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OCCURRENCE OF CHARACTERISTIC PULSES IN POSITIVE GROUND LIGHTNING IN BRAZIL

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1 - INTRODUCTION

A ground lightning is referred as a high transient electrical discharge involving a thundercloud and ground. Many discharges or processes compose it. One of them is the *Return Stroke* discharge (or stroke for short), which makes a naked eye visible connection between cloud and ground. It also has the most powerful energy content in the whole lightning. A ground lightning may have more than one *Return Stroke* and other processes may occur prior to the first stroke, between consecutive strokes and after the last stroke. The processes occurring before the first stroke are located inside and outside the cloud and they are basically the *Preliminary Breakdown* (B), the *Stepped Leader* (L) and Attachment Process (A). The first occurs inside the cloud while the others occur outside the cloud, between the cloud base and ground. These processes generate electric field changes prior to the *Return Stroke* discharge that Clarence and Malan (1957) named *Preliminary Variations* (PV). Clarence and Malan (1957) showed that a typical *PV* is a combination of *Breakdown*, *Intermediate* (I) and *Stepped Leader* field changes, composing what they called “BIL category”. Differently from Clarence and Malan (1957), Beasley et al. (1982) defined *Preliminary Variations* as the field variations prior to the *Stepped Leader*. In this paper we adopted the definition given by Clarence and Malan (1957).

Many observations of pulses in Preliminary variations in negative ground lightning (e.g., Appleton and Chapman, 1937; Clarence and Malan, 1957; Norinder and Knudsen, 1957; Kitagawa and Brook, 1960; Weidman and Krider, 1979; Le Vine, 1980; Beasley et al., 1982; Brook, 1992 and Ogawa, 1993) and initial field pulses in cloud lightning (e.g., Weidman and Krider, 1979; Le Vine, 1980; Cooray, 1984; Cooray and Lundquist, 1985; Bils et al., 1988; Villanueva et al., 1994) were made.

According to Clarence and Malan (1957) the *B* stage is due to electric *Breakdown* occurring inside the cloud, between the negative main charge center and the positive small pocket charge center, located near the cloud base. Beasley et al. (1982) observing broadband electric field waveforms and VHF radiation from lightning events at about 11 km far from the observer, found pulses which were named *Characteristic Pulses* (CP). The CP were located at about the end of the PV and at about the beginning of the *L* stage and were typically bipolar with initial excursion in the same direction as the L and RS changes and were assigned to the initiation of the stepped leader. From 80 cases observed by Beasley et al. (1982) 6 presented a reasonably good records of CP. These pulses have been previously characterized by Weidman and Krider (1979) as been sometimes superimposed by few fast and narrow pulses on the initial half cycle and generally a smaller overshoot amplitude in comparison with the initial peak. Beasley et al. (1982) also showed a case in which the CP occurred at about 2.4 milliseconds before the RS. CP observations were done by Brook (1992) and Ogawa (1993). Ogawa (1993) labeled the CP as PBL (a last stage of the B) and showed some cases in which the B stage occurred between 4 and 6 ms before the RS. The CP or PBL were successive and intermittent pulses separated by about 140 μs. Contrary to Beasley et al. (1982), Ogawa (1993) observed some cases in which the initial excursion of the PBL were opposite to the initial excursion of the RS. CP are correspondent to K changes between

RS, which are related to discharges inside the cloud (K discharges) during an interstroke time interval.

While many observations of pulses preceding the first stroke of a negative cloud-to-ground lightning have been done, only a few authors have reported field changes prior to the first RS (eg., Rustan et al., 1981; Fuquay, 1982; Kawasaki and Mazur, 1992; Gomes et al., 1997; Ushio et al., 1998 and Gomes and Cooray, 2004) in positive ground lightning.

The interest in observing PV of positive ground lightning has increased once some authors believe that sprites are in some way related to in-cloud electrical activity just prior to positive RS. For example, according to Boccippio et al. (1995) sprites are coincident with large-amplitude positive ground lightning which contains a long horizontal progression of in-cloud discharges before the occurrence of the RS. Milikh et al. (1995) presented a physical model in which sprites are initiated by electromagnetic pulses due to intracloud discharges. The real origin of sprites is still uncertain. As a matter of fact very few is known about the preliminary variation of a positive ground lightning to relate them to the in-cloud discharges suggested by Boccippio et al. (1995) and Milikh et al. (1995). The most recently works are due to Ushio et al. (1998) and Gomes and Cooray (2004). Ushio et al. (1998) observed electric field waveforms of lightning in Japan, in a bandwidth from 0.2 Hz to 0.5 MHz and digitized in a resolution equals to 1 μs. They observed pulse trains preceding the return stroke in a positive lightning, with characteristics different from those preceding first negative return strokes. The pulse trains included bipolar pulses with pulse width from 5 to 52 μs and mean value equals to 18.8 μs, and time intervals between successive pulses from 10 to 180 μs and mean value equals to 54 μs. Gomes and Cooray (2004) observed electric field waveforms in a resolution equals to 50 ns. They observed that similarly to the preliminary breakdown in negative return strokes, the positive strokes also are preceded by bipolar pulses. They observed a diversity of pulse trains which lead them to classify their pulse trains in four types (a, b, c, d). The *type a* pulse trains were composed by pulses with the same polarity as the return stroke. The *type b* pulse trains were composed by two distinct regions. The first region had pulses with polarity opposite to the polarity of the return stroke while the second region was composed by pulses with the same polarity as the return stroke. The *type c* pulse trains had pulses opposite polarity to the polarity of the return stroke and *type d* pulse trains had pulses with irregular structure. The *type a* pulse trains consisted of more than 80% of their sample and the mean values of pulse width and time intervals between pulses, for pulses in this category, were 38 μs (σ = 16 μs) and 93 μs (σ = 56 μs) respectively. For the first region of *type b* pulse trains they found mean values equal to 27 μs (σ = 6 μs) and 62 μs (σ = 8 μs) for pulse width and time intervals between consecutive pulses, respectively. For the second region of *type b* pulse trains they found mean values equal to 26 μs (σ = 9 μs) and 38 μs (σ = 10 μs) respectively. For *type c* pulse trains the pulse width and time interval between consecutive pulses were 31 μs (σ = 7 μs) and 51 μs (σ = 9 μs) respectively. No statistics was presented for *type d* pulse trains, possibly due to the irregular waveforms of the pulses in this type.

The goal of this work is observing the occurrence of CP at the end of PB and at the beginning of L in positive ground lightning in Brazil and compare the results with the results of the most recent works of Ushio et al. (1998) and Gomes and Cooray (2004). The results of Ushio et al. (1998) were obtained from electric field records of positive lightning occurred in winter thunderstorms in Hokuriku (Japan), for a period between 1994 and 1996. The results of Gomes and Cooray (2004) were obtained from electric field records of positive lightning occurred in summer frontal thunderstorms in Uppsala (Sweden), in the periods of June 1993 and June-August 1996. So, the results of this work are the first to be obtained from summer thunderstorms in a tropical region.

2 - INSTRUMENTATION

The apparatus used to the acquisition data consisted in an electric field antenna and an A/D converter, which was located in (45.864 W, 23.215N) in São José dos Campos, São Paulo Brazil. This system was time-synchronized trough a GPS antenna connected to the computer where the A/D converter was installed.

The electric field antenna was a two flat plate antenna with radius equals to 20 cm connected to an integrator circuit (Miranda, 2004). The separation between the flat plates was about 1 cm and was achieved by insulator material. The integrator circuit had a 260 μs decay time constant in order to have a better view of leader and breakdown pulses (Kitagawa and Brook, 1960) and the bandwidth of the system was up to 300 kHz. The electric field signal was digitized by a 14-bit A/D converter with 800,000 sample rate and $\pm$ 5V analog input range. Figure 1 shows a schematic view of the acquisition apparatus.

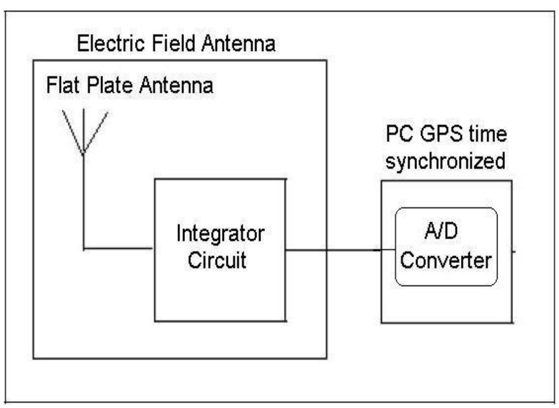

Figure 1 – Electric field acquisition apparatus used to obtain the data analyzed in this work.

3 - RESULTS

For this work electric field records of 10 positive ground lightning were analyzed. The records were obtained from summer thunderstorms at distances less than 300 km from the observation site in May and July 2003.

In this paper a negative initial polarity indicates a positive decreasing charge over the location. For caution only RS of positive ground lightning isolated in the electric field record was selected in order to avoid contamination by signature of other lightning events. Another condition to the selection was the presence of electric field activity prior to the RS. Nine out of ten selected waveforms fit the BIL category and in only one the B stage was not well defined. Figure 2 shows an example of the electric field waveform of a positive ground lightning which fits properly to the BIL category.

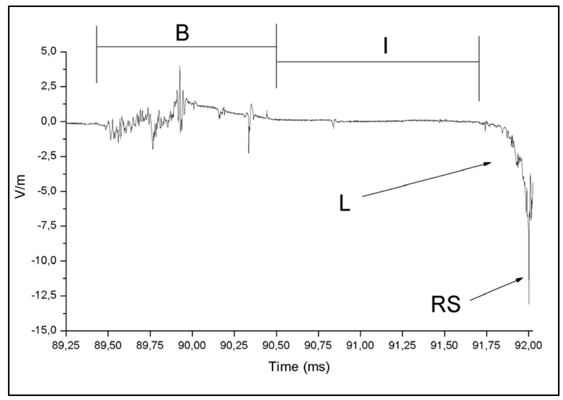

Figure 2 – An example of the type of the electric field waveform analyzed in this paper. In this figure the three stages B, I and L are clearly observed.

In this paper some features of CP at the end of B stage and at the beginning of L stage were observed. These features are: the time interval between the begin and the end of the bipolar CP pulse (full pulse width), time interval between successive CP pulses (Δt_{CP}), time interval between the end of B and RS ($\Delta t_{B\text{-}RS}$), the ratio of the peak amplitude of the initial polarity to the maximum overshoot amplitude ($CP_{peak}/OvershootCP_{peak}$), the ratio of the maximum peak amplitude of successive CP to the amplitude of the respective RS ($Maximum\_CP_{peak}/RS_{peak}$). In this study, the observed positive return strokes were preceded by a train of bipolar pulses with initial polarity equal to the return stroke polarity. The results are presented in table 1. For comparison, it also shows the results obtained by Ushio et al. (1998) and Gomes and Cooray (2004) for *type a* pulse trains.

TABLE 1 – Features of CP observed in preliminary breakdown of positive ground lightning.

	Pulse Width (μs)	**Δt_{CP} (μs)**	**Δt_{B-RS} (ms)**	**$PEAK_{CP}/Overshoot_{cp}$**	**$Max\_PEAK_{cp}/PEAK_{RS}$**
Ushio et al. (1998) (For 19 flashes)	< 18.8 > σ = 7.9 [5, 52] NE = 132 pulses	< 54.2 > σ = 35.7 [10, 180] NE = 219 pulses	< 12 > σ = NA [1, 38] NE = 19 pulse trains	< 1.3 > σ = NA [0.4, 4.7] NE = NA	< 0.27 > σ = NA [0.02, 1.9] NE = NA
Gomes and Cooray (2004) (For 57 flashes	< 38 > σ = 16 [0-10, 80] NE = 57 pulse trains	< 96 > σ = 56 [21-30, > 200] NE = 57 pulse trains	< 56 > σ = 48 [0-10, > 100] NE = 57 pulse trains	No Data	No Data
This work (For 10 flashes)	< 22.4 > σ = 18.3 [6.25, 76.25] NE = 61 pulses	< 262.4 > σ = 262.2 [2.5, 1033] NE = 61 pulses	< 20.6 > σ = 41.9 [0.45, 138] NE = 10 pulse trains	< 2.6 > σ = 1.5 [0.348, 8.958] NE = 61 pulses	< 0.296 > σ = 0.274 [0.04, 0.81] NE = 10 pulse trains

< > = mean value, σ = standard deviation, [ ] = interval of occurrence, NE = number of events, NA = Not Available. In the interval of occurrence [ ], for Gomes and Cooray (2004), the begin is presented by two numbers, once it was observed directly from their histograms.

4 – DISCUSSION

The mean values of Gomes and Cooray (2004) are larger than the results of Ushio et al. (1998) and the results of this work. According to Gomes and Cooray (2004), the mean values of Ushio et al. (1998) are at least twice less than their mean values. Gomes and Cooray stated that this difference could be due to different techniques of analysis or due to different types of thunderstorms to which the two data sets belong. However, the mean values of this work, related to the same type of thunderstorm (summer) as Gomes and Cooray (2004) are nearer to the results of Ushio et al. (1998) for winter thunderstorms. This seems to reinforce that the difference of mean values are due to different techniques of analysis. Nevertheless, a variance analysis in Table 1 indicates that no statistically significant difference was found. This fact seems to suggest that the features of the characteristic pulses in a tropical region are similar those in others regions and do not depend on the type of thunderstorms (summer or winter).

Another interesting result in Table 1 is the fact that the maximum value for the time interval between CP observed in this work is much larger than that observed by Ushio et al. (1998) and probably Gomes and Cooray (2004). The maximum time interval between CP in this work is about 13 times that one observed by Ushio et al. (1998). Although Gomes and Cooray (2004) did not state limits for these parameters, they observed values of time interval between CP larger 200 μs in 3 (5%) cases of the 57 *type a* pulse trains analyzed by them.

Figure 3 shows a histogram of time interval between CP in which we can see that about 49% of the time intervals observed were larger than 200 μs and Figure 4 shows the distribution of these intervals with respect to the total numbers of intervals in each lightning.

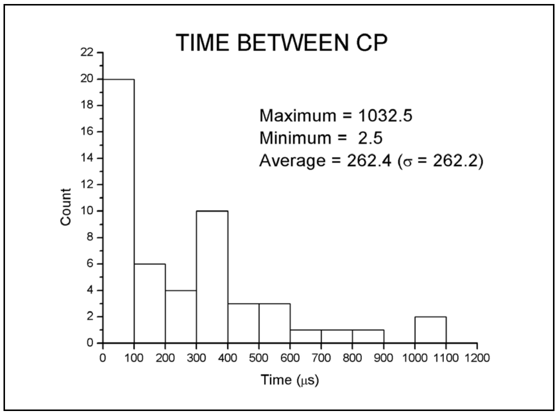

Figure 3 – Distribution of the time intervals between CP observed in this work.

FLASH	DATE	TIME	TIME INTERVALS LARGER THAN 200ms (TOTAL INTERVALS)
01	05/03/2003	17:08:48.854	01 (01)
02	05/03/2003	17:08:55.294	01 (02)
03	05/03/2003	17:09:08.588	05 (05)
04	05/03/2003	17:09:13.423	01 (01)
05	05/03/2003	17:09:30.392	02 (03)
06	05/03/2003	17:09:35.514	04 (05)
07	05/03/2003	17:09:37.671	00 (03)
08	05/03/2003	17:09:40.762	01 (03)
09	07/03/2003	19:52:15.606	00 (01)
10	07/03/2003	20:51:06.580	10 (27)

Figure 4 – Distribution of the time intervals between CP larger than 200 μs inside the pulse trains observed in this work.

Figures 3 and 4 seem to indicate a major trend in occurrence of time intervals between CP larger than 200 μs. In this work 8 out of 10 pulse trains observed presented time intervals between CP pulses larger than 200 μs. However, further studies are needed to verify this possibility.

5 – CONCLUSIONS

Statistics of characteristic pulses preceding positive return strokes was done. In this statistics full pulse width, time interval between successive characteristic pulses, time interval between the end of breakdown and the return stroke, the ratio of the peak amplitude of the initial polarity to the maximum overshoot amplitude and the ratio of the maximum peak amplitude of successive characteristic pulses to the amplitude of the respective return strokes were analyzed from electric field records. No significant statistical difference among this work and the more recent works (Ushio et al., 1998; Gomes and Cooray, 2004) was found. The results suggest that the features of characteristics pulses in a tropical region are similar to those in other regions and that they do not depend on the type of the thunderstorm. But larger maximum value of time interval between successive characteristic pulses was observed and a major trend in the occurrence of time interval between successive characteristic pulses larger than 200 μs was observed. This larger value of the maximum time interval between characteristic pulses and this major trend may be related to differences in charges distributions inside the clouds in Brazil, as compared to the non-tropical countries (Japan and Sweden).

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