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A study of the time interval between return strokes and K-changes of negative cloud-to-ground lightning flashes in Brazil

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Abstract

This paper presents the results about the time interval between return strokes and K-changes of negative cloud-to-ground lightning flashes in Brazil based on millisecond scale observations of electric field waveforms. They were obtained in São José dos Campos (45.864°W, 23.215°S), Brazil, in the period from October 1998 to February 1999. It was found that the interstroke time interval has an average value of 69.0 ms, a geometric mean value of 49.6 ms and does not depend on the return stroke order. The time interval between K-changes has an average value of 18.5 ms, a geometric mean value of 12.0 ms, and also does not depend on the return stroke order in which they occur between. These values are in reasonable agreement with the values obtained in other regions of the world.
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Keywords: Negative cloud-to-ground lightning; Interstroke time interval; K-changes; Electric field; Inter-K time interval; Return stroke

1. Introduction

A cloud-to-ground lightning is an electrical discharge between two regions with different potentials located one in the cloud and other on the ground. It starts with some discharges in the cloud called *breakdown discharges*. At the moment that the breakdown discharge begins to move in the atmosphere it is called stepped leader, because it moves in steps of the order of 50 m in 1 μs or less with an average interval of 50 μs. When the stepped leader is near to the ground, the potential between the low tip of the leader and the ground is too high that an upward discharge, called connecting discharge, starts with opposite charge. At the moment that the stepped leader contacts the connecting discharge, a very strong discharge occurs transferring charges accumulated in the channel to the ground. This strong discharge is called *return stroke* and its peak current intensity is of the order of 30 kA. In some cases, it reaches some hundreds of kiloampères. Usually, the cloud has enough charge to generate other strokes some tens of milliseconds after the first return stroke and so on. Between two consecutive strokes the occurrence of small discharges inside of the cloud called K discharges is possible, generating electric field changes called K-changes.

Kitagawa and Kobayashi (1958) analyzed 102 flashes occurred in Kanto (Japan) during summer thunderstorms from 1954 to 1956 and concluded that the higher the stroke order the longer the time interval between strokes. However, Schonland (1956) stated from an analysis of 1482 strokes from frontal storms in South Africa that the interstroke time interval does not follow a regular distribution, showing no dependence on the stroke order. Their results indicate that 87 percent of the intervals ranged from 10 to 100 ms, and

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the most frequent interval is 40 ms. The average interstroke time interval was 63 ms. Applying the same statistical test (analysis of variance) as Kitagawa and Kobayashi (1958), Thomson (1980) found no systematic variation of the interstroke time interval with stroke order for flashes in Papua New Guinea. Thomson et al. (1984) analyzed 105 flashes from convective activity in Tampa (Florida) in 1979. From 310 interstroke time intervals they found a mean value of 90 ms and a geometric mean value of 69 ms. They also found that the interstroke time does not depend on the stroke order, a result in agreement with Schonland (1956) and Thomson (1980), but in disagreement with Kitagawa and Kobayashi (1958). Thomson et al. (1984) also found that the interstroke time interval follows a log normal distribution rather than a normal distribution. Rakov and Uman (1990) found an interstroke time interval geometric mean value of 60 ms for 270 interstrokes time intervals, a value slightly shorter than the geometric mean reported by Thomson et al. (1984), a result attributed to their use of better processed data. Rakov et al. (1990), using the same data of Rakov and Uman (1990), determined for 18 strokes presented in their Table 1 a geometric mean previous interstroke interval of 47 ms, not too far from the result obtained by Rakov and Uman (1990) for all 270 interstroke time intervals. Rakov et al. (1994) show a statistical summary of lightning characteristics in their Table 1 with a geometric mean value of 60 ms for 270 interstroke time intervals. Some of the results in this table differ from those found in previous studies based on the same tape recorded data (Master et al., 1984; Thomson et al., 1984). They say that their statistical data characterization is more reliable than the derived previously due to their use of more advanced data processing techniques.

Brook and Vonnegut (1960) and Kitagawa and Brook (1960) suggested that the slow field change due to the J-process can be interpreted as due to the instrumental time integration of a series of rapid K-field changes of duration less than 1 ms due to the K-process. In this view, the J-change is the smoothed trace of the electric field record which actually consists of a number of small K-changes steps. Kitagawa et al. (1962) suggested that the K-changes are evidence of the movement of penetrative streamer into fresh regions in the cloud and that the occurrence of these streamers must be determined wholly by conditions inside the cloud. Ogawa and Brook (1964) suggested that when a propagating positive streamer comes in contact with a concentrated negative charge region inside the cloud, a negative recoil streamer analogous to a return stroke in ground flash propagates along the positive streamer channel generating the K discharge and its variations of electric field measured on ground. They also argued that the J process is a sum of individual K-changes.

Kitagawa and Brook (1960) based on the similarity between both the histograms of the inter-K time of K-changes occurring in the latter portion of cloud flashes and of K-changes in ground flashes, stated that the processes giving rise to both types of K-changes are the same. Even though, later they reported that the cloud flash K-changes to be larger than the K-changes in ground flashes. Kitagawa and Brook (1960) in New Mexico found that the time interval between K-changes (inter-K time interval) lasts some milliseconds, with an average value of 8.5 ms. Later, Thottappillil et al. (1990) found for inter-K time intervals for ground flashes in Florida a geometric mean value of about 13 ms.

M components are temporary increases in the luminosity of the faintly luminous channel due to the continuing current. They are observed after some ground return strokes and they generate electric field changes termed M-changes. Kitagawa et al. (1962) based on the similarity between the histogram of the inter-K time intervals and the histogram of the time intervals between M-changes, reported that the M components are due to K-changes occurring during continuing currents. Thottappillil et al. (1990) present a statistics on the occurrence of the K-changes and of the M components and found a dissimilarity between both distribution, claiming that the K-changes and the M components are not the same physical processes, as argued by Kitagawa et al. (1962). Thottappillil et al. (1990) also argued that the conclusion of Kitagawa and Brook (1960) that the J-change is the sum of individual K-changes was not supported by their data. Rakov et al. (1992) observing the occurrence and wave shape of microsecond-scale electric field pulses associated with both millisecond scale steplike K-changes and millisecond scale hook-shaped M-changes, stated that the K- and M-changes are associated with dissimilar physical processes and that the observed microsecond scale pulses associated with K-changes are not consistent with the characteristic wave shape proposed by Arnold and Pierce (1964). A more detailed review about K-changes can be found in Thottappillil et al. (1990) and Rakov et al. (1992).

This paper presents the results of the first study about time intervals between return strokes and K-changes of negative cloud-to-ground lightning flashes in Brazil. It is based on the analysis of electric field waveforms in millisecond scale, and it is divided in two parts: (a) interstroke time interval and (b) inter-K time interval.

2. Instrumentation

The apparatus used to obtain the electric field waveforms consisted of two whip antennas of 0.6 and 1.5 m length coupled to an electronic circuit to process the signal. The circuit had a decay constant of a few milliseconds, and it was linked to a computer with a digitizer board with acquisition rate equal to 37 μs. The apparatus frequency response was up to 100 kHz. The system was incapable of faithfully reproducing pulses waveforms, but the time intervals analyzed here could be easily measured. The long antenna was used when the storm was distant and the short one when the storm was near.

Fig. 1. 28-m tower located in São José dos Campos, where the electric field waveforms were obtained.

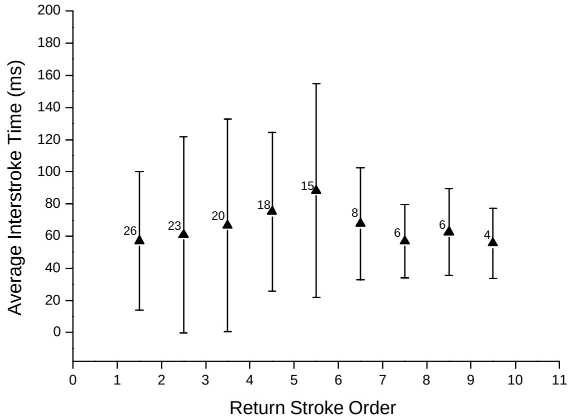

Fig. 2. Average interstroke time versus stroke order for negative cloud-to-ground lightning in Brazil. The numbers on the triangles indicate the number of interstroke time intervals used to obtain the average value. The standard deviations are indicated by bars.

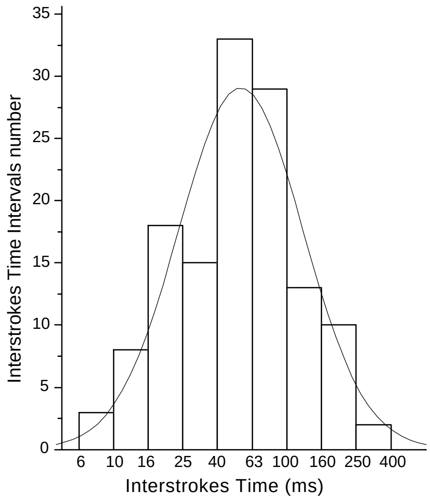

Fig. 3. Log normal curve for the interstroke time intervals in Brazil.

The apparatus was installed at the top of a 28 m tall tower, located at São José dos Campos (45.864°W, 23.215°S) in the period from October 1998 to February 1999. The tower offers the advantage of being far from possible noise sources and had an architecture favorable to the unobstructed view of the lightning because of its hexagonal shape with windows in almost all walls allowing a field of view of about 360°, as it is shown in Fig. 1. So, the electric field waveforms were obtained in such a way that it was possible to identify the type of lightning associated with it. A more detailed description about the apparatus is presented by Miranda (2000).

As the electromagnetic radiation of the lightning reached the antenna, a variable voltage was induced accordingly to the electric field waveform of the radiation. This signal was processed by the electronic circuit, digitized and then stored in the computer memory in files of nearly 1 s of duration. The antenna gain could be adjusted by the operator avoiding saturation of the signal.

3. Results and discussion

3.1. Interstroke time

In the study of the interstroke time interval, 26 electric field waveforms of multiple-stroke negative cloud-to-ground lightning with 131 strokes were analyzed. All 26 flashes were identified visually. An average interstroke time interval of 69.0 ms and a geometric mean interstroke time interval of 49.6 ms were found. These values are close to those obtained by Schonland (1956) in South Africa, and Thomson et al. (1984), Rakov and Uman (1990) and Rakov et al. (1990) in Florida. After that, the average interstroke time interval was calculated considering the stroke order in the sample. Fig. 2 shows the average interstroke time interval versus stroke order. For each order, the total number of events and the standard deviation are indicated. From Fig. 2 we can see no dependence of the average interstroke time on the stroke order. This result confirms the results obtained by Schonland (1956), Thomson (1980) and Thomson et al. (1984), who did not find any systematic variation of the interstroke time interval with the stroke order. It was also found that the distribution of the interstroke time interval follows a log normal distribution, as it can be seen in Fig. 3. This is in agreement with Thomson et al. (1984).

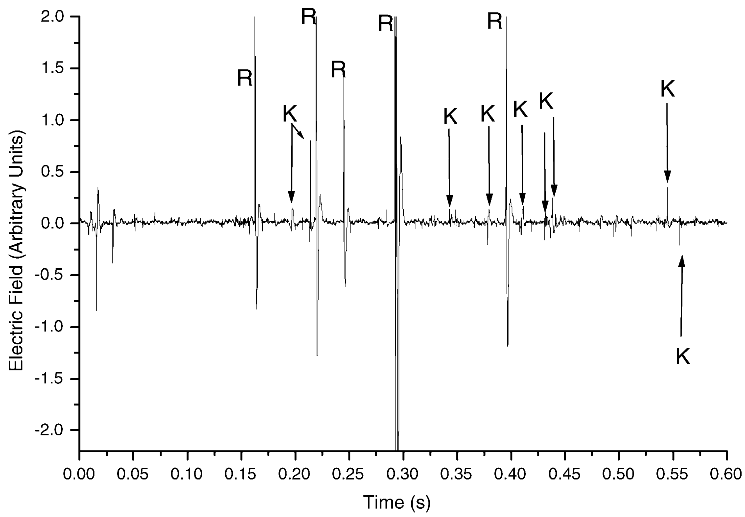

Fig. 4. A typical electric-field waveform. R = return stroke, K = K discharge.

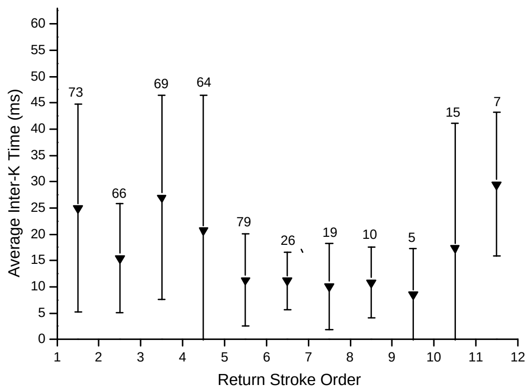

Fig. 5. Average inter-K time versus stroke order for K discharges in Brazil. The numbers on the bars indicate the quantity of inter-K time intervals used to obtain the average value. The standard deviations are indicated by bars.

3.2. Inter-K time

Fig. 4 shows a typical waveform in which we can see return strokes (R) and K-changes pulses (K). The criterion to distinguish the K-changes pulses from the noise was the following: all return strokes and preliminary variation pulses were eliminated considering the amplitude and the instant of occurrence, respectively; then, the average value (E) and the standard deviation (δ) of the remaining data were computed. An interval with a higher limit ($E + 3\delta$) and a lower limit ($E - 3\delta$) was defined, so that, every pulse whose amplitude was not entirely inside of this interval was considered a K-change pulse. After identified the K-changes pulses, 433 inter-K time intervals were found. The average inter-K time interval was computed as a function of the return stroke order. Fig. 5 shows the inter-K time intervals versus stroke.

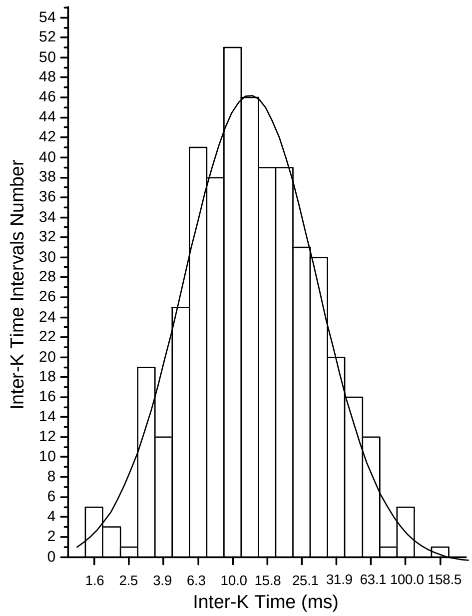

Fig. 6. Log normal distribution of inter-K time intervals of negative lightning in Brazil.

We can see no dependence of the inter-K time interval on the stroke order. An average inter-K time interval of 18.5 ms and a geometric mean value of 12.0 ms were computed without considering the stroke order. This last value is higher than the value obtained by Kitagawa and Brook (1960), 8.5 ms, but similar to the value obtained by Thottappillil et al. (1990), of 12.5 ms. The difference in these values is probably a result of the different criteria used to identify the K-changes. It was also found that the inter-K time interval follows a log normal distribution as it can be seen in Fig. 6.

4. Conclusions

This is the first study about the interstroke and inter-K time intervals based on electric field lightning waveform observations in Brazil. The average values for the interstroke and inter-K time intervals were 69.0 and 18.5 ms, respectively. The geometric mean values for the interstroke and inter-K time intervals were 49.6 and 12.0 ms, respectively. These values are close to those obtained in other regions of the world. The interstroke time interval was found to have no dependence on the stroke order and its distribution follows a log normal curve. Also, no dependence of the inter-K time interval on the stroke order was found. Both, the interstroke and the inter-K time interval distributions follow a log normal curve. These results are in agreement with the literature.

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