Luminosity Variation during Propagation of Lightning Channels

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ABSTRACT

Luminosity variations of natural cloud-to-ground lightning flashes were studied by analyzing a set of high speed video recordings. The frame rate and resolution of the camera was 5000 fps at 512×512 pixel resolution. The frames were stored as black and white sequence (SEQ) files which were converted to sequence of image files using the software provided by the camera. Algorithms were developed to scan the image files and extract maximum brightness of channels as well as maximum brightness at selected locations along the channels. The variation of current along the channel was analyzed by assuming that the brightness of the channel is directly proportional to the current that flows through it. The study shows that there is a loss of current in lightning channels when current flowing through the channel. The amount of current reduction increases with the propagating distance. Preliminary estimates show that there is approximately 3% reduction in current when propagation from cloud-to-ground.

1. INTRODUCTION

Lightning is a one of the impressive and frequently observed natural phenomena. Although there are number of microphysical and numerical models available to model the lightning discharges, the process of lightning discharge is not yet fully understood.

In general lightning is an electrical discharge exchanging between cloud-to-cloud or cloud-to-ground. Ice crystals inside a cloud is thought to be the key element in lightning development which is responsible for the separation of positive and negative charges within the cloud. When positive and negative charges accumulate in separate regions, large electrical field can be developed between the charged regions as well as between a charged region and the ground. When this voltage developed 50 to 500 million volts, the air in-between may become significantly ionized and form a plasma column which is the electrically conducting channel we see as lightning [1].

Normally, each cloud to ground lightning flash involves roughly 10^9 to 10^{10} J amount of energy [2]. However, all this energy is not delivered to the strike point of the ground. Bulk of the energy is lost as heat, light and sound. The estimated range of energy delivered to the strike point of the ground due to lightning is from 10^6 to 10^7 J, which is only 10^{-2} to 10^{-4} of the available total energy [2]. Also due to the horizontal electric field gradient, part of energy along the lightning channel dissipated as the corona discharges. Thus, it is very conceivable that there is a loss of current in each cloud to ground lightning flash. In this work we tried to estimate qualitatively, the loss of current in cloud to ground lightning flashes along the channel using optical measurements.

Obtaining direct measurement of lightning current is quite difficult and complex. A number of previous studies have shown that there is a good correlation between the brightness of lightning channels and measured current. Diendorfer *et. al.* [3] have shown that there is a strong linear correlation between channel brightness and channel current for natural lightning. This is not only true for the natural lightning but also for the long electrical discharges. In a recent study, Amarasinghe *et. al.* [4] have shown that a high degree of correlation exists between the measured peak current and the brightness of the main channel for 500 cm long sparks. Thus, in this work channel brightness was used as a proxy to study the variation of lightning current along the discharge path.

In another study, Diendorfer *et. al.* [5] reported their findings for sum of brightness of the lightning channel as a function of time at four different heights. Their results indicate that the channel brightness at different heights is very similar in overall wave shape. i.e., the same current is flowing at the different heights along the channel. The luminosity variation with time for natural negative cloud to ground lightning flashes was reported by Campos *et. al.* [6]. Using the graphs of luminosity versus time they were able to identify positions of return strokes and M changes, number of M components, time interval between M components, time interval between Return strokes and M components and time duration of M components. In this study, luminosity of the lightning channel with time was recorded using a high speed camera to investigate the variation of luminosity/current at different heights of natural cloud to ground lightning channels with time.

2. METHODOLOGY

2.1 Acquiring High Speed Video Image Sequence

A high speed video camera OPTRONICS CamRecord 5000 was used to record lightning flashes. The frame rate of the camera is 5000 fps with a resolution of 512x512 Pixel. The maximum internal memory of the camera is 4GB. The frames were stored as black and white sequence (SEQ) files. User software which comes with the camera was used to convert the video sequence to an image sequence. In these images the brightness (or intensity) value of each pixel is in the range between 0 (black) – 255 (white). The saturation limit of brightness values is 255. Figure 1 shows several consecutive frames of a typical cloud to ground flash analyzed in this work.

Figure 1: Several consecutive frames of typical cloud to ground flash

2.2 Selecting Channel Area and Calculating Channel Current

For each selected frame, a flash region absent of other background objects was chosen (see Figure 2a). Horizontal range of this region is about 162 pixels wide where as the vertical range is about 283 pixels long. Then by using an algorithm, average peak current of the channel was calculated for each frame separately. The program extracts intensity (brightness) values of every pixel starting from the top most pixel row in the selected region and locates the pixel with maximum intensity. Once the pixel is found, program moves to the next row and search for the pixel having maximum intensity in that row. By repeating this procedure, the maximum intensity values of each row were obtained and formed the sum. Finally the sum was divided by the number of rows to obtain the average peak current of the lightning channel which is in arbitrary units.

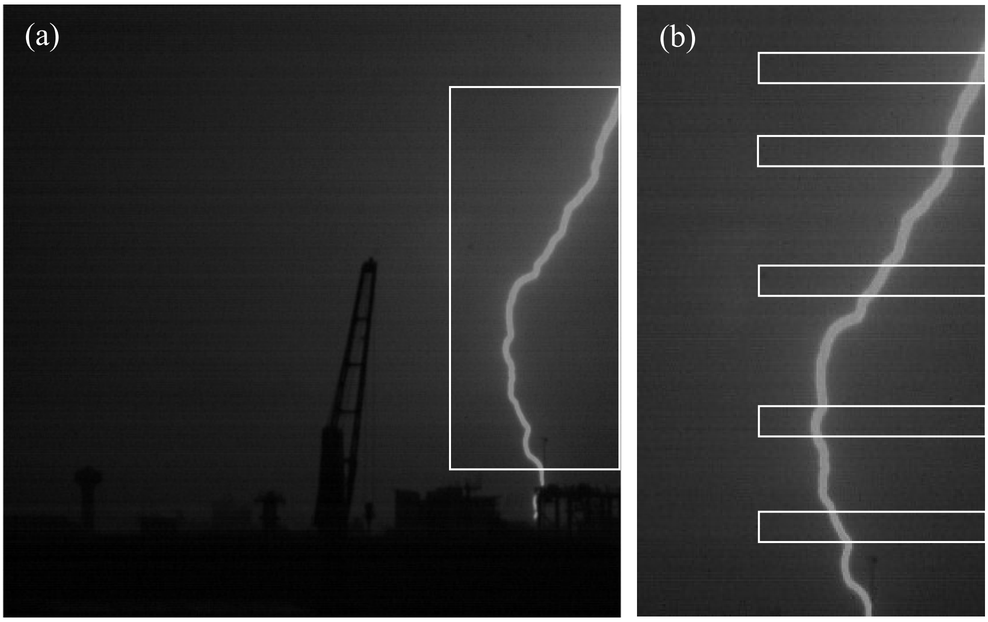

Figure 2: (a) Selected flash region (b) Selected channel segments

2.3 Selecting Channel Segments and Calculating Average Current of Segments

In order to study the current variation alone the channel for each frame, five separate segments were selected and the same algorithm described in section 2.2 was applied to calculate average peak current of segments. The locations of selected channel segments alone the channel is shown in Figure 2b.

Lightning segments which are non-parallel to the image plane of camera will result in an increase of sum – brightness (sum of gray values of horizontal pixel line) due to projection effects [4, 5]. This is due to increase in the intensity value stored in pixels when channel is tortuous and align perpendicular to the image plane. Therefore, sum – brightness of turning positions tends to show higher intensity compared to channel segments which are straight. Since maximum intensity value of each row was selected from regions where the channel path is straight, it was assumed that the projection effects do not alter the intensity values.

3. RESULTS AND DISCUSSION

3.1 Analysis of Luminosity/Current Variation of Channel with Time

As described in section 2.2, first, average peak brightness of full channel was calculated for each frame. Since the camera takes one second to generate 5000 frames (speed of camera was 5000 fps) it generates one frame after every 0.2 millisecond. The variation of average peak brightness versus time is shown in Figure 3.

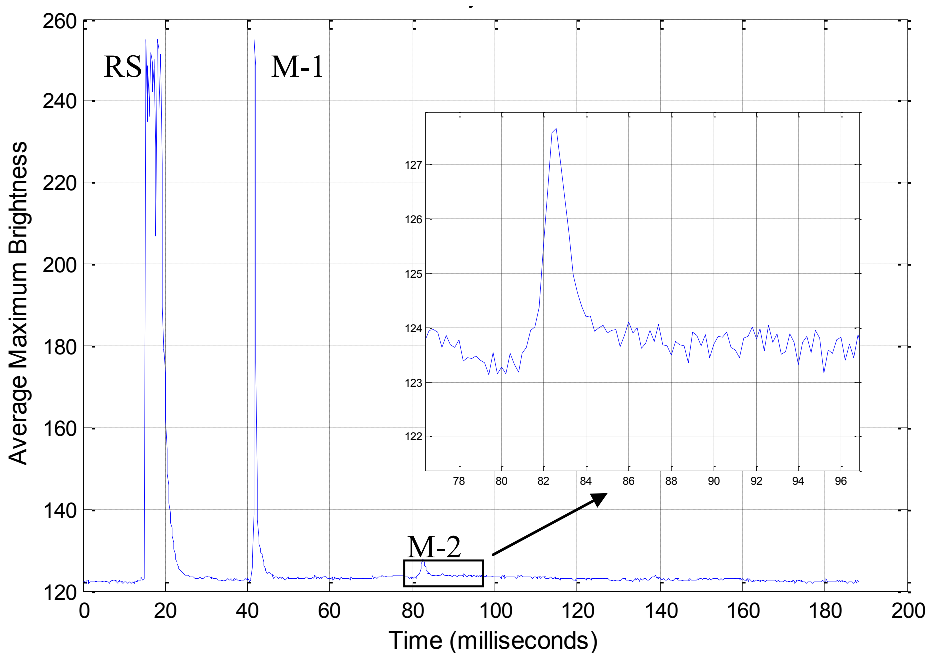

Figure 3: Luminosity variation of channel with time. The inset shows the luminosity variation of channel on a 21 ms time scale.

The data show that the return stroke (RS) has appeared near 0.02 sec. Two M-components (M-1 and M-2) are also identified. Originally, the M-component is defined as luminosity increase of the channel during the occurrence of a continuing current event [6]. Time interval between two consecutive M-components was 40.9 ms. M-elapsed time from the stroke is 26.3 ms for M-1 and 67.2 ms for M-2 respectively. The duration for M-1 is 4.4 ms and for M-2 is 2.4 ms respectively. These results nearly agree with the results published by Campos *et. al.* [6]. They have estimated the mean time interval between two consecutive M-components as 11 milliseconds, mean M-elapsed time as 42ms and mean M-duration as 4.8 ms.

When return stroke occurs, a powerful sharp current travels upward along the channel. At this time, electric field change occurs suddenly in all directions in air at the speed of light. Due to this field change electric current waves can induce along any conductive bodies including conductive leader channel [7].

3.2 Analysis of Luminosity/Current Variation of Channel Segments with Time

As described in 2.3, for this part of the work, average peak brightness of each selected channel segment was calculated separately for individual frames. The average peak brightness versus time for five segments is shown in Figure 4.

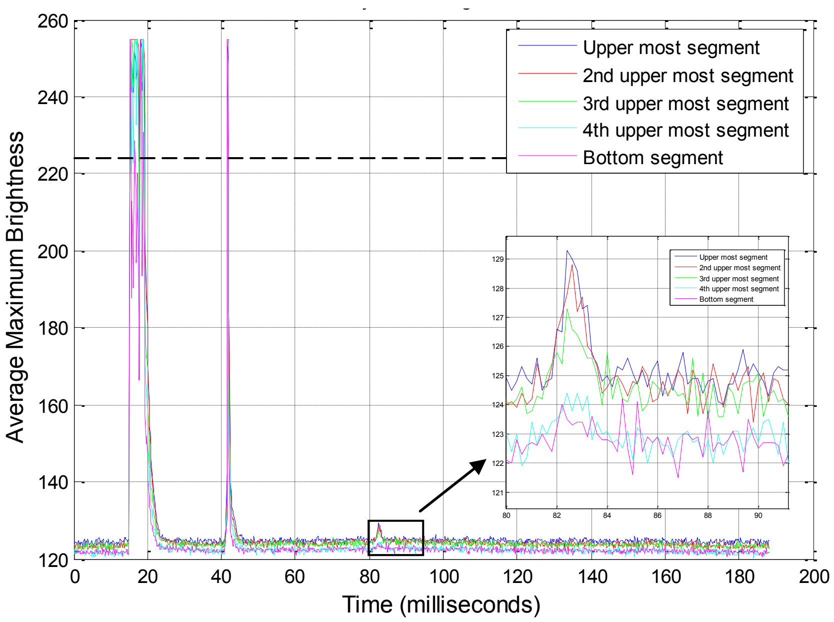

Figure 4: Luminosity variation of selected channel segments with time

The average maximum brightness at different heights is very similar in its overall wave shape. It was thought, if same current passing through the channel, luminosity/current variations for segments will be identical with small time shift. The data show a shift in the luminosity levels indicating a change in current. Expanded view shows the brightness/current of upper most segment is at the highest level. The 2nd upper most segment is at the next level followed by the 3rd at the next level and so on.

The shape of return stroke peak is asymmetric and the rising time is shorter than the decay time. At rising, all the segments appear to be having the same rise time. But at decaying, there is a significant time difference between segments. Decay constant is longer for segments at higher positions. These variations can occur due to the direction and speed of current flow in return strokes.

Correlation between the magnitude of the current flowing through different segments was investigated by plotting brightness values of each segment against the upper most segment (see Figure 5). The data show a linear relationship for most of the lower brightness values. The strength of linearity gets reduced with the distance from the upper most segment. This implies that there is high similarity in current along two points of the same lightning channel when the distance between the two points is shorter. i.e., there is a loss of current along the lightning channel. It is possible to estimate the loss of current between the upper most segment and bottom segment using average peak brightness of the two segments. The brightness level (arbitrary units) in

each segment is; Upper most segment = 128.4; Bottom segment = 124.8. Thus there is a 3% drop in brightness between upper most and bottom segments.
It can be seen that the strong linear correlation between brightness/current in the upper most segment and other segments vanished after 226. According to Figure 4, at this brightness level all segments contribute to the return stroke stage with high current flow. According to Figure 5, linearity between upper most segment and bottom segment is vanished after the bottom segment brightness value of 166. This value for 4th upper segment is 187, 3rd upper most segment 199 and 2nd upper most segment 226. When comparing these levels, we can see each segments after this level are in return stroke process. During this time all the segments exponentially increase their brightness to saturation limit of 255.

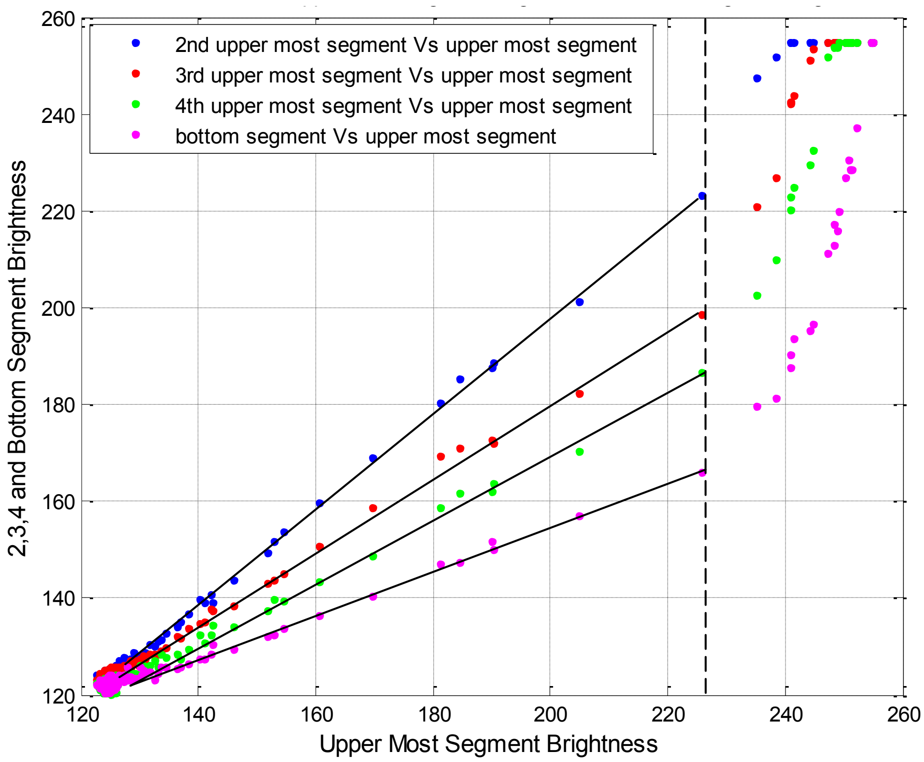

Figure 5: Correlation of brightness between upper most segment and other segments.

Various research studies suggest that the lightning current at sea level is higher than that at higher altitudes [8]. Therefore, the instantaneous brightness of the lightning channel at the bottom might be higher than that of the higher altitudes at the return stroke stage. However, in this study the channel brightness is calculated not for single events. Since each frame duration is 20 μs, we get the total brightness during the total time interval considered. During this time interval, charges at the cloud are continuously flowing toward the ground. Some of these charges are lost in the air due to corona effects. Meanwhile other activities such as M components are contributing to the channel brightness. As a result, higher pixels, which are corresponding to the higher altitude of the flash, show higher brightness. During the return stroke stage we can see this trend is changed drastically causing a chaotic behavior (see Figure 5).

4. CONCLUSIONS

This research work was carried out to investigate the brightness variation of negative cloud to ground lightning channels. The preliminary results for the variation of channel brightness in full channel as well as the variation along the channel by selecting segments are presented.

For the cloud to ground lightning discharge shown, two M-components were observed. Time interval between the two consecutive M-components was 40.9 ms. M-elapsed time from the stroke is 26.3 ms for the first M-component and 67.2 ms for the second M-component. The M duration for the first M-component is 4.4 ms and for the second M-component 2.4 ms.

It was observed that the shape of the return stroke peak is asymmetric and the rising time is shorter compared to the decay time. There is a linear relationship between the brightness values of each segment and the upper most segment. The linearity becomes weak when the distances between the segments are increased. This was linked to the current loss, when electrical charges flowing through the channel path. This can happen due to the discharges between channel current and ionized air particles in corona sheath. Loss of the current during propagation from upper most segment to bottom segment was calculated as 3%.

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