High Speed Optical Observations of Cloud Flashes

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***Abstract*—Luminosity variations of natural cloud lightning channels were studied using high speed video recordings in Sri Lanka in the tropic. Five cloud flashes were selected for the study, which were recorded with 5000 fps with 512X512 pixel resolution. Luminosity variation along channels and along selected channel segment, duration of cloud activities was studied. It was found that the average duration of selected flashes is 266.44 ms. No particular pattern was observed for the luminosity variation along channel segments. However the luminosity variation across the channel followed a Gaussian distribution pattern. Pattern of the luminosity variation along channels were compared with existing models to understand the development process of cloud flashes. Results show that it is hard to collaborate the observation to a single process for cloud discharges.**

Keywords-cloud flashes; luminosity variation; channel duration; lightning

I. INTRODUCTION

Lightning is one of the natural phenomena which is not fully understood yet. Lightning is an electrical discharge that can occur within clouds, between clouds or between cloud and ground. Although majority (~3/4) of lightning discharges are cloud discharges, cloud discharges are less studied compared to cloud to ground discharges. From the point of view of the lightning hazards, cloud discharges are generally considered to be of relatively little or no consequence and inherently exhibit more variability than ground discharges [1].

According to [1] a cloud discharge begins as a bidirectional leader, the positive section of this leader pervading the negative charge region and effectively supplying negative charge through the discharge origin to the negative section that extends in to the positive charge region.

However, according to the [2] cloud flash commences with a movement of negative discharges from the negative charge centre towards the positive one in a more or less vertical direction [2]. This stage is followed by an active stage in which horizontal extension of the upper level channels takes place while charge is being transported from the lower level to the upper level along the vertical channel. In the latter part of this active stage, significant extensions of the lower level channels take place but the extensions take place retrogressively. In the final stage the conductivity of the vertical channel decreases and the upper level channels will be cut off from the low level channels.

Obtaining direct measurement of lightning current is quite difficult and complex. High speed photography can play a major role in remote sensing of lightning current. A number of previous studies have shown that there is a good correlation between the luminosity and measured current of electrical discharges [3-4]. In this study, high speed time resolved photographic technique was used to examine the charge transfer process of cloud discharges. Luminosity variation with time was obtained and the observed variations are used to explain the charge transfer process of cloud discharges.

II. METHODOLOGY

The lightning flashes were recorded by using a high speed video camera OPTRONICS CamRecord 5000. The frame rate of the camera was 5000 fps with a resolution of 512x512 pixels. First the frames were stored as black and white sequence (SEQ) files. Then by using the software which comes with the camera, video sequence was converted to an image sequence. The saturation limit of brightness value of a pixel is 255.

A flash region absent of other background objects was chosen for each frame in an image sequence. Then by using an algorithm, average peak current of the channel was calculated for each frame separately (see Figures 1 and 4).

In order to study the intensity variation along the channel, five separate segments of the channel were selected and using the same algorithm, average peak intensity of the channel segments was calculated for each frame separately.

More details about the methodology are given in [5].

III. RESULTS AND DISCUSSION

A. *Example I (C39_ (5))*

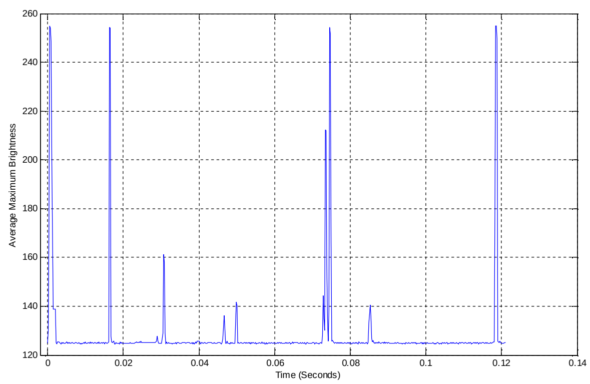
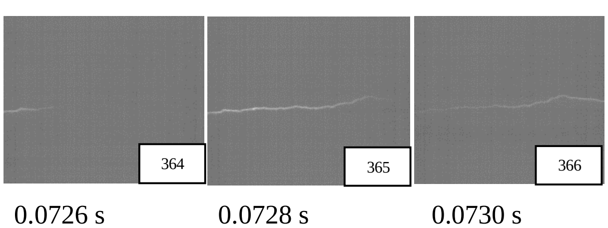


Figure 1: Luminosity variation of a channel with time.

Figure 1 shows the luminosity variation of a selected channel with time. No continuing current is observed. After each discharge the conductivity of the channel decreases. But along the hot ionized path, charges are transfer between two charge centers randomly as shown in the figure 2. The peaks are corresponds to charge transfers.

Luminosity variation of the cloud flashes do not show a regular pattern like ground flashes. In ground flashes, return stroke peak followed by subsequent peaks and M-component peaks are well identified. Luminosity variation of cloud channels show irregular peak pattern suggesting irregular charge transfers. Following are the frames correspond to 0.0726 seconds to 0.0754 seconds of Figure 1.



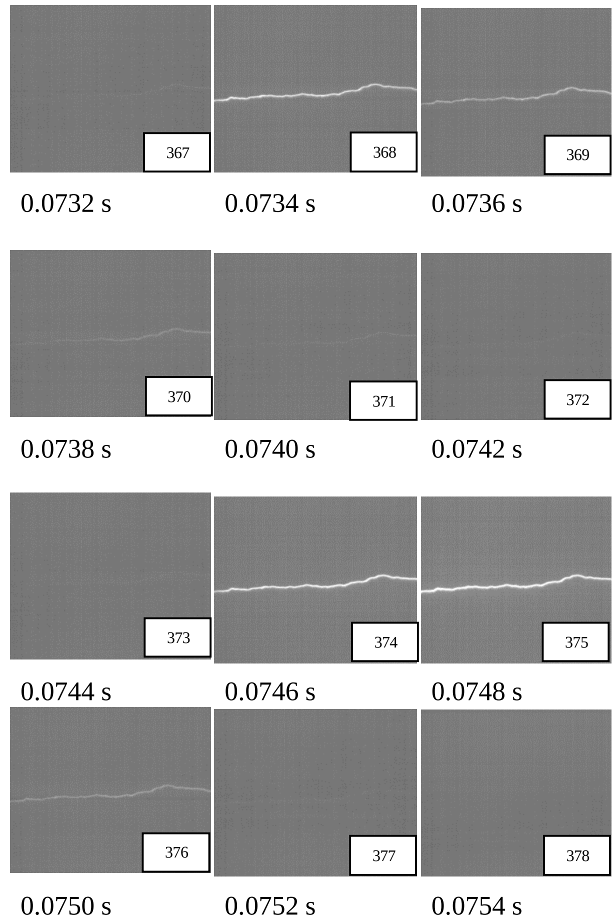


Figure 2: Cropped video frames correspond to 0.0726 s to 0.0754 s of Figure 1.Integers inside boxes indicate the frame number and time duration relative to the first frame.

When considering the overall luminosity variation, the first two frames (364-365) show leader propagation. Frames (366-367) show only the front part of the leader propagation while stern part of the leader disappears. In frame 368 stern part of the channel illuminate and in between frame 369-371 front part of the channel illuminate. In frame 372, channel is very faint. Then again front part of the channel starts to illuminate in frame 373 suggesting charge transferring process. In frame 374 whole channel illuminate and in frame 375 stern part of the channel illuminate. In last three frames (376-378) luminosity of the channel reduces. Unfortunately, the complete channel is not visible due to the frame size of the video.

These variations can be due to the bidirectional leader development process. In first two frames (364-365) leader starts to propagate. But in the next two frames (366-367) only the positive part of the leader propagate while negative part of the leader stop propagating. Since the whole channel (both negative and positive leader) is hot and ionized, in frame 368 charges are injected to the stern part of the channel (negative leader). Therefore the stern part of the channel illuminates and charge flows to the other end of the channel (368-371). In frame 372 no considerable charge transfers occur. As describe in [1], in the frame 373 charges are inject to the front part of the channel and they starts to flow toward the opposite direction (373-375). Positive section of the leader (front part of the channel) pervades to the negative charge region (right side or the frame) and effectively supplies negative charge to the positive charge region (left side of the frame). In last three frames (376-378) no charge transfers occur and channel cease to exist. But when considering Figure 1 it shows peaks before as well as after above discussed event (0.0726 s to 0.0754 s). This means charge transfers occur irregularly. It does not show long continuing current like ground flashes. After establishing a channel, charges flow on both directions between two charge centers with the help of bidirectional/bipolar leaders.

Duration of the channel is 121 milliseconds. Channel width is 7 pixels and the standard deviation for intensity variation across the channel is 4.6 pixels. Figure 3 shows the Brightness variation across the channel which is Gaussian distribution.

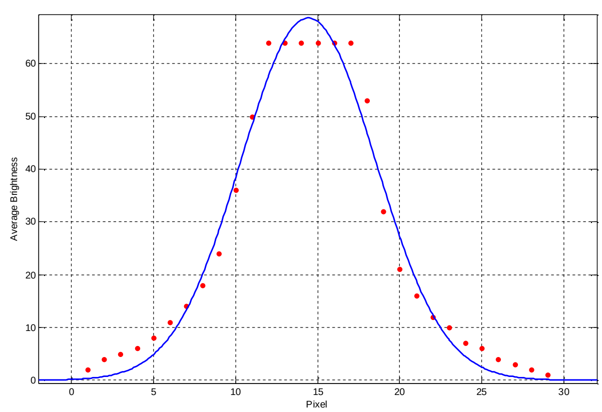


Figure 3: Brightness variation across the channel.

Polarity of leaders was found by considering the properties shown by the leaders. Normally positive leaders show continuous progression while negative leaders show discrete steps in progression with very bright tip [6], [2].

B. Example II (C5_ 4_5_2013)

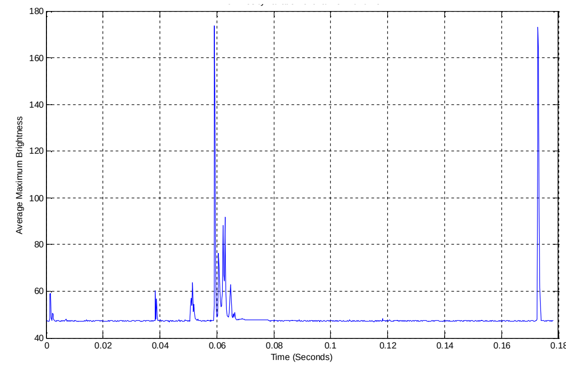


Figure 4: Luminosity variation of channel with time.

Figure 4 shows the luminosity variation of another selected channel with time. No continuing current is observed. After each discharge the conductivity of the channel decreases. But along the hot ionized path, charges are transfer between two charge centers randomly as shown in the figure 5.

Similar to example I, luminosity variation of this cloud flash also do not show a regular pattern like ground flash. Following are the frames correspond to 0.0588 seconds to 0.0598 seconds of Figure 4.

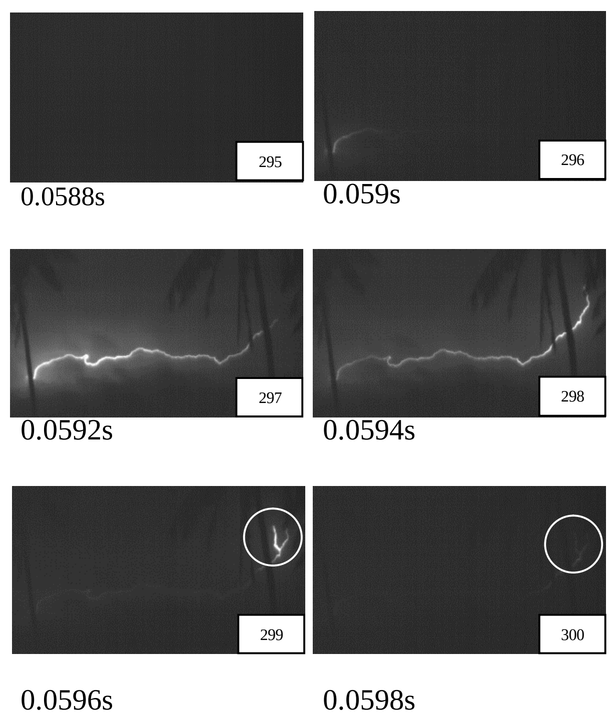


Figure 5: Cropped video frames correspond to 0.0588 s to 0.0598 s of figure 1.

Integers inside boxes indicate the frame number and time duration relative to the first frame also given.

As describe in [2] frame 296-298 shows initiation of a discharge with a movement of charges from one charge center to the other charge center. Frame 299 and 300 shows horizontal extensions (white circle) in the upper level of the channel while charge is being transported from the lower level to the upper level along the channel.

Luminosity variations of remaining cloud flashes (not shown) also show an irregular pattern except for one flash. That particular cloud flash has started with a negative stepped leader. Therefore process is similar to the ground flash process. It was the only cloud flash which shows stepping process and continuing current. Some channel statistics are summarized in the Table 1.

TABLE I: SOME STATISTICS OF CLOUD FLASHES

Channel Name	**Duration of the flash (ms)**	**Channel width in pixels**	**Standard deviation for intensity variation across the channel**	**Distribution of Brightness variation across the channel**
C39_ (5)	121	7	4.6034 ~ 5	Gaussian
C5_4_5_2013	178.2	2	1.5099 ~ 2	Gaussian
C23_ (5)	576	5	2.7946 ~ 3	Gaussian
C3_4_5_2013	217	11	4.2298~4	Gaussian
cloud 1_ (3)	240	5	3.5358~4	Gaussian

III. CONCLUSIONS

As mentioned in literature, cloud flashes exhibit more variability than ground flashes. Cloud flashes do not show a sequence process like ground flashes. Four out of five cloud flashes used positive or bidirectional leaders to transfer the charge. The other flash uses negative leader to start the event. For this case preliminary break down process, stepping process and continuing current process was observed.

The average duration of the cloud flashes was 266.44 ms. This value is acceptable when comparing with previous studies [7, 8, 9, 10, 11, 12, 13]. Cloud flashes that start with negative stepped leader show relatively high flash duration compared to others. Brightness variations across all cloud channels show a Gaussian distribution.

IV. ACKNOWLEDGMENT

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