Observed Electric Field Changes of Positive Lightning Flashes Preceded by Preliminary Breakdown in Padang

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Abstract: Positive lightning can do more damage than negative lightning. We have observed 77 positive cloud to ground (CG) flashes preceded by preliminary breakdown (PB) in Padang, Indonesia. It was found that there were two types of polarity between the PB pulse train and the following first return stroke (RS) pulses, namely the same polarity (type S) and composite polarity (type C). The occurence percentages of type S and type C were 92.2% and 7.8%, respectively. The aritmathic mean (AM) and geometric mean (GM) PB/RS separations and durations were 97.31 ms, 76.33 ms and 98.15 ms, 77.49 ms, respectively. The AM and GM PB/RS ratios were 12.26% and 10.20%, respectively. In addition, the characteristics of the PB pulse such as individual pulse duration, pulse train duration, and interpulse duration are discussed in this paper.

Keywords: positive lightning, preliminary breakdown, tropics, cloud to ground

1. Introduction

Positive cloud to ground lightning occur only about 10% of all ground flashes [1]. They may lead to more damage to grounded objects than negative lightning. They are often related to severe weather that produces phenomena such as heavy rain, strong winds and large hail storms [2]. Furthermore, they also have properties that are different from those of negative lightning flashes, such as preliminary (initial) breakdown, leader propagation and high peak current [2-5]. The electric field produced by the PB process in positive ground flashes is not the same as that of negative ground flashes. It has been found that in positive ground flashes, the initial pulse polarity of the electric field that is preceded by the PB process is sometimes different from that of the following RS [6-10]. The initiating mechanism of the positive lightning discharge remains a mystery because the charge structure of thunderclouds that create positive lightning is more complex than in the case of negative lightning [1,2,11,12]. In addition, only few studies have been reported about lightning flashes in tropical regions compared to temperate regions [13-14]. To the best of our knowledge, this is the first time that electric field waveform variations produced by positive lightning in thunderstorms have been measured in Padang, Indonesia. In this study, positive ground flash characteristics preceded by PB in the equator region in the tropics were examined. Comparison of our observation results with a few of available studies in other regions is provided.

2. Instrumentation and Data

77 positive CG flashes were analyzed in this study, which recorded on 31 thunderstorm days during May-October, 2014. Our measurement station was located at the Andalas University (-0.98 N and 100.3 E) at an altitude of about 311 m above sea level and 13 km away from Padang Beach, Indian Ocean. Furthermore, the measurement system was able to record the broadband electric field changes (E) of lightning flashes using a fast antenna that was connected to buffer electronics and a 12-bit oscilloscope. The record length was 1 s including a pretrigger time of 400 ms. The decay time constant of integrator was 100 ms with a capacitor (C) of 1 nF. A more detailed description of the measurement system can be found in [15].

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3. Result and Discussion

In this study, we used the same methodology as applied in [9,10,14,16,17] to analyze the PB pulse parameters, such as PB/RS separation, PB/RS duration, PB/RS ratio, individual pulse duration, pulse train duration, interpulse duration, and pulse number, as shown in Figure 1. The physic sign convention is used to examine the electric field waveforms. PB-RS separation and duration are defined here as the time interval between the highest peak and the very initial peak of the PB pulse train and the highest peak of the RS pulse [14]. The PB/RS ratio is the ratio between the highest peak amplitude of the PB pulse train and the RS pulse. Furthermore, the individual pulse duration (T_{pw}) is determined by the pulse duration of the individual bipolar pulses. Pulse train duration (T_{pd}) is defined here as the time interval from the peak of the initial pulse to the last pulse in the train. Interpulse duration (T_{ps}) is defined as the time separation between the two peaks of consecutive pulses.

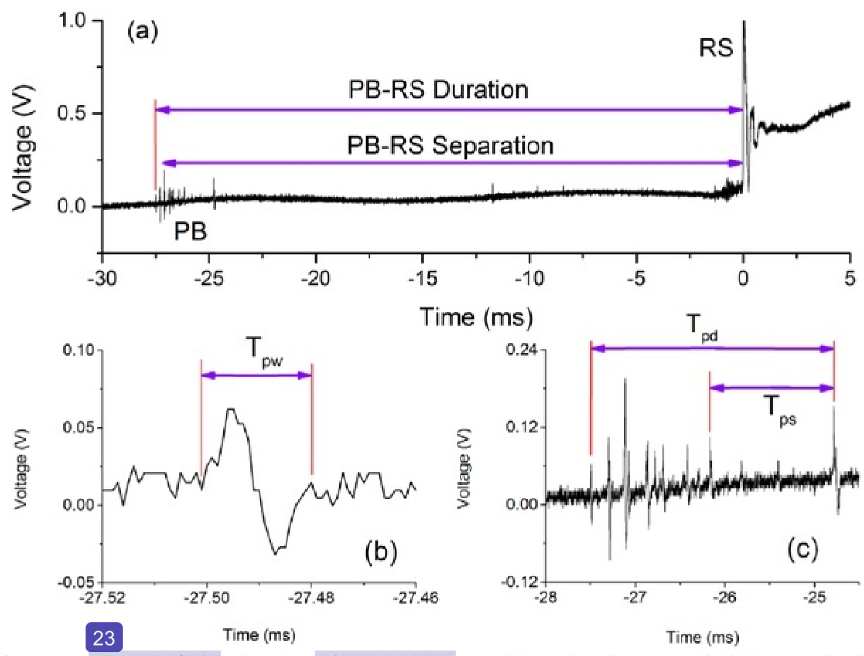

Figure 1. Electric field changes of PB and RS (a). PB pulses in expanded time scale (b-c)

A. Electric field waveforms of PB pulse train

A summary of positive CG lightning and PBP train types is displayed in Table 1. Over the whole period, a total of 11,392 lightning events was recorded by the measurement system. From Table 1 it can be seen that the number of positive CGs was 0.68% (77) of all lightning events during the 31 thunderstorm days. Several researchers have reported that the electric field changes of positive CG flashes are preceded by a PB process in the cloud that lasts about 12-200 ms on average [7,9,17,1[illegible]]. It was found that all positive CG flashes were preceded by a PB pulse that was the same as in negative CG flashes, as reported previously by Hazmi et al. [19]. The very initial polarity of the PB pulse train is usually unipolar and sometimes opposite to that of the following RS pulse [7,9]. A typical PB pulse train is shown in Figure 2. In the present study, two types of PB pulse trains were indentified: type S and type C. For convenience, type S is defined as PB trains with single and double regions, where the initial half cycle polarity of the PB pulse trains of each region has the same polarity as the following RS, as shown in Figures 2 and 3. Meanwhile, type C is defined as PB trains having double regions, where the first region of PB pulse trains is usually the same as the next one and the initial half cycle polarity of the PB pulse trains for the second region is mixed or opposite to the following RS, as shown in Figure 4. The

PB pulse trains may be accompanied by a few pulse clouds because the PB process occurs inside the cloud.

Table 1. Summary of positive CG lightning and PBP train type

Month	Thunderstorm			Polarity of PBP train type			
				Single Train (1 region)		Multiple Train (2 regions)	
	Days	Total Lightning Events	No of Positive CG Lightning	Same (S)	Composite (C)	Same (S)	Composite (C)
May	8	4911	17 (0.35%)	11	-	3	3
August	5	2191	8 (0.37%)	8	-	-	-
September	6	3555	25 (0.70%)	22	-	2	1
October	12	735	27 (3.67%)	25	-	-	2
Total	31	11392	77 (0.68%)	66	-	5	6

The occurrence of single and double PB pulse trains of type S numbered 66 cases (85.7%) and 5 cases (6.5%), respectively, while the occurence of type C numbered 6 cases (7.8%). It was found that the PB pulse trains that were the same as the following RS (type S) amounted to 92.2% of all PB pulse trains. This indicates that the position of the negative charge under a main positive charge center of a thundercloud producing type S is dominant in positive CG flashes in Padang. According to Nag et al. [2], an inverted dipole with a lower negative charge (LNC) may lead to an electric field change of positive lightning with such a charge configuration. Our dominant type percentage of PB pulse trains is similar to that of Gomez and Cooray [9], found at a higher latitude. Next, the charge structure of thunderclouds that created type C was more complex than in the case of type S. Type C occurs due to there being two possible discharge processes in the thundercloud [20]. In the first region, PB pulses are initiated by a negative charge under the main positive charge center that is similar to type S, as shown in Figure 4b. In the second region, shown in Figure 4c, PB pulses of the opposite polarity of the following RS may be produced, either by the main negative charge center and a lower positive charge (LPC) associated with producing the negative CG lightning, or by the charge configurations from the negative and positive charge upper layers and lower charge regions. Furthermore, this occurs at almost the same time as the main positive charge center initiates a leader to ground [21]. In contrast, different results were reported by Gomez and Cooray [9] at a higher latitude, where they found that the PB pulse train polarities were opposite to those of the following RS pulse in the first region and the same as the RS pulse polarity in the second region. It is still a mystery how to explain the occurrence of PBP trains in positive CGs. We speculate that in type C, there are different charge configurations in different regions of the PB pulse process [9,17,20] and the leader channel is not in vertical propagation [22,23] and has many branches in the cloud, so that there is more than one PB pulse train prior to the RS, as shown in Figure 4.

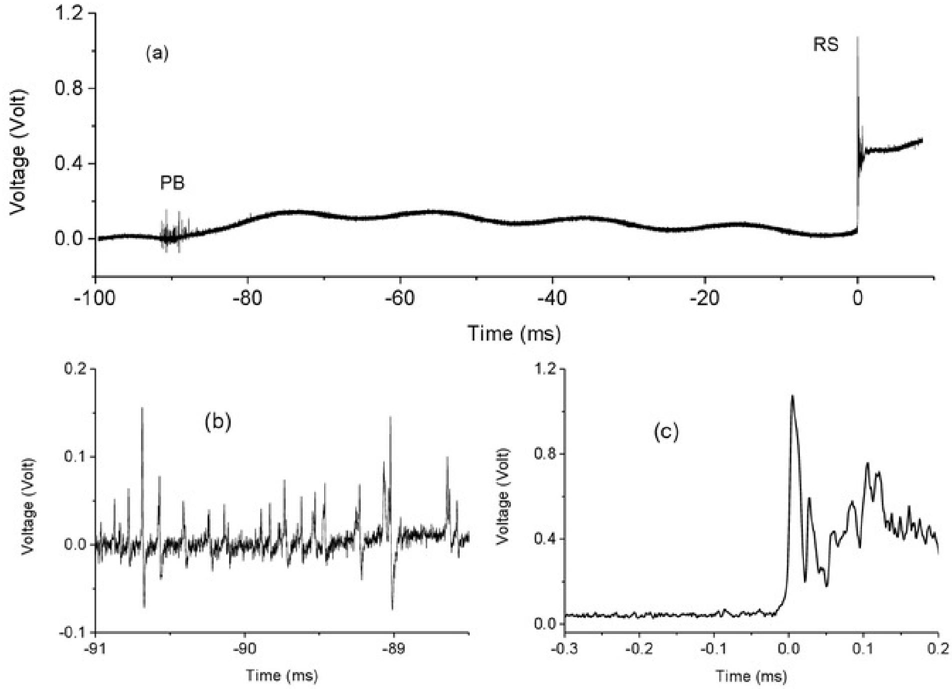

Figure 2. Typical electric field waveforms of positive lightning ground flash preceded by PB (a). Expanded time scale for type S (same polarity) of PB pulse train and RS (b-c).

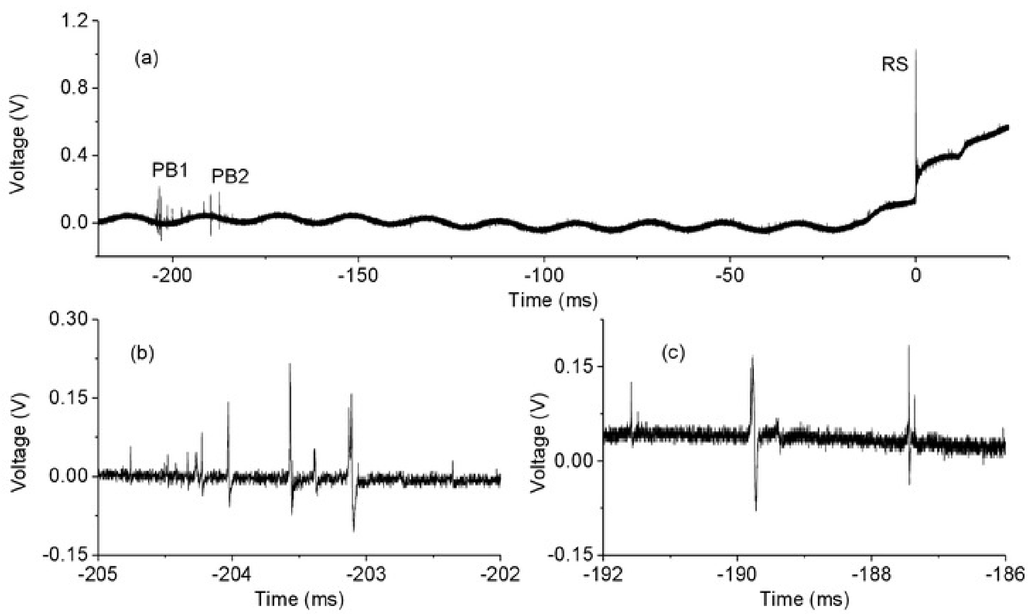

Figure 3. Typical electric field waveforms of positive lightning ground flash preceded by multiple PB trains of type S (a). Expanded time scale for PB pulse train 1 and 2 (b-c).

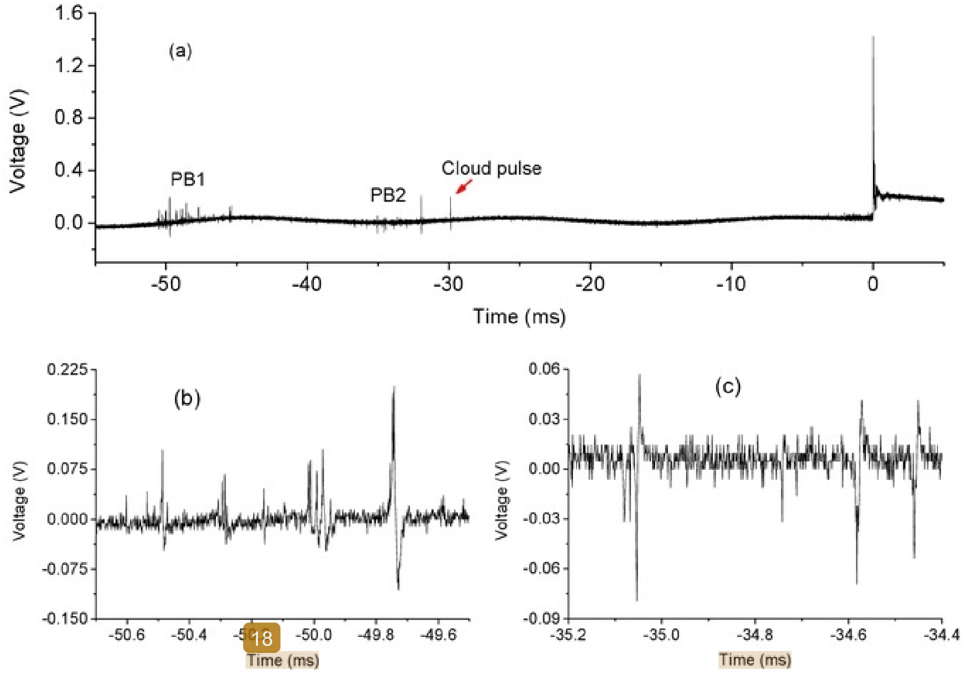

Figure 4. Typical electric field waveforms of positive lightning ground flash preceded by multiple PB trains of type C (composite polarity) (a). Expanded time scale for PB pulse train 1 and 2 (b-c).

B. *PB Pulse Characteristics*

The PB pulse characteristics presented in the following section belong to the first region only due to their dominant percentage. The PB pulse parameters were: analyzed PB-RS separation, PB/RS ratio, individual pulse duration, interpulse duration, pulse train duration, and pulse number. A comparison with other authors is shown in Table 2. Figure 5 shows scatterplots between RS amplitude and PB parameters such as RS amplitude versus individual pulse duration, RS amplitude versus pulse train duration, RS amplitude versus pulse number, RS amplitude versus PB-RS separation, and PB/RS ratio. Histograms of the PB pulse parameters are presented in Figure 6.

Table 2. Comparison of AM values of PB pulse parameters with other authors.

	This Study	Usio et al. [7]	Gomes and Cooray [9]	Schumann et al. [10]	Zhang et al. [17]		Qie et al. [11]
Location	Padang -0.98 N	Japan 35.6 N	Sweden 59.8 N	Brazil 23.2 S	Beijing 39.9 N	Guangzhou 23.3 N	Da Hinggan Ling 50.4 N
Pulse duration (μs)	39.40	18.80	38	25.2	21	31	21.11
Interpulse duration (μs)	356.09	54.20	96	280	141	256	148.72
Pulse train duration (ms)	3.79	1	3	3.1	3.09	5.06	2.97
PB-RS separation (ms)	101.05	12	56	157	94.19	99.52	108.13
Number of pulses/train	7.18	-	-	-	-	-	-
PB/RS ratio (%)	12.33	27	-	-	19.7	19.5	32

B.1 PB-RS separation and duration

The AM and GM PB-RS separations and durations were 101.05 ms, 78.15 ms and 101.92 ms, 79.33 ms, respectively. Our AM PB-RS separation was smaller than the mean values found by Schumann et al. [10], Zhang et al. [17] and Qie et al. [11]. We suspect that the difference may be caused by the charge configurations at the observation locations and the small number of samples.

B.2 PB/RS ratio

Our PB/RS values varied from 1.3 to 48.39% with AM and GM values of 12.32% and 10.27%, respectively. Referring to other authors, our AM value was smaller than those from other locations, as shown in Table 2. This is evidence that only a small amount of energy is required from a main positive charge to break the barrier that is created by the LNC to produce a positive CG in tropical regions. According to Cooray and Jayaratne [13], LPCs in the tropics are located about 7 km higher than those in temperate regions. LPCs may play a significant role in producing negative CG lightning flashes. On average the concentration of LPCs in clouds in the tropics is lower than in temperate regions. In positive CG cases, we speculate that the concentration of LNCs at low latitude is lower than at higher latitudes. Our observation results support this hypothesis. It was also found that there was no strong correlation between RS amplitude and PB parameters. An increase in RS amplitude did not significantly change the PB parameter values. This indicates that the PB pulse characteristics depend on other factors such as meteorological conditions and thunderstorm types.

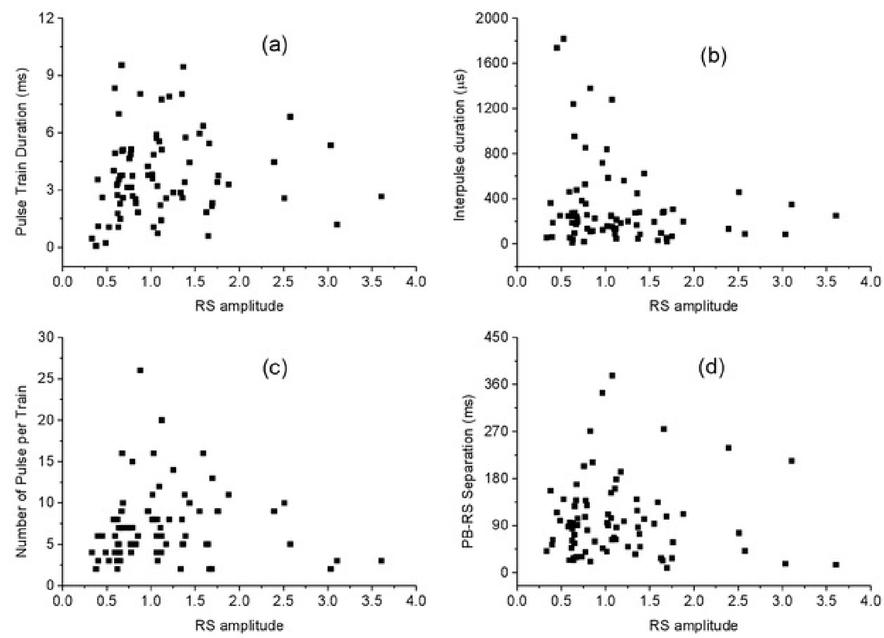

Figure 5. Scatter plot of RS amplitude versus the PB parameters. (a) RS amplitude and T_{pd}, (b) RS amplitude and T_{ps}, (c) RS amplitude and pulse number, and (d) RS amplitude and PB-RS separation.

B.3 Individual pulse duration (T_{pw})

Our observations showed that the AM and GM individual pulse durations were 39.41 µs and 34.25 µs, respectively, with variation between 7.58 µs and 129.5 µs. In Table 1, the corresponding AM values from previous studies conducted at higher latitudes in Japan, Sweden, Brazil, Beijing, Guangzhou and Da Hinggan Lin were 18.8, 38, 25.2, 21, 31, and 21.11 µs, respectively [7,9,10,11,17]. Our AM pulse duration was slightly longer than in the previous studies.

B.4 Interpulse duration (T_{ps})

The minimum, maximum, AM and GM interpulse durations were 10.03 μs, 1987 μs, 356.09 μs and 218.69 μs, respectively. The corresponding AM values from previous studies conducted in Japan, Sweden, Brazil, Beijing, Guangzhou and Da Hinggan Lin were 54.2 μs, 96 μs, 280 μs, 141 μs, 256 μs, and 148.72 μs, respectively [7,9,10,11,17]. Our AM pulse separation was longer than that in the studies conducted at higher latitudes. This difference may be due to the smaller LNCR in tropical regions compared to that in the subtropics regions.

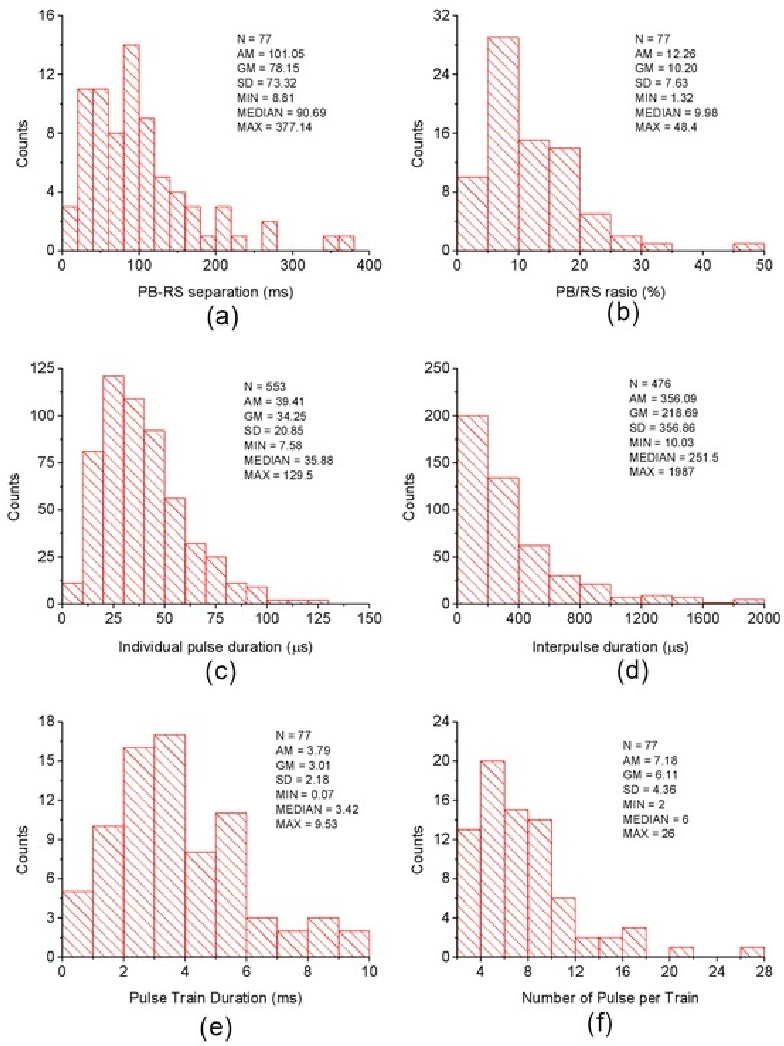

Figure 6. Histogram of the PB pulse parameters. (a) PB-RS separation, (b) PB/RS ratio (c) T_{pw} (d), T_{ps}, (e) T_{pd}, and (f) Number of pulses per train

B.5 Pulse train duration (T_{pd})

In this study, the pulse train duration varied from 0.07 ms to 9.53 ms. The AM and GM values were 3.79 ms and 3.01 ms, respectively. Our AM value was smaller than that reported by Zhang et al. [17] in Guangzhou and longer than that reported by Ushio et al. [7], Gomez and Cooray

[9], Schumann et al. [10] and Qie et al. [11]. There is no clear correlation between location latitude and pulse train duration. The difference may be due to differences in charge configuration, thunderstorm type, noise level, distance from the observer and so on. It was also found that the number of AM pulses per train was 7.18.

4. Conclusion

The characteristics of 77 electric field changes of positive CGs preceded by PB in Padang in the tropics were examined. It was found that the PB pulse train occurence percentages of type S and type C were 92.2% and 7.8%, respectively. The AM and GM PB-RS separations and durations were 101.05 ms, 78.15 ms and 101.92 ms, 79.33 ms, respectively. The AM and GM PB/RS ratios were 12.26% and 10.20%, respectively. The AM and GM individual pulse durations, pulse train durations, and interpulse durations were 39.41 μs, 3.79 ms, 356.09 μs and 34.25 μs, 3.01 ms, 218.69 μs, respectively. The PB pulse characteristics not only depend on the concentration of LNCs but also on charge configuration variations of the thunderclouds in producing the electric field changes of positive lightning. Further research is needed to enhance the understanding of the initial breakdown process in positive lightning.

5. Acknowledgments

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