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Characteristics of lightning discharges over AOS

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Abstract

Lightning discharges over the Array Operations Site (AOS) were measured with electromagnetic field antennas. A total of 107 lightning discharges recorded in summers of 2002–2003 were statistically analyzed. Although thunderstorms over the AOS are rare, once occurred, strong lightning activity with a lightning frequency of 1.6 flashes per minute and the cloud-to-ground discharge percentage of about 66%, both comparable to summer lightning at lower altitudes, was observed. Among cloud-to-ground discharges, about 7% were positive cloud-to-ground discharges that often neutralize large amount of charges. The number of strokes per flash of the cloud-to-ground discharges was very large, with a maximum value of 24 and a median value of 8. The median value of the inter-stroke time interval was very short (25 ms), suggesting shorter distance to the thunderstorm charges. The continuous current component that neutralizes large amount of charges were observed in 39% of the cloud-to-ground discharges, and the median value of the continuous current duration was long (140 ms) and was comparable to that of typical summer lightning at lower altitudes.

1 Introduction

Lightning is a powerful natural event capable of damaging even intentionally protected structures and it can be lethal to people. Because ALMA will be constructed at very dry Andean plateau that is very flat without any trees and tall structures other than the array itself, and because the area apparently covered by the antennas is very wide, lightning protection will be an important issue. Unfortunately upper soil resistivity is very large near the AOS ($> 1000\,\Omega\,$m, Sakamoto et al. 2000a; Sakamoto & Sekiguchi 2001; Sakamoto 2001a), and thus high-quality grounding is costly and often very difficult. Moreover, understanding of characteristics of lightning at high altitude ($\sim 5000\,$m above the sea level) has been very limited so far. To make a proper lighting protection/prevention design of the array, it is necessary to know the basic characteristics of lightning over the site. The total charge transferred (the integrated current) is important in causing heating and thus in causing fires and spalling, and is dominated by the low frequency components of lightning (continuous currents). The characteristics of the rapid current rise at the beginning of each stroke are important in causing arcs and in modern lightning protection.

One possible effect of high altitude on lightning discharge is the smaller distance from the ground to charged regions in thunderclouds. There are a number of evidences that the temperature is the determinant factor of the location of positive and negative charges. Krehbiel et al. (1983) reported that the negative charge locates in a range with the temperature near -10°C and the positive charge near -30°C in the thunderclouds of both New Mexico (1800 m above the sea level) and Florida (close to the sea level). For the thunderclouds in Chinese inland area at an altitude of 2000 m above the sea level, it is reported that there is a strong positive charge region underneath the negative charge which ranges at 2.7–5.4 km in height (equivalent to a temperature range from -2°C to -15°C) (Qie et al. 1999). The positive charge usually causes positive cloud-to-ground lightning (CG) discharges. For the Japanese winter thunderclouds, negative charges are also in the temperature range near -10°C, and positive charges near -30°C (Brook et al. 1982). The vertical distance to the charge region from the ground is small for both Chinese inland plateau and Japanese winter thunderclouds. Lower ground level temperature is considered the main reason why the height of the charge regions is low. It is well known that Japanese winter lightning have the following characteristics: (1) the percentage of the positive cloud-to-ground lightning is high; (2) the positive discharge usually neutralizes a great amount of electric charge; (3) the peak current is usually large in amplitude (Miyake et al. 1990). Therefore, the resultant damage on electric power facility, etc. is generally huge (Shinjo et al. 1996). Since the array site is very high in altitude and consequently has low temperature, the lightning may have some similarity to that in Japanese winter thunderstorms. However, no observation data on the lightning occurred at an altitude of around 5000 m above the sea level have ever been documented. For this reason, we have performed measurements of lightning over the AOS. This paper presents initial report on activity, multiplicity, inter-stroke interval, and percentage and duration of continuous current. Spatial and seasonal distribution of lightning events over the AOS will be presented in a separate paper (Sakamoto & Radford 2004).

2 Instruments and Site

For the present observation, a magnetic field antenna and an electric field slow antenna were employed (Figure 1). The magnetic field antenna was composed of a rectangular loop antenna installed vertically about 1.5 m above the ground, and an amplifier right below the loop antenna. The magnetic field antenna had a frequency bandwidth from 160 Hz to 5 MHz. The electric field slow antenna was composed of an aluminum flat plate with a diameter of 30 cm, installed horizontally about 1 m above the ground, and an amplifier right below the plate. The electric field antenna had a frequency bandwidth from 1 Hz to 6 MHz, and its outputs were used to examine from the aspect of whole lightning discharge process to the initial sharp rise of return strokes. The signals from both antennas were digitized at a sampling frequency of 2 MHz, and then were automatically recorded in the hard disk of a digital oscilloscope. A microphone was installed as well in order to record thunders, but its data were not included in this analysis. Because the data were taken only when there were people at the observation site and lightning events were expected, the data coverage is far from complete.

The measurements were conducted at Pampa La Bola, which locates in the sterile Atacama highland area in the northeast of Chile, with an altitude of 4800 m above the sea level, 22.96°S in latitude, and 67.70°W in longitude (Sakamoto 2001b). The Pacific Ocean lies in west 300 km away and the Andes range, and mountain areas around 6000 m altitude above the sea level lie in the south, north and east. The ground level atmospheric temperature monitored with a nearby weather station (Sakamoto et al. 2000b) ranged from -8 to $+12$°C during January–March period, and is close to or lower than 0°C during stormy summer afternoon. The wind speed was almost $0\,\mathrm{m\,s^{-1}}$ at night (22h–9h local time) and became over $10\,\mathrm{m\,s^{-1}}$ in the afternoon.

3 Results and Discussion

3.1 Lightning Activity

A total of 107 lightning discharges were recorded during four thunderstorms in the summers of 2002–2003. Table 1 presents the statistical results. Among the 107 lightning discharges, 71 were cloud-to-ground discharges and the remaining 36 were intercloud discharges. The occurrence percentage of the cloud-to-ground discharges was 66%. Out of the 71 cloud-to-ground discharges, 66 were negative and the remaining 7 were positive. The percentage of the positive lightning was about 7%, similar to that reported for summer thunderstorms in low- and mid-latitude regions (Livingstone & Krider 1978). However, if we focus on the storms that produced positive discharges, the percentage of the positive lightning was 85%. One storm produced only two positive lightning and its activity was very weak. These characteristics are similar to that of Japanese winter thunderstorms.

The relationship between the lightning discharge number per minute and the percentage of cloud-to-ground discharges in whole lightning discharges is shown in Figure 2. Black triangles are for Pampa La Bola lightning. As a comparison, the corresponding data for the summer lightning of Japan and New Mexico (Takeuti 1966) are also included. The larger elliptical circle in Figure 2 corresponds to that of Japanese winter lightning. As seen in the figure, lightning over the AOS exhibits higher lightning frequency and larger percentage of cloud-to-ground lightning than the Japanese winter thunderstorms, and its activity is comparable to that of summer lightning at lower altitudes.

With the consideration of 30 s dead time of the digital oscilloscope, the lightning discharge frequencies of the three Pampa La Bola thunderstorms on 2002 March 6, 2002 March 9 and 2003 January 18 that produced only negative lightning were calculated to be 1.3, 1.2 and 1.6 flashes per minute, respectively. The lightning discharge frequency was 0.25 flashes per minute for the thunderstorm that produced only positive cloud-to-ground discharges. For the one Pampa La Bola thunderstorm on 2003 March 4 that produced not only negative but also positive cloud-to-ground discharges, the lightning discharge frequency was 0.15 flashes per minute. The number of positive cloud-to-ground discharges is similar to that for Japanese winter thunderstorms.

3.2 Multiplicity

Multiplicity is shorthand for the number of strokes in a flash, and is one of the basic parameters for lightning protection design. Cumulative frequency distribution of the multiplicity of cloud-to-ground lightning discharges is shown in Figure 3. For comparison, the corresponding statistical results reported previously by other authors are also included in Figure 3a (Takeuti & Nakano 1983; Sumi 1986). Figure 3b presents the statistical results of Pampa La Bola data for separate years. As shown in Figure 3a, the maximum number per flash of thunderstorms over Pampa La Bola was 24 with the median value of 8. For negative ground flashes measured over Pampa La Bola in 2002 and 2003, the median values were 8 and 5, respectively, as given in Figure 3b, whereas the median value for the Japanese summer thunderstorms reported by Sumi (1986) was only 4. The multiplicity of negative cloud-to-ground lightning discharges over Pampa La Bola was considerably high, similar to that of rocket-triggered discharges in winter of Japan.

3.3 Inter-stroke Time Interval

Cumulative frequency distribution of the inter-stroke time interval is shown in Figure 4. For comparison, the corresponding statistical results for summer lightning at other places are included in Figure 4a. Figure 4b presents the statistical results of Pampa La Bola data for separate years. As given in Figure 4a, the minimum and the maximum inter-stroke time intervals of negative lightning over Pampa La Bola were 8 ms and 460 ms, respectively. The median value was 25 ms, much shorter than the corresponding value of 50–80 ms for usual summer lightning (Nakano et al. 1984). This smaller time interval observed at Pampa La Bola is consistent with the idea that the thunderstorm charges are lower in height, resulting in shorter leader propagation time.

3.4 Continuous Current

The total charge transferred is dominated by the low frequency components of lightning, or continuous current, and duration of continuous current will be reflected in neutralized charge and resultant damages. For instance, it is reported that even a transmission line could be melted with the neutralized charge exceeding 200 C (Shimizu et al. 1997). As shown in Table 1, a total of 28 cloud-to-ground lightning discharges contain continuous currents. The percentage for producing continuous currents is 39%, similar to that for the usual summer lightning in low- and mid-latitude regions (Livingstone & Krider 1978).

Cumulative frequency distribution of the continuous current duration is shown in Figure 5. For comparison, the corresponding statistical results for summer lightning at other places are included in Figure 5a. Figure 5b presents the statistical results of Pampa La Bola data for separate years. As shown in Figure 5, the median duration of negative lightning over Pampa La Bola was 140 ms, which is similar to 160 ms for typical negative summer lightning (Cianos & Pierce 1972; Fuquay 1982). Although the continuous current is at the order of several hundred amperes in summer lightning, it could neutralize a huge amount of charge due to its long duration. It is therefore recommended that the statistics of continuous currents reported in this paper to be taken into account in the lightning protection design for ALMA.

4 Summary

Lightning discharges occurred over the Array Operations Site (AOS) around 5000 m above the sea level were measured with electromagnetic field antennas installed at Pampa La Bola. The following characteristics have been revealed. (1) Thunderstorms over the AOS are usually strong in lightning activity with a lightning frequency of 1.6 flashes per minute. (2) The percentage of the cloud-to-ground discharge was 66%, and the percentage of the positive cloud-to-ground discharge was around 7%. (3) The maximum multiplicity of cloud-to-ground lightning was 24 and the median value was 8. The median value of the inter-stroke time interval was 25 ms. (4) The occurrence percentage of the continuous current was 39%, and the median value of the continuous current duration was 140 ms, comparable to that of typical summer lightning at lower altitudes. The lightning discharges show some different characteristics compared to both summer and winter lightning in Japan.

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Figure 1: Appearance of the magnetic field antenna (*left*) and the electric field slow antenna (*right*) installed at the site.

Table 1: Statistics of lightning discharge events over Pampa La Bola

UTC		Lightning discharges				Continuous
Date	Time	Total #	Intercloud	Negative CG	Positive CG	current
2002-03-06	13:07–13:51	34	1	33	0	13
2002-03-08	14:54	1	1	0	0	0
2002-03-09	13:13–13:53	29	1	28	0	10
2002-03-09	17:10–17:19	2	0	0	2	2
2003-01-18	13:15–13:34	8	4	4	0	2
2003-03-03	15:52–17:52	3	3	0	0	0
2003-03-04	12:37–15:51	27	23	1	3	1
2003-03-04	17:09–17:42	3	3	0	0	0
Total		107	36	66	5	28

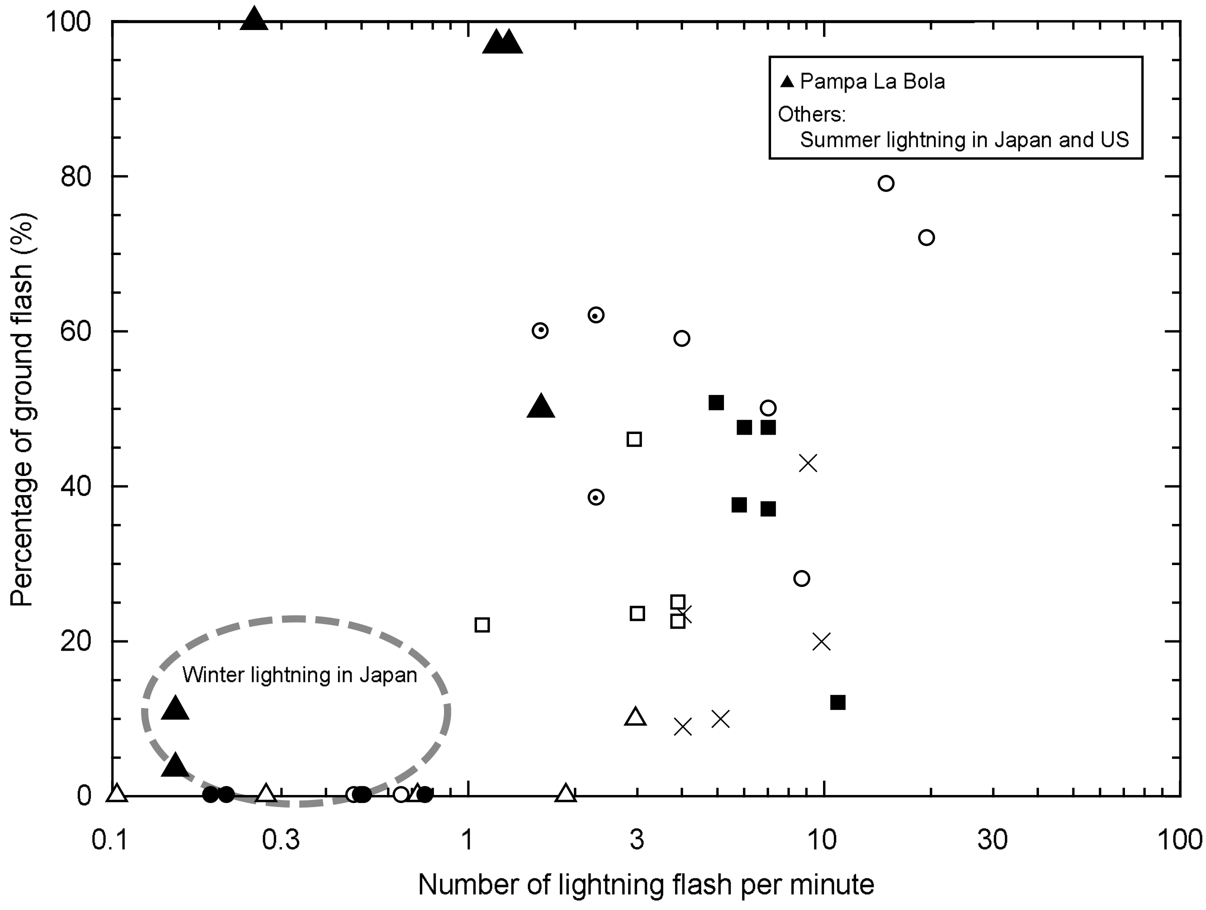

Figure 2: Relationship between the number of lightning discharges per minute and the percentage of ground discharges. The large dashed oval schematically indicates distribution of typical Japanese winter lightning.

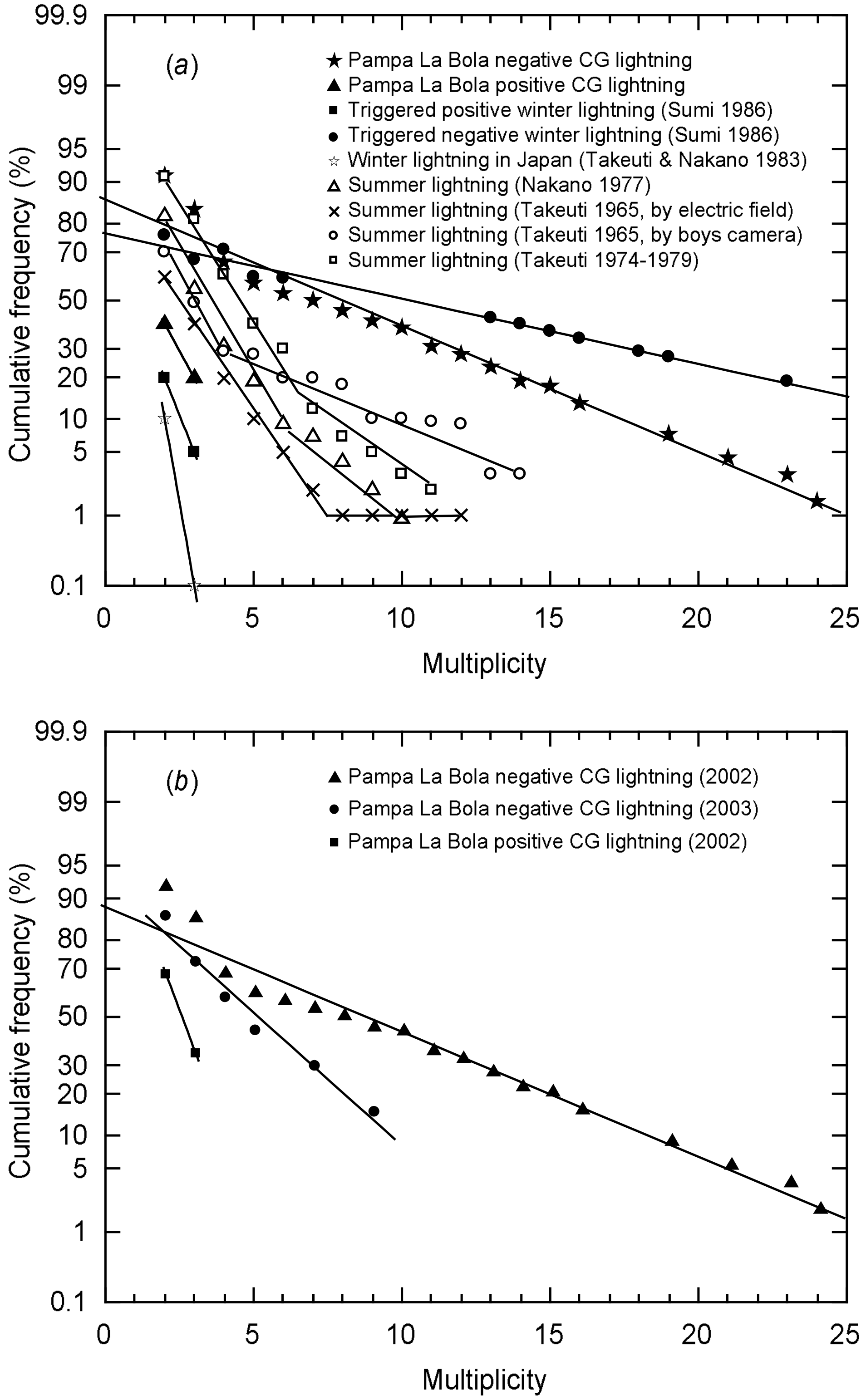

Figure 3: (a) Cumulative frequency distribution of the multiplicity of ground discharges. Corresponding results taken from literature were also shown for comparison. (b) Same as (a) but to examine the multiplicity in different year and month.

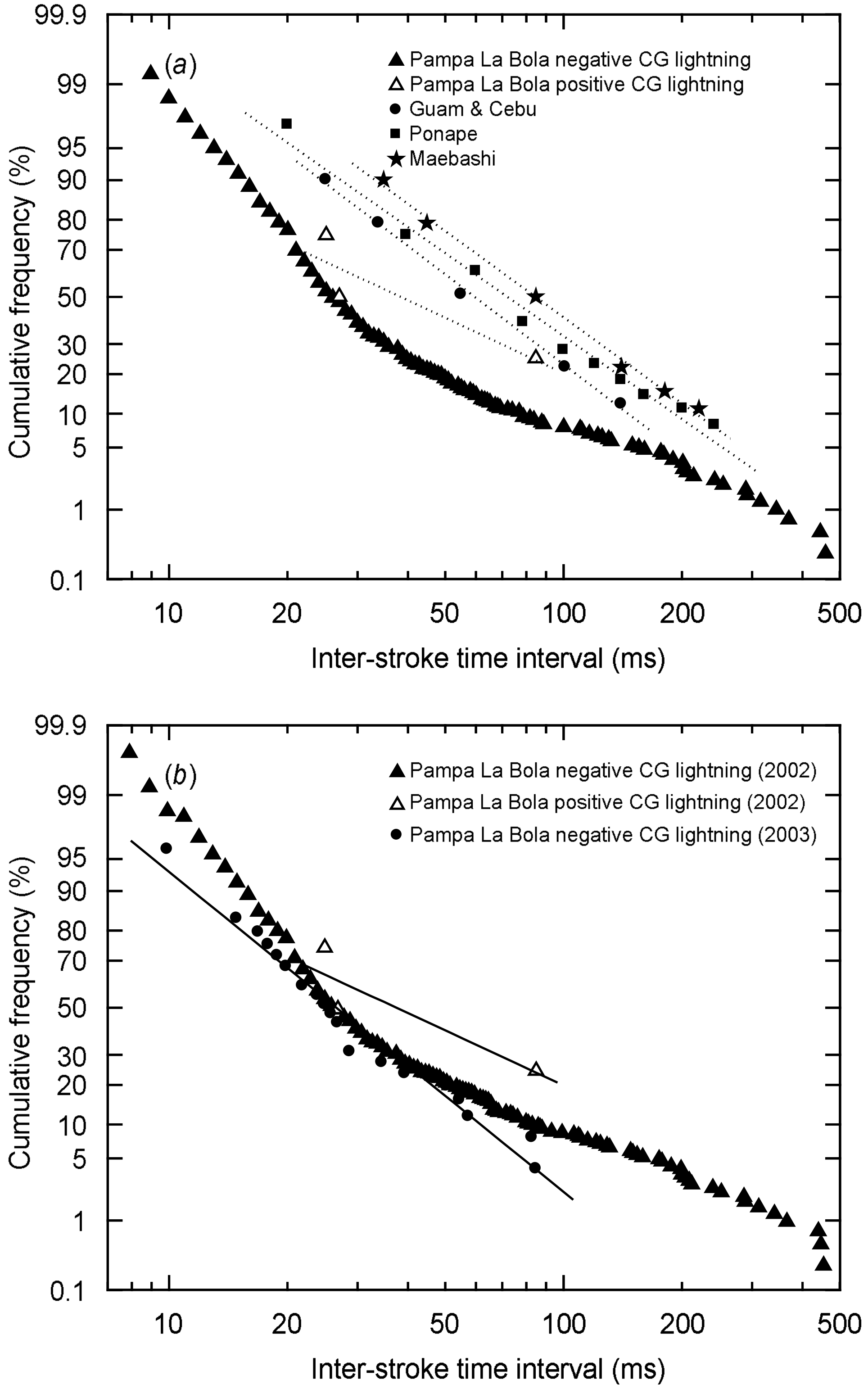

Figure 4: (a) Cumulative frequency distribution of the inter-stroke time intervals. Corresponding results taken from literature were also shown for comparison. (b) Same as (a) but to examine the inter-stroke time intervals in different year and month.

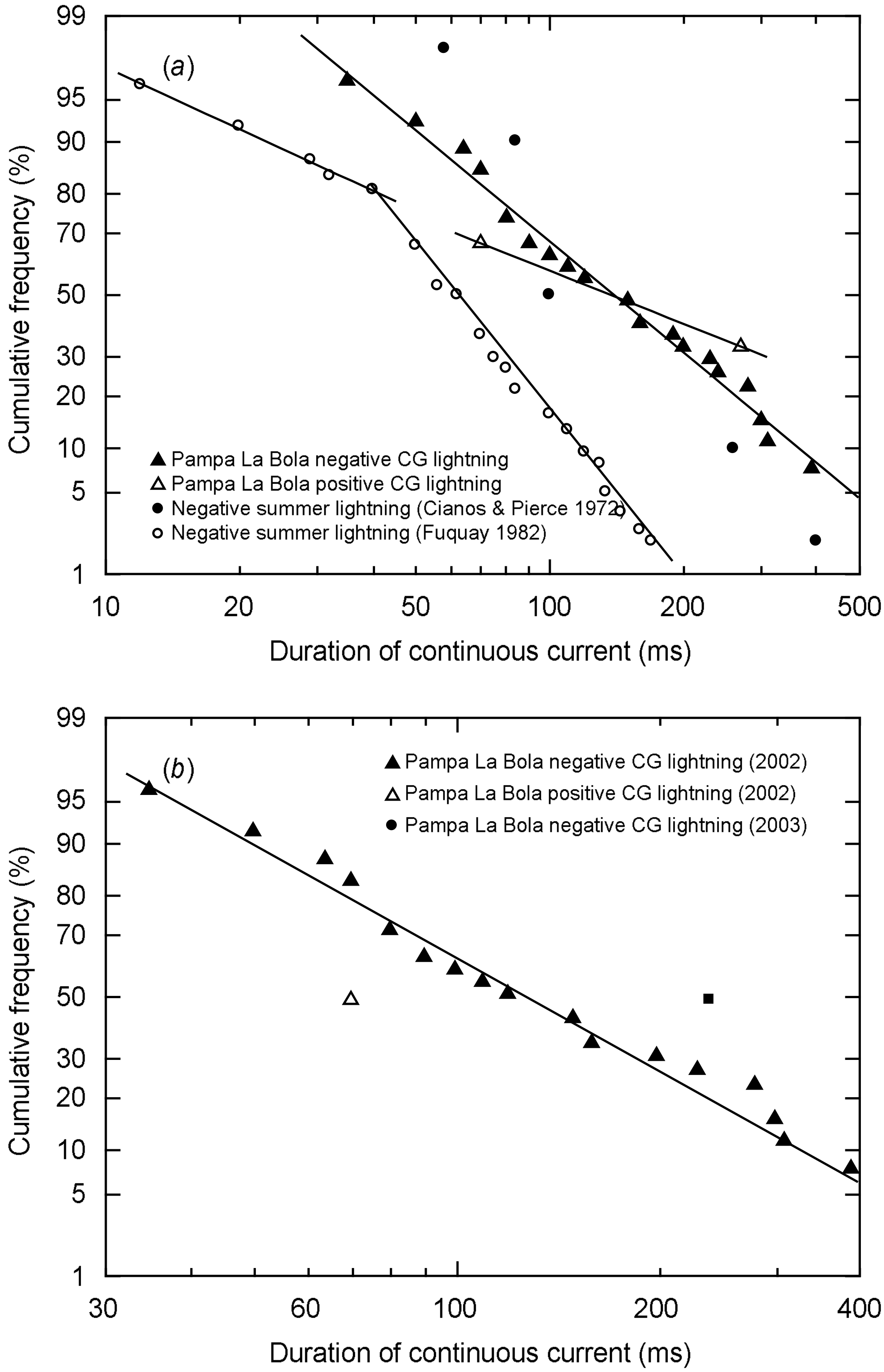

Figure 5: (*a*) Cumulative frequency distribution of the continuous current duration. Corresponding results taken from literature were also shown for comparison. (*b*) Same as (*a*) but to examine the continuous current duration in different year and month.