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DETAILED BRIGHTNESS VERSUS LIGTHNING CURRENT AMPLITUDE CORRELATION OF FLASHES TO THE GAISBERG TOWER

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Abstract: In 1999 a digital high speed video camera was installed at the lightning experimental site at the Gaisberg tower. The camera is capable of capturing black and white images in speeds of up to 1.000 frames/s. The camera is triggered by a trigger signal derived from the lightning current measured at the tower top. In summer 2000 five flashes were recorded by the digital camera and for those five flashes time correlated current measurements (sampling rate 20MS/s) are available.

In summer 2000 the frame rate of the camera was set to 500 frames per second with a total recording time of 2.1 s and a pretrigger of 50 %. Therefore these data provide sufficient time resolution for investigations on the optical development of the entire flash with a total time duration of up to several hundred milliseconds. On the other hand the 2 ms exposure time per frame is insufficient to analyze brightness details of individual strokes with a pulse duration of some tens to some hundreds of microseconds only.

From the gray values of the frame pixels of a single frame we calculate a summed brightness value at a given channel cross section. By doing this for all light exposed frames of a flash we can derive a plot of brightness as a function of time. Comparison of the plots of brightness versus the plots of the channel current for four flashes is shown in the paper. For all four flashes we found a very similar wave shape for brightness and current.

Keywords: lightning, luminosity, high speed camera

1. INTRODUCTION

The radio tower on Gaisberg with a height of about 100 m is located 1287 m above sea level and about 5 km east of the city of Salzburg, Austria. This tower was selected for lightning experiments because analysis of historical data from the lightning location system ALDIS showed a flash rate of about 40 – 50 flashes per year to the tower.

It is worth to note that elevated objects like the radio tower experience primarily upward initiated discharges similar to rocket-triggered lightning. Typical for this upward initiated discharges is a so-called initial continuing current (ICC) with a duration of some hundred milliseconds and an amplitude of some tens to some hundreds of amperes, often followed by one or more downward leader - upward return stroke sequences. In many of the upward initiated discharges to the Gaisberg tower all the superimposed current pulses have amplitudes of a few hundred amperes up to 1 - 2 kA. Often these current pulses show a very slow rising front even with higher amplitudes.

Lightning photography as a tool for lightning research has been in use for many decades. As an example digitized streak-camera photographs were analyzed by Jordan et al. (1997) and revealed an increase of rise time and a decrease of amplitude of the light pulses associated with return-stroke processes in the lightning channel as a function of height above ground level.

The characteristics of the lightning channel light, to the extent that these characteristics relate to the current flowing in the lightning channel, contain important information for the understanding of the physical processes that occur along the lighting channel at different heights. Return stroke models typically specify a distribution of channel current i(z,t) as a function of height and time. From this current distribution along the lightning channel the associated electromagnetic fields are calculated as a function of distance to the striking point.

Analysis of lightning flashes to the CN Tower in Toronto based on high speed digital camera frames was presented by Janischewskyj et al. (1998). They give plots for the maximum and the average brightness at a single line on the time series of frames for a flash.

During the year 2000 we obtained optical data for 5 flashes to the Gaisberg tower. For those flashes time correlated lightning current records are available.

2. DATA

2.1. High speed video images

In 1999 a digital high speed camera (KODAK MotionCorder Analyzer SR-1000) was installed at the lightning experimental site at the Gaisberg tower. The camera is capable of capturing black and white images in speeds of up to 1.000 frames/s. The camera is triggered by a trigger signal derived from the lightning current measured at the tower top. In summer 2000 the frame rate of the camera was set to 500 frames per second and a pretrigger of 50 % resulting in a total recording time of 2.1 s (1.05 s before and after the trigger time, respectively). These data provide sufficient time resolution for investigating the optical nature of the entire flash with a total time duration of up to several hundreds of milliseconds. On the other hand the 2 ms exposure time per frame is too long for analyzing details of individual strokes with a pulse duration of some tens to some hundreds of microseconds. Return strokes usually cause overexposure of a single frame with significant light dispersion.

The resolution of the camera (512x240 pixels) and the focal length (8.5 mm) of the lens gives a corresponding two-dimensional resolution at the tower location of about 20 cm x 20 cm. The frames are stored as black and white bitmap files (BMP). In these files the brightness value of each pixel is in the range between 0 (black) and 256 (white - saturation limit).

In most of our datasets we observed a more or less pronounced horizontal movement of the entire lightning channel caused by wind. It is worth to note, that we have to be aware of the effect of the two dimensional character of the BMP frames. Any information about possible movement of the lightning channel or spatial extension of the lightning channel in direction of view - in the third dimension - can not be resolved from the two dimensional video images. In Fig.1 we show an overlay of two frames from a flash recorded at 19:08:38.526 on August 17, 2000. During the time of 500 ms between the begin and end of the current flow in the lightning channel, the entire channel has moved by about 7 meters (35 pixels) in the two dimensional picture. In reality this distance could have been even more, if there was a velocity component in the third dimension. A distance of 7 m in 500 ms corresponds to a velocity of 14 m/s equivalent to about 50 km/h - a realistic wind speed during a thunderstorm.

2.2. Lightning Current data

Details of the experimental setup for the measurement of lightning current on the tower are described in Diendorfer et al. (2000). Due to the wide range of expected current peak amplitudes the signals are recorded at two channels with different sensitivities:

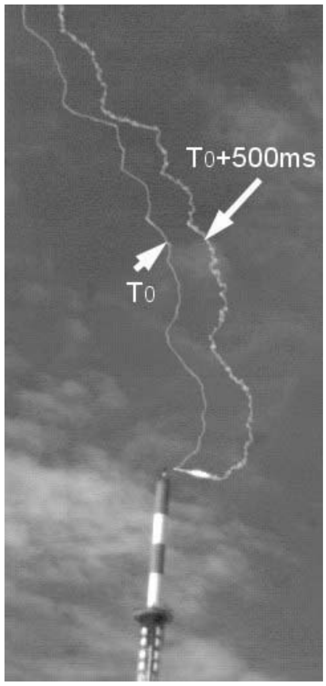


Fig.1: Overlay of two lightning frames separated in time by 500 ms to demonstrate the shift of the lightning channel as a result of strong wind. The two lightning frames are superimposed on a daylight photograph of the tower to see the striking point on top of the tower.

- Channel 1: 0 - 2.1 kA
- Channel 2: 0 - 40 kA

The current signals are recorded by an 8 bit digitizing board installed in a Personal Computer. The digitizing board (National Instruments PCI-5102) with a bandwidth of 15 MHz and a memory of 16 MB per channel is operated with a sampling rate of 20 MS/s. The trigger of the recording system is set to a corresponding lightning current level of ±200A.

All recorded waveforms as well as the individual frames of the video system are time stamped using the time information provided by a GPS clock (Meinberg GPS167PC) in order to be able to time correlate the different datasets with each other and with the data from the Austrian lightning location system ALDIS.

3. ANALYSIS OF BRIGHTNESS AS A FUNCTION OF HEIGHT AND TIME

When we analyze a single frame obtained by the video camera we realize that several pixels are illuminated at a given height. As mentioned before a single pixel corresponds to a horizontal extension of about 20 cm. It is our opinion that light dispersion does not allow to estimate any real diameter of the lightning channel from these images.

In Fig.2 we show a zoom of a section of the lightning channel labeled as "Detail A" in Fig.3 with the corresponding gray values for the illuminated pixels along a horizontal pixel line.

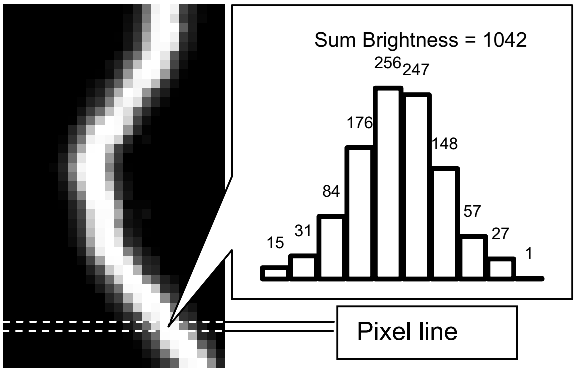


Fig.2: Detail of Fig.3 (25 x 40 pixels) with the corresponding gray values of the channel cross section of a single horizontal pixel line. One pixel is saturated (gray value = 256), black pixels (gray value = 0) are ignored.

We have to find a proper measure to describe the channel brightness at a given height and time (channel cross section). In Fig.3 we show the plot of the sum of gray values at each horizontal pixel line -we call this the sum-brightness - for a single frame. We have to note that in case of saturation (gray value = 256) of one or more pixels along the channel cross section these values are underestimating the actual brightness. The sum-brightness of the pixel line shown in Fig.2 is 1042.

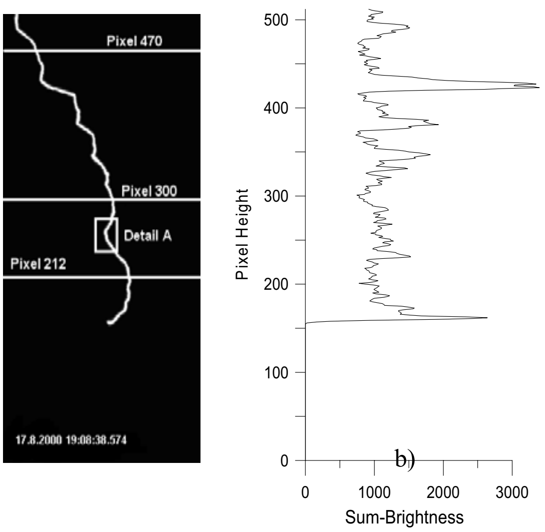


Fig.3: Brightness analysis of a single frame.
(a) Video frame with labeled pixel lines
(b) Sum-brightness as a function of height

The variation of sum-brightness along the channel depicted in Fig.3b is caused by the lightning channel tortuosity. Any lightning channel segment non parallel to the image plane of the camera will result in an increase of sum-brightness due to the projection effect. The segment length is reduced on the image whereas all the emitted light of the inclined segment is accumulated on this smaller section. On the other hand also channel segments in non vertical direction will show up with increased sum-brightness (see pixel height 420 to 440 in Fig.3).

In Fig.3 at pixel line 155 - the lower end of the lightning channel (top of the tower) - a higher brightness of the channel is visible. We have observed this feature of increased brightness at the attachment point also for all the other analyzed flashes.

We have developed software for the determination of the channel brightness at a given height for the full set of camera frames of a recorded flash. By this procedure we obtain a brightness value for 2 ms time intervals for a specified channel height, when the camera is operated with a frame rate of 500 frames/sec. This method provides appropriate data for the channel brightness as a result of the continuing current, typical for upward initiated discharges. Obviously return strokes, that occur during one of these 2 ms time intervals, often cause saturation at a large fraction of the illuminated pixels and show up as a sharp peak in the following figures.

The current record of the flash given in Fig.3a showed, that in this particular flash almost a pure continuing current (total charge transfer 118 As) was flowing in the lightning channel without any pronounced current pulses. In Fig.4 we have plotted the sum-brightness of the lightning channel as a function of time at the four different pixel heights 212, 300 and 470, respectively. The positions of these pixel lines along the lightning channel are shown in Fig.3. We have chosen these heights, because at these positions the sum-brightness (Fig.3b) is about a minimum. We assume therefore, that at these positions the channel is most likely straight and vertical. As mentioned before, any inclination of the channel would result in an increased sum-brightness.

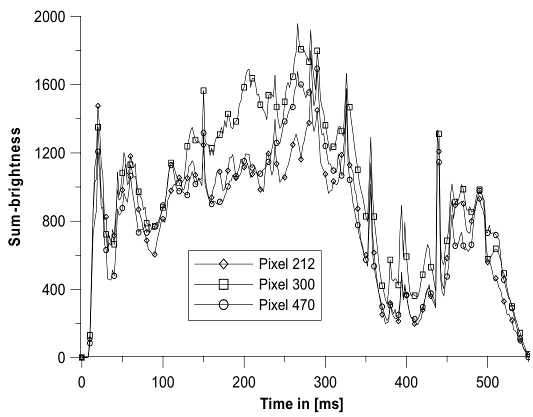


Fig.4: Sum-brightness as a function of time and height at three cross sections of the lightning channel (pixel 212, 300 and 470)

Obviously from Fig. 4 the channel brightness at height 212, 300 and 470 is very similar in its overall wave shape indicating that about the same current is flowing at the different heights.

4. CHANNEL BRIGHTNESS VERSUS LIGHTNING CURRENT

For comparison of brightness and recorded current wave shape we have to reduce the 20 MS/s current records with about 16 million data points. For each 2 ms time window of a video frame we have 40000 data points of the current record. As mentioned before the 2 ms resolution of the video records is insufficient to resolve any return stroke details. Therefore we only analyze the channel 1 data of our current records with a measuring range of 0 – 2.1 kA. For a direct correlation of the channel brightness with the recorded lightning channel current we have calculated an average channel current for each 2ms time slice specified by the video frame time stamping. Sometimes saturation of channel 1 in the current recording system caused by superimposed high current pulses results in an inverse overshoot of the current signal. This is not a bipolar lightning current and has been eliminated from the data.

In Fig 5 we show a comparison for the first 100 ms section of the recorded lightning current of the flash in Fig.1. Fig 5a depicts the full resolution current data (20MS/s) and Fig.5b shows the reduced 2 ms-current data. Obviously Fig.5b is an excellent representation of the overall current in the lightning channel and this 2 ms resolution current is used for the following direct comparisons of channel brightness and lightning current. For the plot of the brightness we are using the sum-brightness as a function of time at a pre-selected channel section, where a minimum of pixels was saturated.

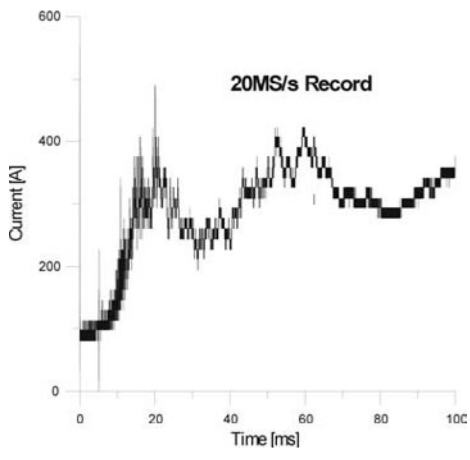


Fig.5a: Full resolution current record

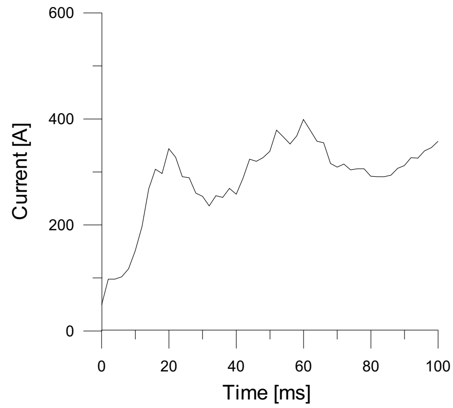


Fig.5b: Data reduced lightning current – 2 ms-average

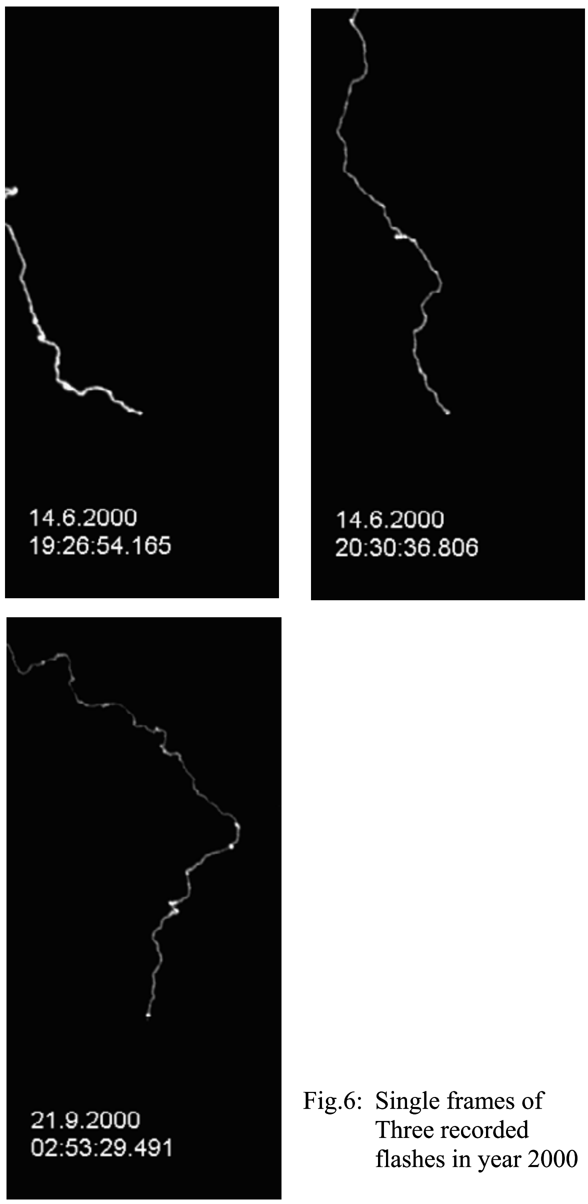
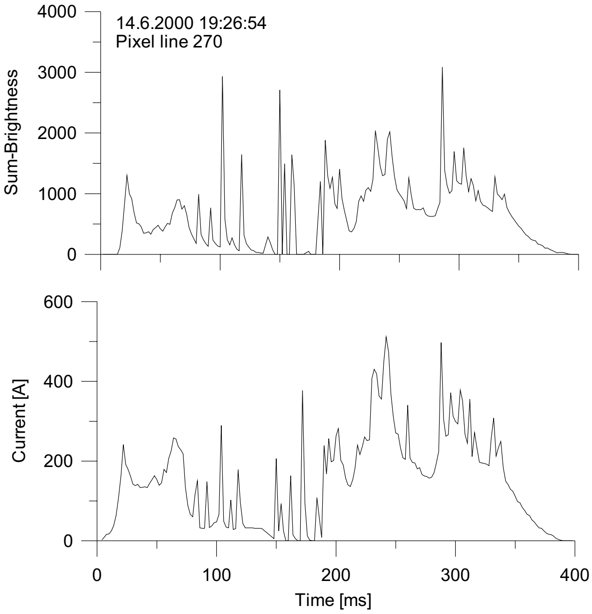


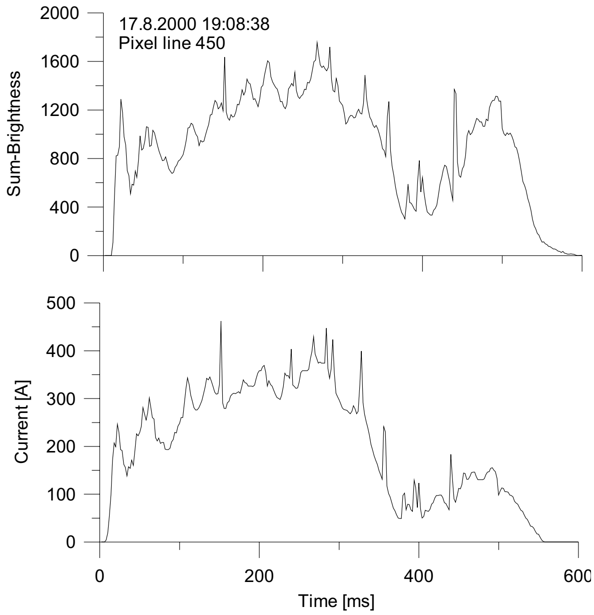
Fig.6: Single frames of Three recorded flashes in year 2000

In addition to Fig.3 in Fig.6 we show a single frame of three other recorded flashes in year 2000. The corresponding comparisons of sum-brightness versus lightning current are summarized in Fig.7 for the four analyzed flashes.

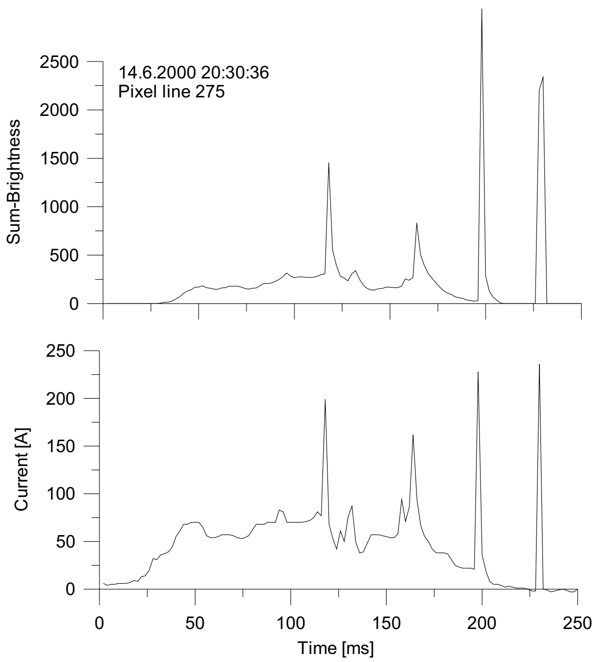
Obviously the sum-brightness and the continuing current wave shape have very similar wave shapes.



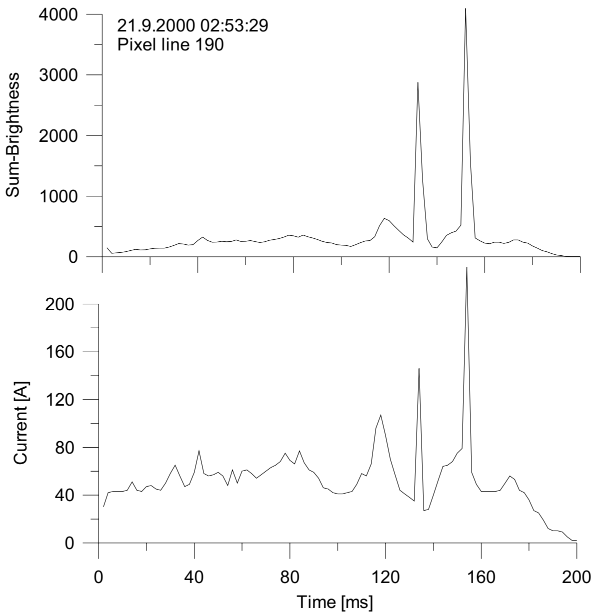
a)



c)



b)



d)

Fig.7: Sum-brightness at a specified height versus measured lightning current for four different flashes recorded in year 2000.

5. DISCUSSION

Evaluating data from a high speed digital camera requires specification of a measure of brightness. Limitations are given by the saturation of the video system and the visibility conditions at the experimental site during the lightning strike. The local visibility conditions (rain, fog) will affect the absolute ratio of current and brightness, whereas the overall wave shapes should be unchanged.

In fall 2000 we changed the lens to a 3.5 mm lens providing a wider angle of view. In the meantime we have recorded several flashes with extended branching. In a future analysis we will extend this study to estimate the current components in the individual branches based on the channel brightness.

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