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Environmental Analysis of Quasi-Static Electric Field Changes of Tropical Lightning Flashes

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Abstract

The environmental conditions leading to the bouncing-wave discharge and the subsequent electron beam remain to be investigated in more detailed future studies. The analysis of quasi-static initial electric field changes (IECs) were found at the beginning of all 24 lightning flashes detected within reversal distance (22 Negative Cloud-to-Ground (–CG) and 2 normal Intra-Cloud (IC) flashes) in a tropical storm on June 15th, 2017 close to our station in Malacca, Malaysia (2.314077° N, 102.318282° E). The IECs durations averaged 4.28 ms for –CG flashes (range 1.48 to 9.45 ms) and averaged 11.30 ms for normal ICs flashes (range 7.24 to 15.35 ms). In comparison to Florida storms, the duration of IECs for –CG and IC flashes were 0.18 ms (range 0.08 to 0.33 ms) and 1.53 ms (range 0.18 to 5.70 ms), respectively. Moreover, the magnitudes of E-change for tropical thunderstorm were 0.13 V/m (range 0.03 to 0.44 V/m) for –CG flashes and -0.20 V/m (range -0.13 to -0.27 V/m) for IC flashes. The E-change magnitudes of tropical flashes are significantly larger than Florida flashes.

Keywords: breakdown pulse, cloud to ground flash, intra-cloud flash, lightning initiation, quasi-static electric field, environmental factors

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INTRODUCTION

Lightning flash is an electrical discharge that consists several processes within 0.5 to 1 second typical record. Most of the lightning flashes except for narrow bipolar events (NBEs) seems to begin with a series bipolar pulses known by several names called as preliminary breakdown pulses (PBP), characteristic pulses or initial breakdown (IB) pulse (Appleton and Chapman 1937, Beasley et al. 1982, Bils et al. 1988, Clarence and Malan 1957, Esa et al. 2014a, 2014b, Weidman and Krider 1979).

The characteristics of a classical IB pulse (**Fig. 1**) must follow certain criteria where it must be a bipolar shape, pulse duration from 10 μs to 200 μs and have two or three narrow, fast-rising sub pulses superimposed on

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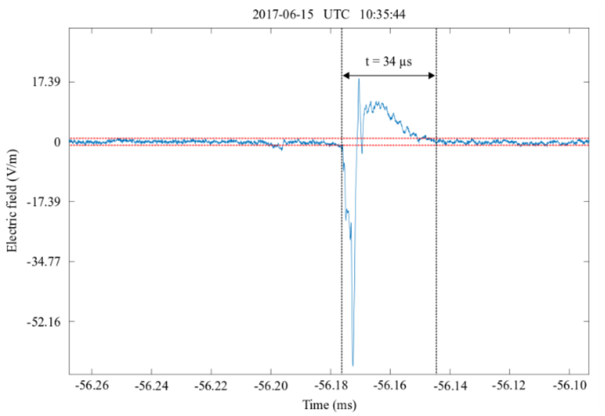

Fig. 1. A classical Initial Breakdown (IB) pulse for a –CG flash captured with wideband fast antenna system on June 15th, 2017 at 10:35:44 UTC (Physics sign convention)

the main bipolar pulse (Marshall et al. 2014, Baharvand 2018).

Based on previous studies by Gomes et al. (1998) and Baharudin et al. (2012), all –CG flashes in Sweden and Florida were found to be preceded by IB process, while for the tropical storms in Sri Lanka and Malaysia, they found that not all –CG was preceded by IB process. In Marshal et al. (2014), the authors found that all CG and IC flashes in Florida storm seems to begin with IB pulses, thereby IB pulses are a necessary part of lightning flashes. From this observation, it seems only tropical flashes are lack of IB process.

A latest study in 2018 regarding the IB process conducted by Ahmad et al. (2018) for a tropical storm that happened in Kuala Lumpur on June 3rd, 2016 consists of 50 CG flashes. The data recorded by broadband E-field antenna system shows that 94% of CG flashes (47 CG flash) were preceded by IB process. On the other hand, by using B-field antenna system with better sensitivity (Zhang et al. 2016, Zavidić and Lovrinić 2018), all CG flashes have been observed to be preceded by IB process. This finding is very significant because we can conclude that all CG flashes are initiated by the IB process when the sensor with better sensitivity are used.

From recent studies conducted by Marshall et al. (2014) and Chapman et al. (2017), they found that, there is another process occurs before the first IB pulse that can be part of lightning initiation called as initial electric field change (IEC). The IEC is a small amplitude, short duration, slow developing electric field (E-field) change that occurs before the first IB pulses in a lightning flash (Marshall et al. 2014). The duration IEC process can be determined when there are slow E-

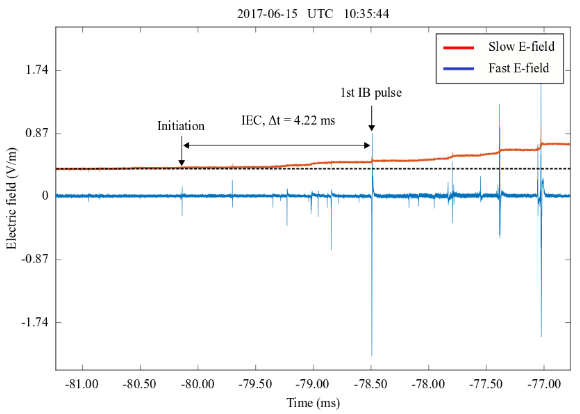

Fig. 2. An Initial Electric Field Change (IEC) (Physic sign convention) and the first Initial Breakdown (IB) pulse for a Negative Cloud-to-Ground (–CG) flash (within reversal distance) captured by wideband fast and slow antenna systems in Malacca at 10:35:44 UTC on June 15th, 2017

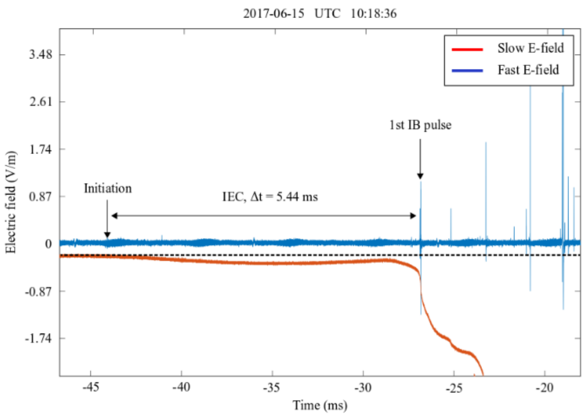

Fig. 3. An IEC (Physic sign convention) preceded the first IB pulse for an Intra Cloud (IC) flash (within reversal distance) captured by wideband fast and slow antenna systems in Malacca at 10:18:36 UTC on June 15th, 2017

field changes starting at zero moving upwards for –CG flash (**Fig. 2**) or downwards for IC flash (**Fig. 3**) and ended at the first IB pulse.

In this paper, we extend the study of Marshall et al. (2014) and Chapman et al. (2017) by searching for IECs in a small tropical thunderstorm with a total of 24 flashes (22 –CG and 2 normal IC flashes) within reversal distance on June 15th, 2017 close to our lightning sensors at Malacca, Malaysia. The analysis aims to validate the findings in Marshall et al. (2014) and Chapman et al. (2017) regarding the IECs as part of the initiation of lightning flashes.

METHODOLOGY

The observations presented here were made from a single measurement station hosting a wideband fast and

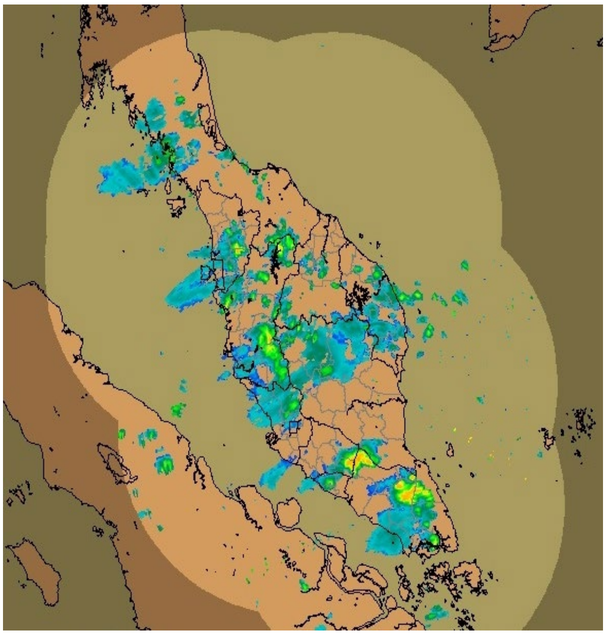

Fig. 4. CAPPI radar data at 2 km altitude for Peninsular Malaysia

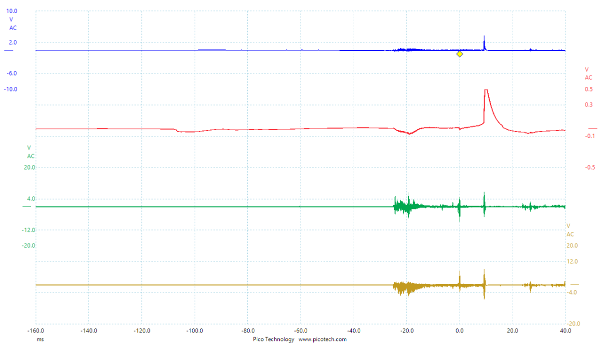

Fig. 5. Incoming signals from the filter were digitized at 20 MS/s by using four channels for fast E-field (blue plot), slow E-field (red plot), north-south magnetic field (green plot) and east-west magnetic field (gold plot)

slow electric field antenna system (decay time constant 13 ms and 1 s) (Ahmad et al. 2014, 2015, 2017, Baharin et al. 2018, Ong et al. 2018, Sabri et al. 2018) and magnetic field sensor (400 Hz to 400 kHz) (Zhang et al. 2016). The sensor is located at the Universiti Teknikal Malaysia Melaka (UTEM), Malacca, Malaysia (2.314077° N, 102.318282° E). Radar reflectivity data (CAPPI format at 2 km altitude) (see **Fig. 4**) used here has been obtained from the Malaysia Meteorological Department (MMD).

The output of the antennas is digitized at rates of 20 MS/s for 4 channels as shown in **Fig. 5** (fast and slow E-field records, and magnetic field or B-field). Data records were event-triggered and were 200 ms long. The timing for each event was provided by a Global Positioning System (GPS). Additional details of the E-field instrumentation are given in Ahmad et al. (2014). The observations presented here were obtained from a single storm that formed in Malacca, Malaysia near to our system on June 15th, 2017. **Fig. 5** shows the 4 channel outputs with different sensor where the blue plot for fast E-field, red plot for slow E-field, green plot for north-south B-field and gold plot for east-west B-field.

RESULTS AND ANALYSIS

The analysis focuses on 24 lightning flashes (22 –CG and 2 normal ICs) detected within reversal distance for a small thunderstorm that happened on June 15th, 2017 near to our station located in Malacca, Malaysia. This analysis focuses on the IEC process in a tropical storm.

IEC was found in all 24 lightning flashes. The average durations of the IECs for 22 –CG flashes is 4.28 ms ranging from 1.48 to 9.45 ms. In comparison to Florida storms by Marshall et al. (2014), average durations of IECs is 0.18 ms ranging from 0.08 to 0.33 ms. For Florida storms by Chapman et al. (2017), average durations of IECs is 0.23 ms ranging from 0.08 to 0.54 ms. For the IC flashes, we found the average durations of the IECs is 11.30 ms ranging from 7.24 to 15.35 ms. For Florida storms by Marshall et al. (2014) and Chapman et al. (2017) the averages are 1.53 ms and 2.70 ms, respectively. Tables 1 and 2 show the difference between tropical storm analysis with Florida storms (Marshall et al. 2014 and Chapman et al. 2017).

During the IEC process, we also found that there are several small pulses that occurs within the period of IEC with minimum of 2 pulses and maximum of 14 pulses as shown in Figure 6. These small pulses were detected with either positive or negative polarity (within reversal distance). Based on our observation, 17 small pulses with positive polarity are found. The mean values of pulse duration, zero crossing time and peak amplitude for these small pulses are 4.41 μs, 2.19 μs and 791.59 mV, respectively. For the negative polarity small pulses with 18 pulses, the mean values of pulse duration, zero crossing time and peak amplitude are 5.99 μs, 2.54 μs and -676.02 mV, respectively.

On the other hand, we also found that 16 out of 22 –CG were detected with these small pulses before the onset of IEC as shown in **Fig. 6**. The mean values of duration from the small pulse to the onset of IEC and pulse duration are 194.56 μs and 6.96 μs, respectively. The mean values of the amplitude and zero crossing time for positive polarity small pulses are 155.94 mV

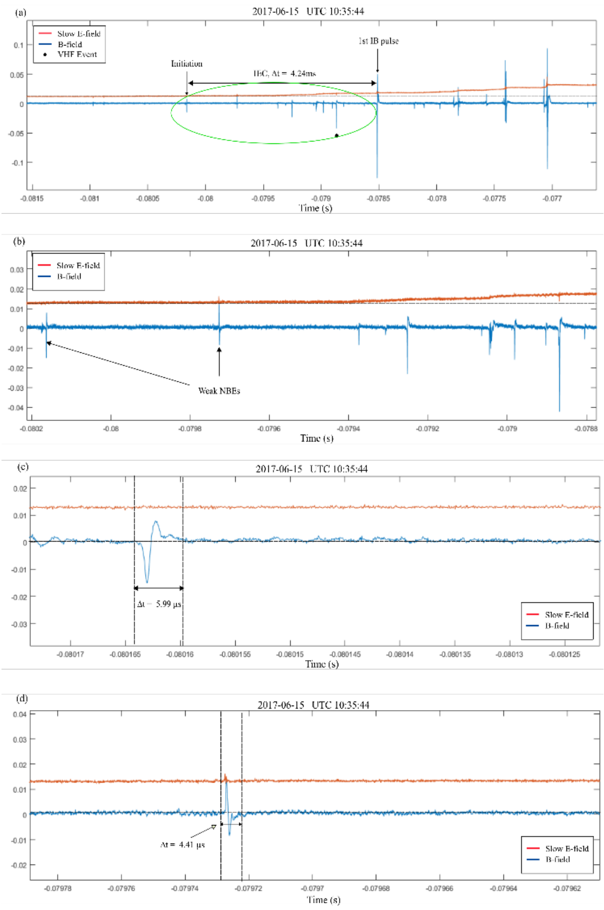

Fig. 6. An IEC for –CG flash. (a) Show the IEC for –CG flash from tropical storm on June 15th, 2017 at 10:35:44 UTC. The green circle is to mention about the small pulses. (b) This figure shows the pulses inside green circle from (a) and some of small pulses got positive and negative polarity. (c) Example of small pulses with average pulse duration of 5.99 μs for negative polarity. (d) Example of small pulses with average pulse duration of 4.41 μs for positive polarity

and 1.04 μs, respectively, while for the negative polarity small pulses, the mean values of the amplitude and zero crossing time are -338.03 mV and 4.09 μs, respectively.

Furthermore, we also observed the magnitudes of the E-change observed in tropical storm and Florida storms. The mean of E-change for –CG and normal IC are 0.13 V/m ranging from 0.03 to 0.44 V/m and -0.20 V/m ranging from -0.13 to -0.27 V/m, respectively. Marshall et al. (2014) reported that the mean of E-change for –CG and normal IC are 1.65 V/m range from 0.10 to 6.60 V/m and -6.30 V/m range from -0.70 to -23.40 V/m, respectively. On the other hand, Chapman et al. (2017) also reported for both –CG and normal IC ranging from 0.20 to 15.20 V/m. **Tables 3** and **4** show the difference in magnitudes of E-field change between

Table 1. Differences in IECs duration for -CG flash between tropical storm and Florida storms

Researcher	IEC duration (mean, ms)	Min (ms)	Max (ms)	IEC duration difference %
Marshall et al (2014)	4.10	1.40	9.12	95.79
Chapman et al (2017)	4.05	1.40	8.91	94.63

Table 2. Differences in IECs duration for IC flash between tropical storm and Florida storms

Researcher	IEC duration (mean, ms)	Min (ms)	Max (ms)	IEC duration difference %
Marshall et al (2014)	9.77	7.06	9.65	86.46
Chapman et al (2017)	8.60	7.20	5.55	76.11

Table 3. Differences in average for magnitude of E-change for -CG flash between tropical storm and Florida storms

Researcher	E-change, ΔEz (V/m)	Min (V/m)	Max (V/m)
Marshall et al (2014)	1.52	0.07	6.16
Chapman et al (2017)	-	0.17	14.76

Table 4. Differences in average for magnitude of E-change for -CG flash between tropical storm and Florida storms

Researcher	E-change, ΔEz (V/m)	Min (V/m)	Max (V/m)
Marshall et al (2014)	-6.10	-0.57	-23.11
Chapman et al (2017)	-	-	-

tropical storm and Florida storms (Chapman et al. 2017, Marshall et al. 2014).

DISCUSSION

Herein, we have shown that the beginning all of 24 flashes for –CG and IC flashes had an IEC process. Therefore, we can say that IEC is essential part of lightning initiation process. Based on Marshall et al. (2014), they hypothesized that:

- IEC helps the cause of the first IB pulse of a flash
- They found that the beginning of the IEC was coincident with VHF event
- Lightning initiation was an impulsive event that causes the VHF event
- This impulsive event produces ions
- Increased the local electric field (the IEC) and causing the first IB pulse

The first hypothesis is proven true by our finding from a tropical storm that the beginning of the first IB pulse must be initiated by IEC process. This is a significant contribution because our work is the first independent work done to validate the hypothesis.

Tables 1 and **2** show the differences in IECs duration for –CG and normal IC flashes between tropical storm and Florida storms (Marshall et al. 2014 and Chapman et al. 2017). Obviously, the duration of IECs for both –CG and IC flashes for the tropical storm is longer and the magnitude of the E-change is lower compared to Florida storms (refer **Tables 1**, **2**, **3** and **4**). Based on this analysis, for flashes in tropical storm the IEC process has taken longer time to increase the local electric field to produce the first IB pulse because of smaller magnitude of E-change. On the other hand, in Florida storms, the IEC process has taken a shorter time to increase the local electric field to produce the first IB pulse because of the larger magnitude of E-change. At the same time, there are several pulses were detected before the onset of IEC. Most of the IEC process were preceded by this small pulse and the duration of the first pulse of small pulse to the onset of an IEC range between 1.54 and 906.54 μs. We believe that, these small pulses are the results of impulsive event associated with VHF emission that produce ions to increase the local electric field until it caused the first IB pulse to happen.

CONCLUSION

In this paper, we have investigated the initiation of lightning flashes and environmental factors in a tropical storm for the existence of IECs as discussed by Marshall et al. (2014) and Chapman et al. (2017). Based on the hypothesis proposed by Marshall et al. (2014), we proved that it is true, where IECs helps to cause the first IB pulse. Besides that, the beginning of 24 lightning flashes within reversal distance that we examined, all the first IB pulse for –CG and IC flashes were preceded by IEC. Lastly, we also find that, the IEC was preceded by small pulses before and during the IEC process. We believe that, these small pulses are the results of impulsive event (perhaps related to Fast Positive and Fast Negative Breakdowns (Rison et al. 2016) that produce ions to increase the local electric field until it causes the first IB pulse to happen.

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