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Methodology of Estimating Time Accuracy in TV Recordings of Sprite Lightning Observed from Gliwice and Świder 2011–2015

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Abstract

We present technical details of the TV observations of sprite lightning phenomena made from Gliwice and Świder in 2011–2015, and propose methods of verification and corrections to the recorded timing of individual cases and series of events.

Keywords: TLEs, sprites, observations, timing, GPS, TV.

1. INTRODUCTION

The upper atmospheric lightning, called Transient Luminous Events (TLEs), are effectively observed optically from air and space (Boeck et al. 1998; Mende et al. 2006). Optical methods have also been used in ground-based observations since the first recording by Franz et al. (1990). Low-light television CCD[1] cameras have been employed in various observational systems operated manually or semi-automatically in the US, Japan, France, and other locations all over the world (e.g., Lyons 1994; Allin et al. 2006). Such observations have been made by both researchers, educators, and enthusiasts of TLEs observations, and over the years provided valuable scientific input (e.g., Yamamoto et al. 2010; Arnone et al. 2020; and references therein). High-speed imaging of TLEs emerged also very early (Stanley et al. 1999). In the television (TV) imaging by recording at the standard rate[2], the duration of an event is limited

[1] Charge Coupled Device.

[2] The standard rate of televison fields is 1/50 s for CCIR systems and 1/60 s in EIA systems (e.g., Damjanovski 2005). CCIR stands for Committée Consultatif des Radiotelecommuniqué, and EIA stands for Electronics Industry Association. In these standards, two subsequent fields are interlaced producing one frame at the rate equal to twice the field rate.

and bound by the length of one video field (20 ms in a CCIR system). Except when other technical solutions allowed (e.g., Rairden and Mende 1995) the standard rate allows capturing of instances of TLEs, but it is usually not sufficient to image the subsequent phases of the development of these events, which is available through the high-speed imaging. The timing for fields or frames is usually provided by video overlay units cooperating with a timing system supported by global satellite navigation, such as the Global Positioning System (GPS). In the absence of GPS timing, it often relies on the support by Network Time Protocol (NTP) servers.

Accurate timing of the TLE frames imaging is important from the scientific point of view, in order to be able to identify the events' parent lightning (in case of sprites) or, more generally, their absolute or relative position in the sequence of the lightning activity of a thunderstorm, or in relation to other natural or superficial signals, e.g. infrasound or VLF or ELF fields. This kind of research investigations begin very early in TLE research (e.g., Cummer et al. 1998; Rodger 1999; Huang et al. 1999; Neubert et al. 2005; and many others). In the scientific literature, the TLE time moments from TV observations are given most frequently at the resolution of 1 ms as the OSD-GPS devices usually nominally allow, and these times are often devoid of additional information or comment on the timing accuracy and estimation of potential errors. One of the reasons why these issues are not discussed could be that such remarks are considered trivial, or because the scientific infrastructure and recordings are of high quality, and no such problems were detected. Errors may result from failures of the timing system and the satellite navigation, accidental failures of the elements and the recording systems, software, and communication between these elements. Most serious timing issues arise from not using the support of precise timing such as GPS or of dedicated NTP servers, relying on standard PC timing which limits their usefulness in research.

In order to estimate the timing errors for the events recorded from Poland in 2011–2015, performed with and without GPS support, we have recently applied procedures that we describe in this paper in order to give a basis for the understanding of the events' times and errors used in further analysis of the recorded sprite events (Odzimek et al. 2022a,b; this issue). Specifically, based on the information from the timestamps on the recorded video we present a methodology of calculations of the errors in a single recording and a numerical method which can be used to correct the timing of events in case the GPS timing was not working properly. The described timing issues and error calculations are general for TV recordings of any other objects of such short duration.

2. TLE OBSERVATIONAL HARDWARE AND SOFTWARE

An observational hardware set-up for TV observations of TLEs usually consists of a low-light camera and lens, a time overlay unit with a GPS antenna, and a recording computer. The camera used at Gliwice was a monochrome 1/2-inch CCD Watec 902H2 Supreme, and at Świder a Watec 902H2 Ultimate model was used, both with 0.0003 lux sensitivity at F-number 1.4 and 570 horizontal lines resolution. The optical signal was recorded and analysed by the motion capture software UFOCapture (V2) from SonotaCo.com (http://sonotaco.com/e_index.html) which become widely used for TLE observations first in Japan, then in Europe (e.g., Ganot et al. 2007; Yaniv et al. 2009; Bór et al. 2009; Iwański et al. 2009; and others). Video frames were saved at 720×562 pixel resolution.

For the timing, the KIWI-OSD (https://sites.google.com/site/kiwiosd/) on-screen time display unit, equipped with a Garmin GPS antenna, was available for Gliwice observations, and a GPSBOXSPRITE2 unit (https://www.blackboxcamera.com/pic-osd/sprite_faq.htm) was used in observations at Świder from 2013. In Figs. 1 and 2 we show examples of the timestamps on the TV frames from selected sprite recordings from either system. Panels aligned vertically

a)
GLC 2012/08/05 20:58:07.413–453 Frame 11

b)
SWI 2014/07/07 23:29:33.483–523 Frame 11

GLC 2012:08:05 20:58:07.413–433 field 1 (even)

SWI 2014/07/07 23:29:33.483–503 field 1

GLC 2012:08:05 20:58:07.433–453 field 2 (odd)

SWI 2014/07/07 23:29:33.503–523 field 2

Fig. 1. Examples of TV frames consising of two fields and their relevant on-screen display of PC time by UFOCapture (in the bottom line) and overlaid GPS timing by: a) KIWI-OSD at Gliwice and b) GPSBOXSPRITE-PIC-OSD at Świder. Note that the PC time label is illegible in the video fields due to interlacing.

show one recorded interlaced television frame integrated over 40 ms in total and its two corresponding deinterlaced fields lasting 20 ms each. The example from Gliwice is an event of jellyfish-like sprite which, according to the GPS, occurred on 5 August 2012, between 20:58:07.433 and 20:58:07.453 UTC; the sprite is visible in the second field. Field count is displayed on the right side. The PC time, 20:58:05.818 UTC, is readable only from the frame, and indicates a ~1.5 s time difference from the GPS time. At Świder, the GPS time display used was different – only the time of the field end was indicated. In the example shown in Fig. 1, a cluster of sprites with tendrils is visible in the 11th frame of the video recording from 7 July 2014. The frame was time-stamped with 23:22:26.859 UTC, and its total GPS time range including both fields can be read as 23:29:33.483-523 UTC. The sprites are visible also only in the second, odd field, 23:29:33.503-523 UTC (Fig. 1).

3. ACCURACY AND CORRECTIONS OF TIMING

During the observations over 2011–2015 we have experienced situations when the status of timing of the recorded events varied from unsatisfactory to correct. Below we describe further procedures for the timing verification and corrections depending on whether only PC timing or GPS timing was available. In case there is no GPS timing, a procedure from Section 3.3 can be applied in order to obtain any estimate of the time difference.

3.1 GPS timing

The operating manuals of time overlay units working with GPS signals indicate a maximum of 0.1 ms accuracy of the displayed time, provided the GPS receiver reported the correct fix over several seconds. Most of TLE recordings, however, do not last longer than a second because such longer recordings deliver additional load for the recording system, and because other events may be missed. After any recording, a check on the whole timing of the video fields in a video file, at least prior to an interesting event, is always recommended to verify the timing consistency. Fatal errors are usually also signalled by the device in a specified way described in the manual, and visible in the time-stamps. The KIWI-OSD unit has also a useful feature of displaying a label showing the field count. It is advisable to follow the GPS field count in order to check if any of the fields or whole frames have not been dropped from the recording, as in the example analysed in Section 3.2.2.

3.2 PC timing

When the recording is not timed with the GPS there are ways to assess the time inaccuracy and provide corrections, especially when a series of events is recorded. In such cases, one can relate them to a series of other events whose timing is known, and try to determine the time difference – assuming it may fluctuate but not be changing fast in a monotonic way which would make such correlation impossible or of little use. In the case of sprites, good candidates are events from parallel observations or detections of positive cloud-to-ground (+CG) parent lightning. The observed coincidence of a sprite and its parent lightning which is the critical source of the quasi-static fields required for the sprite initiation is usually high (Boccippio et al. 1995), e.g., in 72 subevents (discrete sprites) recorded by Arnone et al. (2008), only 7 in 38 sprites timed with GPS have not been associated with a parent +CG. Aside from the issue that the efficiency of CG detection may be below 100%, some sprites may be delayed and their relationship with a parent +CG not so evident. Conditions suitable for the initiation of column sprites and sprite halos may appear in just a few milliseconds after parent lightning, and for more spatially developed sprites these are delayed by dozens of milliseconds (e.g., Rycroft and Odzimek 2010). Li et al. (2008; Fig. 3) have determined that between 60% and 70% of discrete events were delayed by less than 20 ms, and 37% by less than 10 ms. In the case of several events, there should be still a few ones on average shortly following their parent lightning in the next 10–20 ms.

Below, in Subsection 3.2.2, we describe a simplified method of estimating a constant value of a time difference, usually valid for a limited period if the departure of the PC time from GPS changes monotonically or irregularly. It is important that before calculating the time shift one needs to verify the consistency of timing in the recording in every single frame or field event, and calculate the corrected timing of the event frames, for example, in the way we propose below, and which we further applied to all recording from Świder and Gliwice.

3.2.1 Verification of timing and determination of the error of discrete event times

In a TV recording, the time range of an *i*-th subsequent frame can be expressed by $\langle T_i; T_i + 1/\text{fps}\rangle$, where T_i is the start time of the video frame, *i* is the number of the frame in the recording, and fps is the number of frames produced by the camera per second (in PAL system, i.e., with 50 fields per second, fps = 25, so 1/fps = 0.04 s or 40 ms). An event can appear in either both fields of this frame or only the first or second field, further limiting the duration to $\langle T_i; T_i + 1/(2\text{ fps})\rangle$ or $\langle T_i + 1/(2\text{ fps}); T_i + 1/(\text{fps})\rangle$, as shown in Fig. 1. Thus in a video recording the time (beginning or end of integration) of each frame $\{T_i\}$ can be also expressed by:

$$T_i = T_0 + i/\text{fps},\ i = 1..\text{N} \ . \tag{1}$$

Here we assume that T_0 is defined as such when the set of $\{T_i\}$ refers to the frame beginning. Equation 1 is a linear dependency with the linear coefficient equal to 1/fps. In the UFOCapture programme, each frame has its own timing provided by the PC, e.g., supported by NTP service which denotes a time moment within the frame, depending on the programme settings[3]. In order not to rely on this single value (similarly as in timing with GPS) we recommend to determine a general formula to describe all frames within the recording, i.e., find such a time moment T_0 to which the times of subsequent frames $\{\underline{T}_i\}$ can be related by Eq. 1. Having the whole set of $\{\underline{T}_i\}$ rewritten from the time-stamps displayed on the video frames (such as in the bottom label shown in the uppermost panels of Fig. 1) we can determine T_0 and its error ΔT_0 by the linear regression of pairs $(i, \underline{T}_i)$. An example of the regression is shown in Fig. 2. For the estimate of the maximum error of T_0 we find the constants of upper and bottom parallel lines that create a range in which all "PC" time values lie within. Half of this range can be considered as a maximum error and be used instead of the standard deviation of the constant from the regression.

$$\Delta T_0 = 0.5\ |\ \max(\{\underline{T}_i - i/\text{fps}\}_{i\,=\,1..\text{N}}) - \min(\{\underline{T}_i - i/\text{fps}\}_{i\,=\,1..\text{N}}) \ . \tag{2}$$

After calculating T_0 from the results of regression using Eq. 1, and its error from Eq. 2, we calculate the start and ending of the *i*-th frame in the time range $(T_i = T_0 + i/\text{fps},\ T_0 + (i + 1)/\text{fps}) \pm \Delta T_0$.

In the example from Fig. 2, the linear coefficient is 0.0405 s and the constant $T_0 = 20.706$ s. Half of the absolute difference between constants for the upper and bottom boundary lines, 20.703 and 20.710, respectively, i.e., 0.014 s, is set by us as the error of the constant, instead of the standard deviation taken from the regression analysis which in this case is equal to 0.0023 s. An event occurs within frames 11.5–14, which, according to the PC time recalculation by Eq. 1, occur within 23:02:21.166 s and 23:02:21.266 s, ±0.014 s. It is worth noting that when the times $\{T_i\}$ are calculated from Eq. 1, we used the standard rate of fps, independent of what the linear coefficient resulted from the regression, and whether the real rate of the camera slightly differs

[3]In the UFOCapture program, the parameter "msec" denotes the offset to the superimposed time.

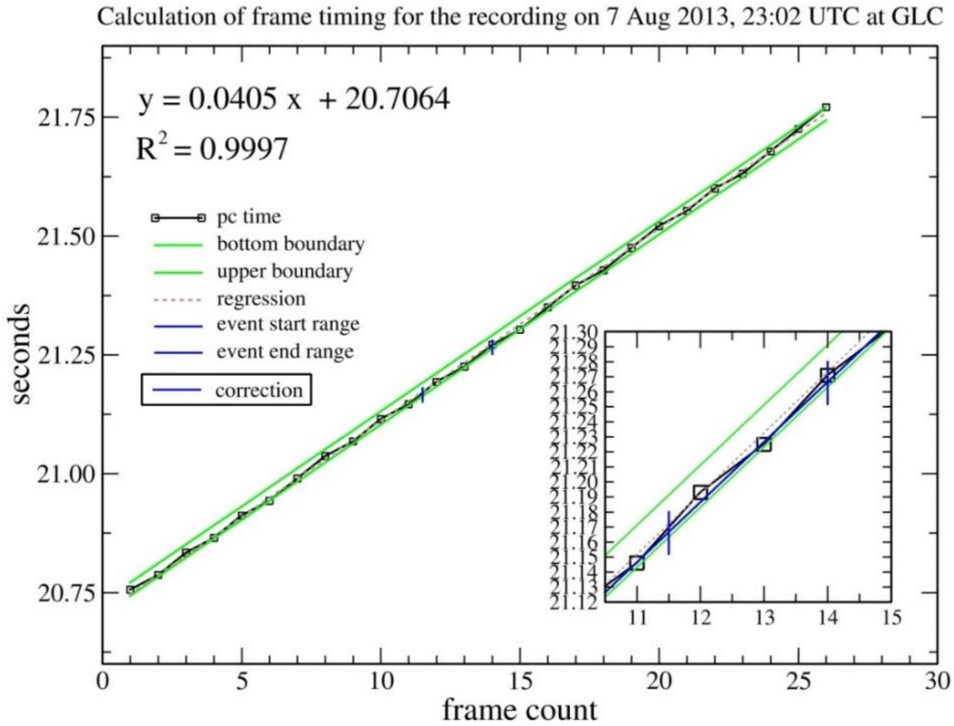

Fig. 2. Results of PC timing recalculation for the video recording from Gliwice on 7 August 2013, ~23:02:22 UTC: a linear regression of PC time records according to Eq. 1, bottom and upper boundary of T_0 error (Eq. 2), regression line, error calculation, and correction with standard fps.

from the standard CCIR fps = 25. For example, the real rate depends on temperature but these changes are rather negligible compared to those we need to take into account when dealing with such time inaccuracy. In the legend to Fig. 2, such calculated series is referred to as the correction.

3.2.2 Missing frames

The above method can be useful providing the numbering of the frames is correct. In order to overcome the issue of missing frames, an examination of any video recording is required, which is an extension to the above procedure and an effective check for missing frames.

Initially, while copying the label values $\{\underline{T}_i\}$, we use counting $\{i\}$ of the frames in the video available from the UFOCapture timestamps (here shown in column 5 in the PC time label), numbered 0001, 0002, 0003, etc. In many recordings, the series of corresponding time labels $\{\underline{T}_i\}$ is a series of time moments separated by ~0.032 s or ~0.047 s, or close to ~0.04 s[4]. If there are no missing frames, a linear regression of these values gives a linear coefficient approximately equal to the value of the fps, ~0.04 s. If this is not the case, we can expect that some frames in the recorded video have been lost. This seems more likely to happen when the recordings are longer or when there are problems with the performance of the system. In case we have a parallel GPS timing, this problem would show also in the GPS timestamps when the receiver updates its timing from the 1PPS[5] signal, not immediately, though. Therefore it is still advisable to check the whole timing of the video frame by frame. Missing frames or fields can easily be revealed by: 1) a linear regression of $\{\underline{T}_i\}$ giving the linear coefficient larger

[4] It happens with the UFOCapture programme when some settings remain that are related to NTSC (default) instead of PAL, such as the time shift of a frame “msec”.

[5] Pulse per second.

Table 1

Example of PC and (KIWI-OSD) GPS timing from the time labels
of the recording on 5 August 2012, ~20:58:07 UTC

	PC timing							GPS timing						
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Count	hh	nn	ss	diff	1+ t/fps	New count	Frame diff	hh	nn	ss f1 start	ss f2 end	Field count	Frame diff	Frame count
1	20	58	5.443	0.000	1	**1**	1	20	58	7.013	7.053	234536	1	1
2	20	58	5.490	0.047	2.2	**2**	1	20	58	7.053	7.093	234538	1	2
3	20	58	5.521	0.031	3.0	**3**	1	20	58	7.093	7.133	234540	1	3
4	20	58	5.553	0.032	3.8	**4**	1	20	58	7.133	7.173	234542	1	4
5	20	58	5.600	0.047	4.9	**5**	1	20	58	7.173	7.213	234544	1	5
6	20	58	5.631	0.031	5.7	**6**	1	20	58	7.213	7.253	234546	1	6
7	20	58	5.662	0.031	6.5	**7**	1	20	58	7.253	7.293	234548	1	7
8	20	58	5.709	0.047	7.7	**8**	1	20	58	7.293	7.333	234550	1	8
9	20	58	5.740	0.031	8.4	**9**	1	20	58	7.333	7.373	234552	1	9
10	20	58	5.787	0.047	9.6	**10**	1	20	58	7.373	7.413	234554	1	10
11	**20**	**58**	**5.818**	**0.031**	**10.4**	**11**	**1**	**20**	**58**	**7.413**	**7.453**	**234556**	**1**	**11**
12	20	58	5.850	0.032	11.2	**12**	1	20	58	7.453	7.493	234558	1	12
13	20	58	5.896	0.046	12.3	**13**	1	20	58	7.493	7.533	234560	1	13
14	20	58	5.943	0.047	13.5	**14**	1	20	58	7.533	7.573	234562	1	14
15	20	58	5.975	0.032	14.3	**15**	1	20	58	7.573	7.613	234564	1	15
16	20	58	6.021	0.046	15.5	**16**	1	20	58	7.613	7.653	234566	1	16
17	20	58	6.068	0.047	16.6	**17**	1	20	58	7.653	7.693	234568	1	17
18	20	58	6.131	0.063	18.2	**18**	1	20	58	7.693	7.733	234570	1	18
19	20	58	6.193	0.062	19.8	**20**	2	20	58	7.733	7.773	234572	1	19
20	20	58	6.240	0.047	20.9	**21**	1	20	58	7.773	7.813	234574	1	20
21	20	58	6.287	0.047	22.1	**22**	1	20	58	7.813	7.853	234576	1	21
22	20	58	6.334	0.047	23.3	**23**	1	20	58	7.853	7.893	234578	1	22
23	20	58	6.381	0.047	24.5	**24**	1	20	58	7.933	7.973	234582	2	24
24	20	58	6.428	0.047	25.6	**26**	2	20	58	7.973	8.013	234584	1	25
25	20	58	6.475	0.047	26.8	**27**	1	20	58	8.013	8.053	234586	1	26
26	20	58	6.537	0.062	28.4	**28**	1	20	58	8.053	8.093	234588	1	27
	Frames total 26 \ New frames total 28							**Frames total 27**						

Note: hh – hour, nn – minute, ss – seconds, diff – difference, fps – frames per second, f1 – first (odd) field 1, f2 – second (even) field (frame = two fields). Green colour in PC timing indicates results of enumerating the frames based on elapsed time 1+ t/fps. Incorrect GPS timings and frame counts are indicated in violet colour.

than 1/fps; 2) calculating time passed measured in "1/fps" units, i.e., t/fps = 1/fps · (($\underline{T}_2 - \underline{T}_1$) + ($\underline{T}_3 - \underline{T}_2$) +…+ {$\underline{T}_{i+1} - \underline{T}_i$}+…); the integer parts of {t/fps + 1} values then indicate to which frame {$\underline{T}_i$} moments theoretically could belong to; 3) by inspection of subsequent {$\underline{T}_{i+2} - \underline{T}_{i+1}$}, {$\underline{T}_{i+1} - \underline{T}_i$} and occurrences being greater than 2/fps (in practice, a sequence of several values exceeding 1/fps).

Let us analyse as an example the video recording from Gliwice made on 5 August 2012, at 20:58:07 UTC, shown in Table 1. This video has been timed by both the PC and GPS. The first column, 1, shows the count of frames in this video. Columns 2–3–4 show hour, minute, and second with the fraction of the second extracted from the subsequent PC timestamps. Columns 5-6 show the time difference between the time in timestamps and the time passed, expressed in theoretical frames count equal to 1 + t/fps. In frame "18" we encounter the first excess of frame time difference of 0.062, followed by another, 0.063, in frame "19", next followed by several 0.047 differences, and ending with 0.062. The theoretical frames count (1 + t/fps) clearly indicates that at row "21" there should be frame "22" and the sequence should finish with frame "28", not "26". The GPS timing (columns 9–15) also indicated a jump in time at frame "23", and none at the end of the video, as probably the time has not been updated yet. In such a situation (even if there is no GPS time), we introduce new, corrected count of frames which is entered in column 7. Next, a regression made with the corrected count gives a linear coefficient close to 1/fps, as shown in Fig. 5. In this example there is only one event appearing in frame "11" and by this moment the frame count is correct. The GPS timestamps are present and, in addition to indications by the device, this analysis can be considered as an additional check.

3.2.3 Calculation of time correction using a relation to external events

Finally, we can try to improve the timing by estimating the difference between the current timing of events and events from other, related processes or other recordings. The time shift, Δt, of a series of N (sprite or other) events at times $T_{i\,=\,1..\mathrm{N}}$, in relation to the set of M events at times $T_{j\,=\,1...\mathrm{M}}$, can be estimated numerically using a method of minimisation of the departures of shifted times from the times of the related events. For instance, we may seek such Δt_k, for which the sum of differences between {$T_i + \Delta t_k$} and {T_j} is minimal. Let $\Delta t_{k\,=\,-K...K}$ be a set of temporary time shifts over a range between $-K\Delta$ and $K\Delta$ seconds, ±25 s in our case, at a resolution of the order of Δ = 10 ms. Calculations may follow the three steps:

1) For each Δt_k, and i = 1..N, create a table of time differences between translated time moments {$T_i + \Delta t_k$} and each j-th external, related event j = 1..M: $\Delta t_{ijk} = |T_i + \Delta t_k - T_j|$;
2) For each Δt_k, and i = 1..N, find the indexes of the external events for which this time difference $|T_i + \Delta t_k - T_{j,\min}|$ is minimal;
3) Sum up the time differences over i = 1…N, for each Δt_k and find Δt corresponding to the minimum of function S, defined as:

$$S(\Delta t_k) = \Sigma_i\, |T_i + \Delta t_k - T_{j,\min}|\,,\quad \Delta t_k = -K\Delta,..0,..K\Delta\ . \tag{3}$$

The numerical procedure is swifter compared to quite strenuous finding it by trial and error, i.e., by visually comparing a shifted series with related series – which is also effective but slow – and gave very similar indications of the time shifts. In the case when a +CG lightning time series is taken as the related series we can set {T_i} not exactly as the start of the first event field but some ~10–20 ms earlier. By using observations where both PC and GPS timing was present we established that a difference of 10 ms used in the procedure recreated the time shift values calculated directly (±0–20 ms). It is also worth noting that this procedure, when applied to GPS-stamped series of events, such as that observed at GLC on 5 August 2012, gave indication of Δt from 0 to 20 ms.

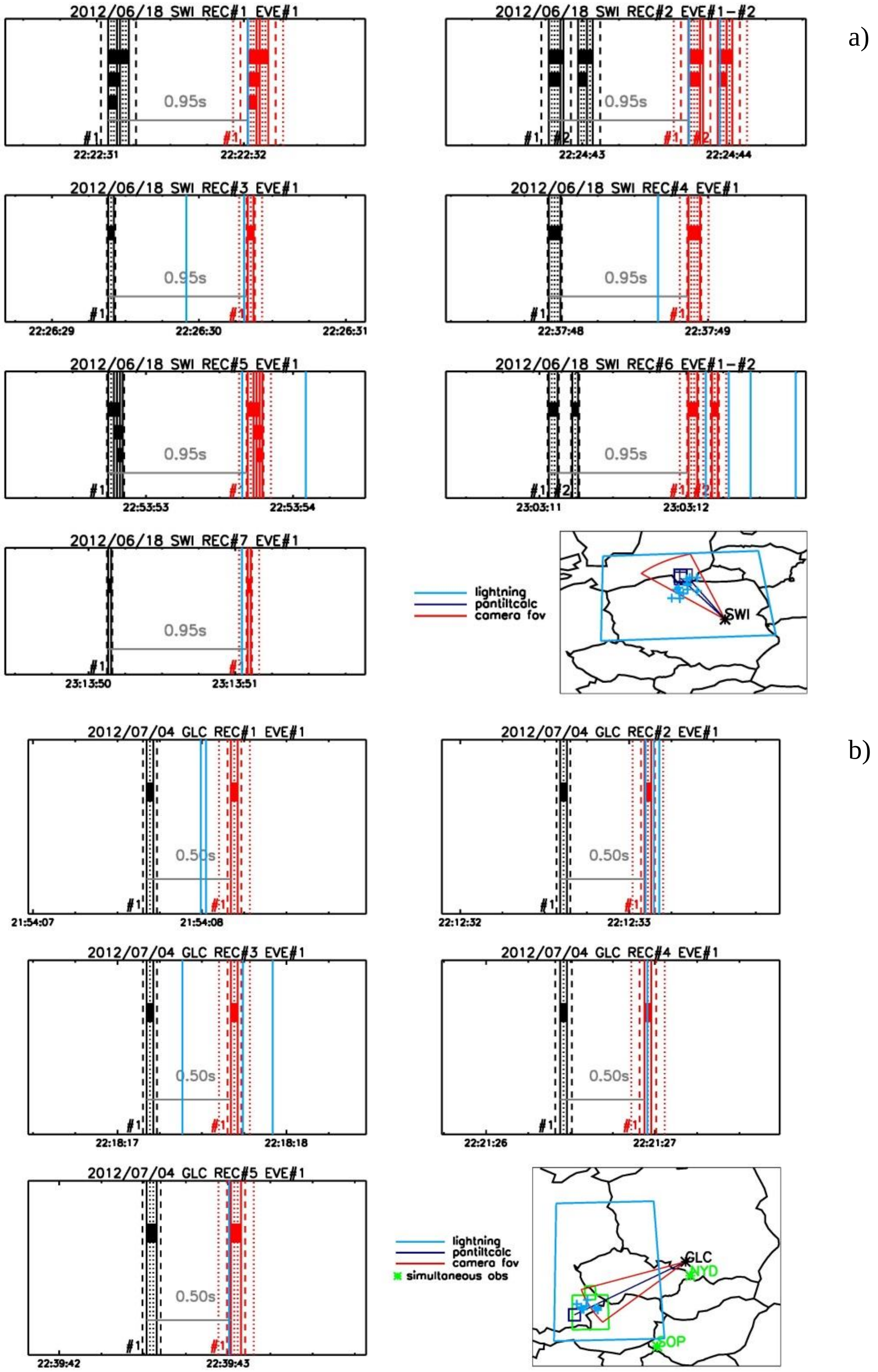

Fig. 3. Results of application of calculated time shifts for a series of sprite events: a) 18 June 2012, Świder (SWI: 7 events between 22:22 and 23:14 UTC); b) 4 July 2012, Gliwice (GLC: 6 events between 21:54 and 23:00 UTC) using +CG times. Black and red lines: times of sprites before and after the time-shift, dashed lines indicate calculated errors, and dotted lines include the 50 ms uncertainty related to the additional translation in time. Light blue lines: time moments of +CG lightning (records courtesy of Torsten Neubert). Grey line and caption: time range between original corrected and translated moments. Map at the bottom shows locations of the +CG lightning displayed in the panels, and the direction and field of view (fov) of the camera based on the aimed calculated azimuth (pantiltcalc) or the azimuth noted in the camera log. Additional camera locations (NYD, SOP) in light green in the map indicate simulataneous observations during this time period and the range of lightning locations (Arnone et al. 2019).

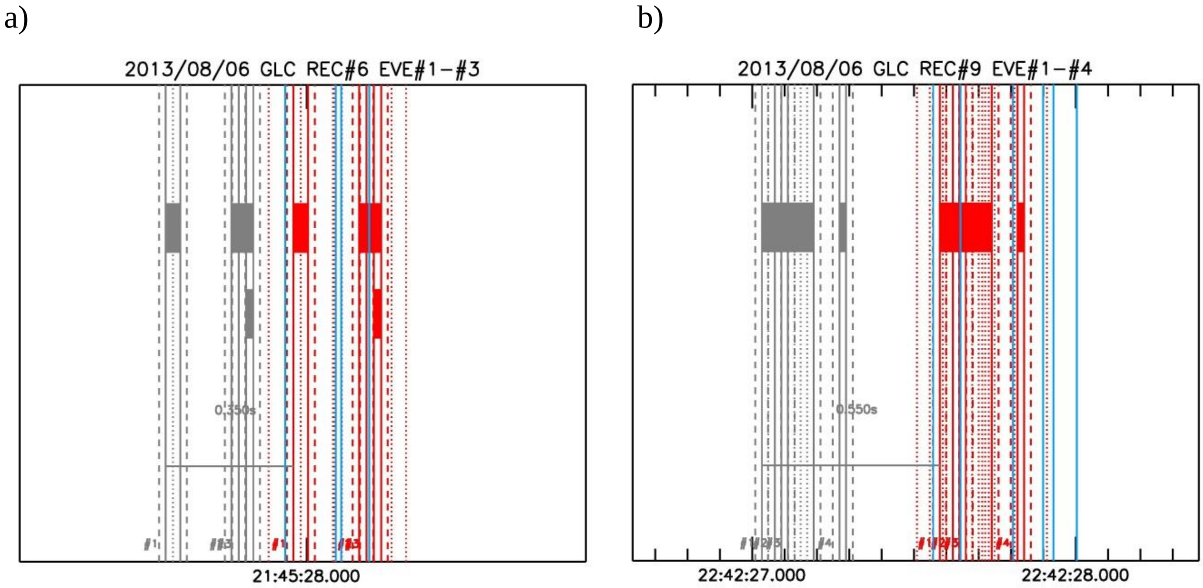

Fig. 4. Results of application of calculated time shifts for two dancing sprite events observed from Gliwice (GLC) on 6 August 2013 at 21:45:27 and 22:42:27 UTC. Description as in Fig. 3, original times indicated by grey lines.

An additional error that needs to be applied after the translation is problematic in the estimate but it is at least of the order of the time step Δ. Accounting also for events which can be delayed we arbitrarily set the final time shift value rounded to the nearest 50 ms and an additional ±50 ms of error (see Figs. 3 and 4).

In the case of events from 18 June 2021, using detections of positive cloud-to-ground lightning as the reference external series, the time correction occurred to be about +0.95 s. In the case of observation of 4 July 2012 from Gliwice, the time shift was estimated at +0.50 s, using all 8 recordings between 21:54 and 22:40 UTC. The results of the time shift are shown in Fig. 3a and 3b, respectively. The time positions of sprites in each recording before and after applying the translation in time are displayed in subsequent panels. Maps attached to panels show locations of lightning displayed in the panels, camera direction and field of view (fov) based on aimed calculated azimuth (referred to as “pantiltcalc”) or a manual camera log. The result seems satisfactory – after application of the time shift all sprites aquire potential parent lightning, and usually no other lightning was detected in the close neighbourhood. The database of the TLE events observed over Western and Central Europe in 2011–2013 by Arnone et al. (2019) indicates that there have been simultaneous observations from Sopron, Hungary, and from Nýdek in the Czech Republic. Observations from Nýdek had no GPS timing, but indicate a consistent difference from the GLC moments of ~3 s (M. Popek, private communication). Other time correction calculations performed for GLC indicated differences in timing on 11 September 2011 by +22.85 s, and on 5 May 2012 by –1.30 s. It is expected that the results of this correction depend on the quality and spatial range of +CG detections; therefore, in our final calculations we also used data from other detection networks[6]. More complicated approach was used for the events of 6/7 August 2013, as discussed below.

[6] These corrections have been confirmed by using data from CELDN, and corrections for Świder have been supported by detections from PERUN lightning detections system (Odzimek et al. 2022b; this issue).

4. ANALYSIS OF TIMING OF DANCING SPRITES OF 6–7 AUGUST 2013

Observations made from Gliwice on 6/7 August 2013 turned out to be the most fruitful, with several dancing sprites. Observational reports indicate favourable TLE-producing conditions that lasted for at least ~5 hours (Arnone et al. 2019). Sprite recordings from Gliwice on this night span between 20:20 and 00:20 UTC. In total 48 events were recorded, 20 of which can be grouped into 7 dancing sprite events (Odzimek et al. 2022a; this issue). GPS timing was only available for the first two events between 20:06:58 and 20:24:14 UTC, indicating a ~0.22 s difference between GPS and PC time. The remaining sprites occurred to be recorded in three main time windows: 21:25–22:05, 22:35–23:00, and 23:55–00:20 UTC. Expecting that the time shift may significantly fluctuate over several hours of observations we calculated the time-shift for each of these windows rather than for the whole period. In addition, we made further test calculations by applying the procedure to subsets of sprites in these periods. For example, in 22:35–23:00 UTC these have given consistent time shifts of 0.55 s. In the first period, 21:25–22:05 UTC, they varied between ~–0.10 and +0.35 s. We applied the latter value only to all events occurring after 21:30 UTC in the first period. We note here that before the calculation of the time differences each recording has been analysed as described in Subsections 3.2.1 and 3.2.2, as a correct frame counting is needed for the relative time differences between events appearing in the same video recording to be determined. In Fig. 4 we present the results of the time correction (shift) procedure for the dancing sprite events at 21:45:27–28 and 22:42:27 UTC. The corrected time ranges for the duration of the events from first to last observed are 21:45:27.614–27.854±0.018, and 22:42:27.030–27.290±0.021 UTC, while the corrected and shifted times are 21:45:28.014–28.254±0.068, and 22:42:27.580–27.840±0.071 UTC, respectively. Bór et al. (2018) give the time frames of these events in the ranges: 21:45:27.939–28.199 UTC, and 22:42:27.570–27.836 UTC, so the new values differ by ~0.075 and ~0.010 s, which is comparable to the error. In addition, the GPS timing of one of the sprites observed simultaneously from Sopron at 22:52:17.144–164 UTC (J. Bór, private communication) agrees well with its corrected timing 22:52:17.167–187±0.070 UTC. The corrected times of the observed sprites with their determined errors now enable further analysis of the events.

5. SUMMARY

We have presented a way of verification and correction of the times and time range of sprites observed optically with a TV camera in Świder and Gliwice over 2011–2015. We give details and results of verification of timing within a single recording and the corrections to timing of series of events in the absence of GPS timing. Calculations of errors allow further analysis of the events.

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References

Allin, T.H., T. Neubert, and S. Laursen (2006), Imaging systems in TLE research. **In:** M. Füllekrug, E.A. Mareev, and M.J. Rycroft (eds.), *Sprites, Elves and Intense Lightning Discharges*, NATO Science Series II: Mathematics, Physics and Chemistry, Vol. 225, Springer, Dordrecht, 101–121, DOI: 10.1007/1-4020-4629-4_5.

Arnone, E., P. Berg, F. Boberg, J. Bór, O.A. Chanrion, C.-F. Enell, M. Ignaccolo, Á. Mika, A. Odzimek, O. van der Velde, T. Farges, S. Laursen, T. Neubert, and G. Sátori (The Eurosprite 2005 team) (2008), The Eurosprite 2005 campaign. **In:** Sandahl I. and J. Arvelius (Eds), *Proceedings of 33rd Annual European Meeting on Atmospheric Studies by Optical Methods*, 28 August – 1 September 2006, Kiruna, Sweden, IRF Sci. Rep., 29–40.

Arnone, E., J. Bór, O. Chanrion, V. Barta, M. Füllekrug, R. Labanti, K. Mezuman, A. Odzimek, M. Popek, S. Soula, D. Valeri, O. van der Velde, Y. Yair, F. Zanotti., and P. Zoladek (2019), *The Eurosprite 2009–2013 Catalogue (Version 1.3)*, Zenodo, DOI: 10.5281/zenodo.3480108.

Arnone, E., J. Bór, O. Chanrion, V. Barta, S. Dietrich, C.-F. Enell, T. Farges, M. Füllekrug, A. Kero, R. Labanti, A. Mäkelä, K. Mezuman, A. Odzimek, M. Popek, M. Prevedelli, M. Ridolfi, S. Soula, D. Valeri, O. van der Velde, Y. Yair, F. Zanotti, P. Zoladek, and T. Neubert (2020), Climatology of Transient Luminous Events and lightning observed above Europe and the Mediterranean Sea, *Surv. Geophys*. **41**, 2, 167–199, DOI: 10.1007/s10712-019-09573-5.

Boccippio, D.J., E.R. Williams, S.J. Heckman, W.A. Lyons, I.T. Baker and, and R. Boldi (1995), *Science* **269**, 5227, 1088–1091, DOI: 10.1126/science.269.5227.1088.

Boeck, W.L., O.H. Vaughan Jr., R.J. Blakeslee, B. Vonnegut, and M. Brook (1998), The role of the space shuttle videotapes in the discovery of sprites, jets and elves, *J. Atmos. Sol.-Terr. Phys.* **60**, 7–9, 669–677, DOI: 10.1016/S1364-6826(98)00025-X.

Bór, J., G. Sátori, and H.D. Betz (2009), Observation of TLEs in Central Europe from Hungary supported by LINET, *AIP Conf. Proc.* **1118**, 1, 73–83, DOI: 10.1063/1.3137716.

Bór, J., Z. Zelkó, T. Hegedüs, Z. Jäger, J. Mlynarczyk, M. Popek, and H.D. Betz (2018), On the series of +CG lightning strokes in dancing sprite events, *J. Geophys. Res.: Atmos*. **123**, 19, 11030–11047, DOI: 10.1029/2017JD028251.

Cummer, S.A., U.S. Inan, T.F. Bell, and C.P. Barrington-Leigh (1998), ELF radiation produced by electrical currents in sprites, *Geophys. Res. Lett.* **25**, 8, 1281–1284, DOI: 10.1029/98GL50937.

Damjanovski, V. (2005), *CCTV. Networking and Digital Technology*, 2nd ed., Elsevier Butterworth-Heinemann, Amsterdam, 584 pp.

Franz, R.C., R.J. Nemzek, and J.R. Winckler (1990), Television image of a large upward electrical discharge above a thunderstorm system, *Science* **249**, 4969, 48–51, DOI: 10.1126/science.249.4964.48.

Ganot, M., Y. Yair, C. Price, B. Ziv, Y. Sherez, E. Greenberg, A. Devir, and R. Yaniv (2007), First detection of transient luminous events associated with winter thunderstorms in the eastern Mediterranean, *Geophys. Res. Lett*. **34**, 12, L12801, DOI: 10.1029/2007GL029258.

Huang, E., E. Williams, R. Boldi, S. Heckman, W. Lyons, M. Taylor, T. Nelson, and C. Wong (1999), Criteria for sprites and elves based on Schumann resonance observations, *J. Geophys. Res.: Atmos*. **104**, D14, 16943–16964, DOI: 10.1029/1999JD900139.

Iwański, R., A. Odzimek, L.B.N. Clausen, V. Kanawade, I. Cnossen, and N.J.T. Edberg (2009), Meteorological study of the first observation of red sprites from Poland, *Acta Geophys*. **57**, 3, 760–777, DOI: 10.2478/s11600-009-0008-7.

Li, J., S.A. Cummer, W.A. Lyons, and T.E. Nelson (2008), Coordinated analysis of delayed sprites with high-speed images and remote electromagnetic fields, *J. Geophys. Res.: Atmos.* **113**, D20, D20206, DOI: 10.1029/2008JD010008.

Lyons, W.A. (1994), Characteristics of luminous structures in the stratosphere above thunderstorms as imaged by low-light video, *Geophys. Res. Lett.* **21**, 10, 875–878, DOI: 10.1029/94GL00560.

Mende, S.B., Y.S. Chang, A.B. Chen, H.U. Frey, H. Fukunishi, S.P. Geller, S. Harris, H. Heetderks, R.R. Hsu, L.C. Lee, H.T. Su, and Y. Takahashi (2006), Spacecraft based studies of Transient Luminous Events. **In:** M. Füllekrug, E.A. Mareev, and M.J. Rycroft (eds.), *Sprites, Elves and Intense Lightning Discharges,* NATO Science Series II: Mathematics, Physics and Chemistry, Vol. 225, Springer, Dordrecht, 123–149, DOI: 10.1007/1-4020-4629-4_6.

Neubert, T., T.H. Allin, E. Blanc, T. Farges, C. Haldoupis, Á. Mika, S. Soula, L. Knutsson, O. van der Velde, R.A. Marshall, U. Inan, G. Sátori, J. Bór, A. Hughes, A. Collier, S. Laursen, and Ib L. Rasmussen (2005), Co-ordinated observations of transient luminous events during the EuroSprite2003 campaign, *J. Atmos. Sol.-Terr. Phys.* **67**, 8–9, 807–820, DOI: 10.1016/j.jastp. 2005.02.004.

Odzimek, A., M. Mielniczek, M. Pajek, and P. Novák (2022a), Red Sprites over thunderstorms in Czech Republic, Germany and Poland, observed from Gliwice in 2011–2013, *Publs. Inst. Geoph. PAS* **D-77 (442)**, 41–54, DOI: 10.25171/InstGeoph_PAS_Publs-2022-024 (this issue).

Odzimek, A., W. Gajda, M. Pajek, and M. Kubicki (2022b), Red Sprites over northwest Poland and the southern Baltic coast observed from Świder Geophysical Observatory 2012-2015, *Publs. Inst. Geoph. PAS* **D-77 (442)**, 55–70, DOI: 10.25171/InstGeoph_PAS_Publs-2022-025 (this issue).

Rairden, R.L., and S.B. Mende (1995), Time resolved sprite imagery, *Geophys. Res. Lett.* **22**, 24, DOI: 3465–3468, DOI: 10.1029/95GL03332.

Rodger, C.J. (1999), Red sprites, upward lightning, and VLF perturbations, *Rev. Geophys.* **37**, 3, 317–336, DOI: 10.1029/1999RG900006.

Rycroft, M.J., and A. Odzimek (2010), Effects of lightning and sprites on the ionospheric potential, and threshold effects on sprite initiation, obtained using an analog model of the global atmospheric electric circuit, *J. Geophys. Res.: Space Phys*. **115**, A6, A00E37, DOI: 10.1029/2009JA014758.

Stanley, M., P. Krehbiel, M. Brook, C. Moore, W. Rison, and B. Abrahams (1999), High speed video of initial sprite development, *Geophys. Res. Lett.* **26**, 20, 3201–3204, DOI: 10.1029/ 1999GL010673.

Yamamoto, M.-Y., S. Okamoto, T. Miyoshi, Y. Takamura, A. Aoshima, and J. Hinokuchi (2010), TLE triangulation campaign by Japanese high school students as a space educational project of the SSH Consortium Kochi. **In:** *Proceedings of 38th COSPAR Scientific Assembly, 18–15 July 2010, Bremen, Germany,* PE1-0016-10, 3 pp., SAO/NASA Astrophysics Data System, available from: https://ui.adsabs.harvard.edu/abs/2010cosp...38.3902Y.

Yaniv, R., A.D. Devir, Y. Yair, C. Price, B. Ziv, and N. Reicher (2009), Calibration of CCD cameras for measurements of sprites and elves, *AIP Conf. Proc.* **1118**, 1, 92–98, DOI: 10.1063/ 1.3137719.

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