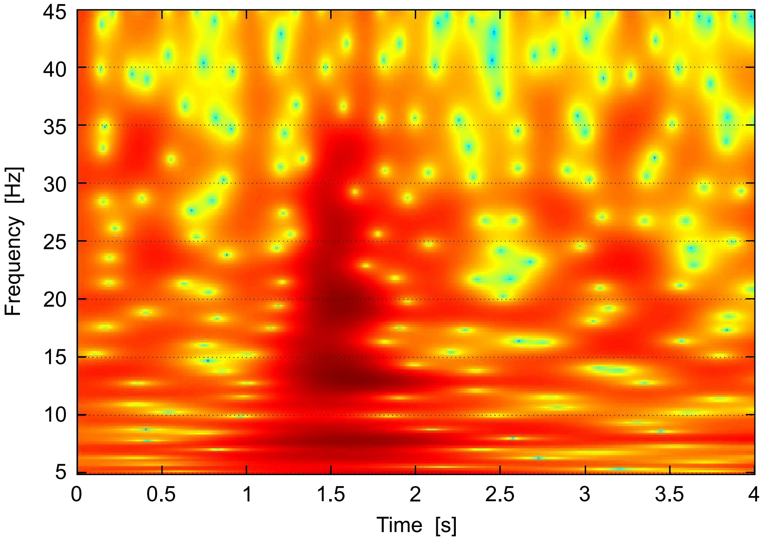

Fig. 4. The time-frequency plot obtained using Morlet wavelet with parameter 14. Shown is a four-second interval containing the studied transient. Dark (dark red) maxima appear near Schumann resonance frequencies at 8, 14, 20, 26 and 32 Hz for a fraction of a second revealing the presence of the transient. A thin weaker line at around 8 Hz in the whole time window is the fundamental mode of the SR background. Zero on the time axis does not coincide with the transient onset.

5. Results and discussion

For the present study, we selected 18 sprites from Table 1 for which we have ELF data from AGO or we obtained ELF data from the neighbouring observatory at Nagycenk (NCK).

Out of the 18 analyzed sprite events summarized in Table 2, in 9 cases ELF transients were found in records from both stations. In 2 cases ELF transients were found only at AGO and in 3 cases only from NCK data. Missing data are due to the gaps in measuring cycles. No transient was found in either of the two stations in 4 cases (23%). In the mentioned 14 cases (i.e. in 77%) when the transient was found at least at one of the two stations, ELF transients were found with time difference less than 114 ms against optical events.

Our study shows that 23% sprites are not accompanied with ELF transients. This is in accordance with the study of 15 sprites over Southern Europe during the 2005 EuroSprite campaign *(Greenberg et al., 2009).* A contrary result was reported by *Price et al. (2002)*, who detected ELF transients for all 31 sprites over the High Plains, USA. On the other side, for a significant number of events (33%) an ELF transient was not associated with sprite occurrence, suggesting that long continuing current of tens of miliseconds, which is responsible for an ELF transient, may not be a necessary condition for sprite production *(Greenberg et al., 2009).* This shows that the relation between the sprite occurrence and the ELF transient is not fully understood yet and needs further investigation.

The time difference found between the optical event (sprite) and the ELF transient is reasonable as the estimated minimum time delays between the sprite-parent +CG and the optical sprite onset ranges from 4 to 130 ms, with an average of 45 ms *(Lyons et al., 2003).* As the average duration of sprite illumination was found as short as 59 ms, ranging between 17 and 119 ms *(Lyons et al., 2003)*, the optical sprite appears sometimes on only one or two frames from the camera. For this reason it is extremely difficult to determine the exact time of the sprite onset and this uncertainty contributes to the time difference between ELF transient and sprite observation.

For comparison, a time delay between the sprites observed over the High Plains, USA, and the associated ELF/VLF transients observed in Israel reached 0.6 seconds on average *(Price et al., 2002)*, which was explained therein not only by the inaccuracies in the timing of the sprite (16.7 ms per video frame) and the propagation time from the United States to Israel, but also by the inaccuracies in the timing of the ELF computer system and the inaccuracies in the timing of the ELF peak based on the slope of the E-field.

Finally, it is worth mentioning that all sprites studied here were associated with +CG discharges, which is in line with the previous studies of this interesting phenomenon.

6. Summary

In the present study, 77% sprites were found to be accompanied with a transient in the ELF band. This finding supports the results reported by

Greenberg et al. (2009) while it seems to be different from the results of *Price et al. (2002)*. Further investigations should reveal a possible difference between parameters of the American and the European sprite producing +CG discharges.

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References

Bór J., Tóth J., Sátori S., Betz H. D., 2008: Simultaneous sprite observations from Sopron, Hungary and Modra, Slovakia. General Assembly EGU, Vienna 2008 (poster).

Greenberg E., Price C., Yair Y., Haldoupis C., Chanrion O., Neubert T., 2009: ELF/VLF signatures of sprite-producing lightning discharges observed during the 2005 EuroSprite campaign, 2009, JASTP 71, 12, 1254–1266.

Kostecký P., Ondrášková A., Rosenberg L., Turňa Ľ., 2000: Experimental setup for the monitoring of Schumann resonance electric and magnetic field variations at the Geophysical Observatory at Modra-Piesok. Acta Astron. et Geophys., XXI–XXII, 71–92.

Lyons W. A., Amstrong R. A., Williams E. R., Bering E. A., 2000: The hundred year hunt for the sprite. Eos, Trans. Amer. Geophys. Union, 81, 373–377.

Lyons W. A., Nelson T. E., Williams E. R., Cummer S. A., Stanley M. A., 2003: Characteristics of Sprite-Producing Positive Cloud-to-Ground Lightning during the 19 July 2000 STEPS Mesoscale Convective Systems. Monthly Weather Review, **131**, 10, (October 2003), 2417–2427.

Price C. P., Asfur M., Lyons W. A., Nelson T., 2002: An improved ELF/VLF method for globally geolocating sprite-producing lightning. Geophys. Res. Lett., **29**, 3, 11–14. doi: 10.1029/2001GL013519