2008
20th International Lightning Detection Conference
21-23 April • Tucson, Arizona, USA
2nd International Lightning Meteorology Conference
24-25 April • Tucson, Arizona, USA

PROPERTIES OF NEGATIVE CLOUD-TO-GROUND LIGHTNING FROM HIGH SPEED VIDEO OBSERVATIONS IN ARIZONA, USA, AND SÃO PAULO, BRAZIL

Saraiva, A. C. V.[1], Saba, M. M. F.[1], Campos, L. Z. S.[1,3], Pinto Jr. O.[1], Cummins, K. L.[2], Krider E. P.[2], Fleenor S. A.[2]

[1]INPE, National Institute for Space Research, S. J. Campos, SP, P.O. Box 515, 12201-970, Brazil
[2]Institute of Atmospheric Physics, University of Arizona, Tucson, AZ, USA
[3]UNESP, Campus de Guaratinguetá, Departamento de Física e Química, SP, Brazil

1. INTRODUCTION

Lightning observations with high-speed video cameras were initially done for isolated events (Mazur et al., 1995, 1998, Saba et al., 2004, among others). More recently high-speed cameras have been used to observe and analyze the characteristics of cloud-to-ground (CG) lightning flashes for larger numbers of events (Saba et al., 2006a, 2006b).

It has been noticed that the different observation techniques may generate different lightning parameters if these parameters are sensitive to the reliability of the stroke identification processes (Rakov and Huffines, 2003). For example, Rakov et al. (1994) used a conventional video camera and electric field measurements for 76 negative CG flashes in Florida (USA) and obtained a flash multiplicity of 4.6, and the fraction of single stroke flashes was 17%; Saba et al. 2006a used a high-speed camera to observe 233 negative CG flashes in São José dos Campos (Brazil) and obtained a multiplicity of 3.8 and 18% single stroke flashes. Are the characteristics of flashes in Florida different from the ones in Brazil, or are the different techniques producing these differences? In an effort to answer that question (and others), an observation campaign was conducted in Tucson, Arizona (USA) using the same high-speed camera that was used in Brazil by Saba et al. (2006a, 2008).

Biagi et al. (2007) made observations using conventional video cameras and electric field observations to evaluate the performance of the U.S. National Lightning Detection Network™ (NLDN). The measurements were made in Arizona and Texas-Oklahoma, and they used the same technique so the characteristics of negative CG flashes in different places could be compared directly. However, since the scope of that work was not to measure the characteristics of CG flashes, there was only information on the flash multiplicity and peak current, in addition to the detection efficiency (DE) of the NLDN.

In this paper we will present preliminary statistics on the characteristics of negative CG flashes observed in Tucson, Arizona (USA) that were obtained using multiple, high-speed cameras, and we will compare these data with observations made by Saba et al. (2006a) in Brazil using the same technique. We will also compare our results with Biagi et al. (2007), because the latter were made in the same region but using different techniques.

2. DATA COLLECTION

The data for this study were acquired during July/August (summer) 2007 in Tucson, AZ, (USA). Two high-speed cameras were used to observe lightning flashes from different angles.

The high-speed cameras are the Redlake MotionScope 8000S and the Photron Fastcam 512 PCI. The main difference between each one is the time and space resolutions. The MotionScope was set up to 1000 frames per second (1 millisecond time resolution) and spatial resolution of 240x210 pixels. The Fastcam 512 was set up to 4000 fps (250 µs of time resolution) and spatial resolution of 512 x 256 pixels, some flashes were also observed in 8000 fps (125 µs of time resolution). Each video has a total recording time of 2 seconds.

The video frames of both high speed cameras were GPS time stamped with an accuracy of 1 ms. This synchronization allowed the comparison of each flash with NLDN data. The detection efficiency of the NLDN in Tucson is about 93% for flashes and 68% for strokes (Biagi et al.,2007). The results will be compared with observations of 233 negative CG done by Saba et al. (2006a) in São Paulo, Brazil. The observations in São Paulo were made with the Redlake MotionScope 8000S camera and were correlated with the Brazilian Lightning Location Network (BrasilDAT).

3. ANALYSIS AND RESULTS

We recorded a total of 242 negative CG flashes in Tucson. The flashes occurred at distances between 1 and 100 km from the observation site.

3.1 Flash multiplicity

The total number of negative strokes observed was 950. Figure 1 shows a histogram for the number of strokes per flash in 242 flashes. Of these flashes, 47 (19%) were single stroke flashes. Figure 1 also shows that the most common value of multiplicity is 2 and the average number of strokes per flash was 3.9.

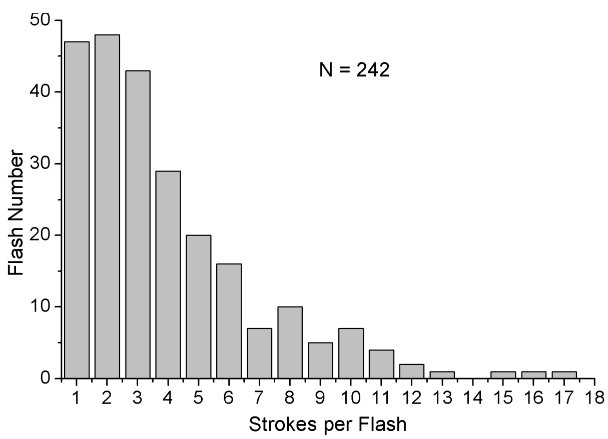

Figure 1. Number of strokes per flash versus number of flashes. For the total number of 950 strokes the average multiplicity as 3.9.

Figure 2 shows a comparison of this work with the observations of Saba et al. (2006a) in São Paulo, Brazil. Note that the percentage of flashes with a given number of strokes is very similar in both regions.

3.2 Interstroke interval

A total of 719 interstroke intervals were observed for 242 flashes. Figure 3 shows the frequency distribution of interstroke intervals; the geometric mean (GM) is 61 ms and the arithmetic mean (AM) is 89 ms. Saba et al. (2006a)

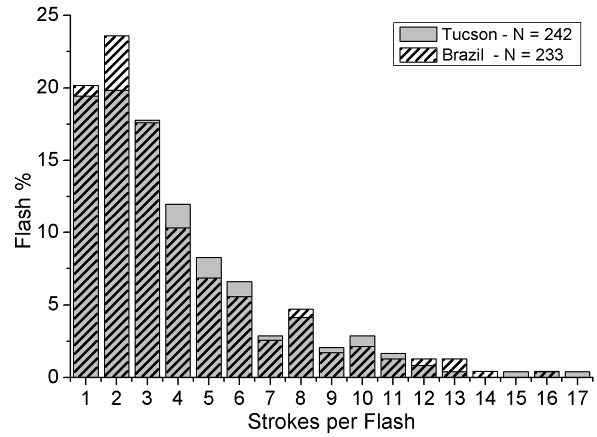

Figure 2. Comparison between the percentage of flashes with different number of strokes observed in Tucson and Brazil.

measured very similar values (GM of 61 ms and AM of 83 ms). The maximum interval between strokes was 597 ms.

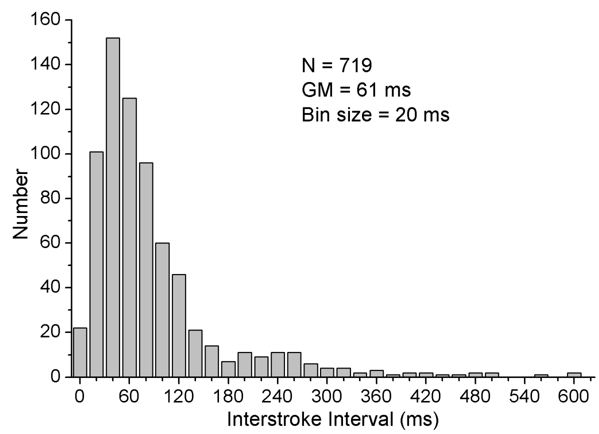

Figure 3. Interstroke interval distribution. The geometrical mean (GM) is 61 ms for 719 intervals measured.

Six interstroke intervals were below 2 ms; three of these were equal to 1 ms and the others were on the order of microseconds. These short intervals were probably related to forked channel development (Ballarotti et al., 2005). About 145 (20%) out of 719 intervals were below 33 ms, which is the time resolution of standard video recordings. This means that at most 20% of the total number of strokes could have been missed if only standard (30 fps) video recordings were used, given the interstroke interval shown in Figure 3.

Figure 4 presents a comparison between our data and observations in Brazil. The two distributions are quite similar.

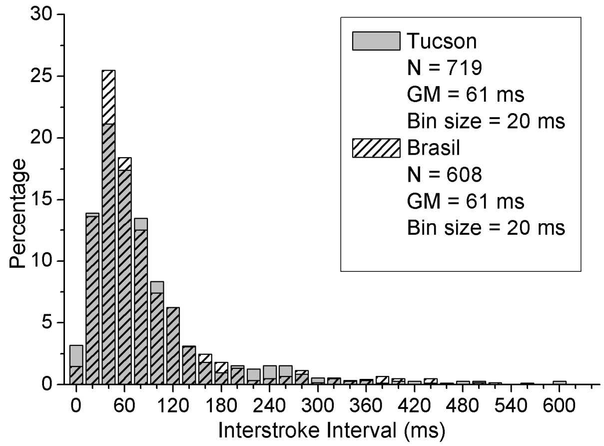

Figure 4. Comparison between distributions of interstroke intervals for Tucson and Brazil.

3.3 Flash duration

The flash duration is defined here as the time between the first stroke and the end of the luminosity of the last subsequent stroke, or the end of the continuing current (if present). There were a total of 204 flash durations measured for 242 negative CG flashes. The geometric mean was 289 ms and its distribution is displayed in Figure 5.

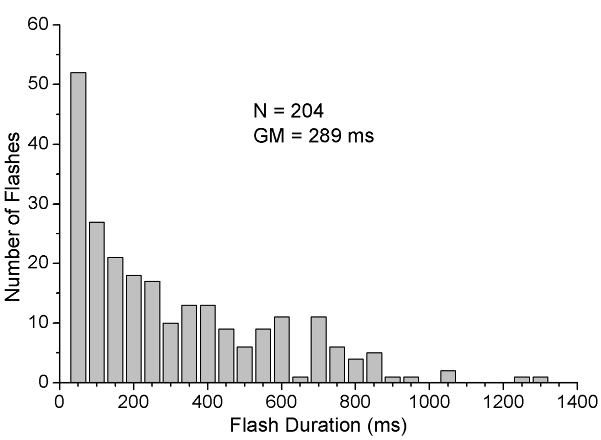

Figure 5. Histogram of number of flashes having a given flash duration.

A comparison of the Arizona durations with data from Brazil (see Figure 6) shows a significant difference for flashes with durations below 50 ms. About 10% more flashes with durations lower than 50 ms were observed by Saba et al. (2006a).

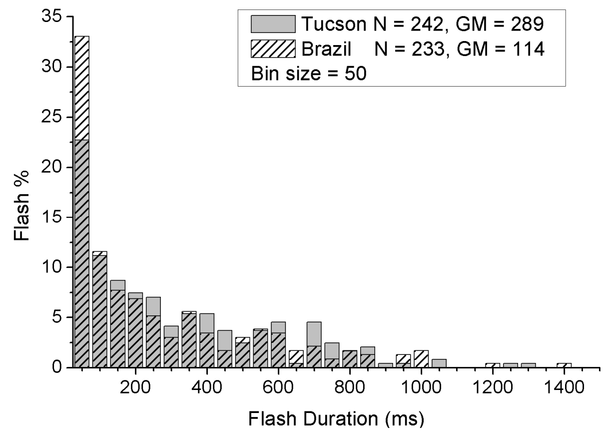

Figure 6. Flash duration versus percentage of flashes for Tucson and Brazil.

The scatterplot in Figure 7 shows the relation between flash duration and number of strokes per flash in Tucson and Brazil. There is a strong similarity in the data from both places, reinforcing the idea that there must be a minimum time required for the reorganization of charge in the cloud to provide sufficiently high fields for the next stroke to occur. The linear fit to the minimum duration values for the combined datasets gave a correlation coefficient of 0.93 and a regression line slope of 63 ms.

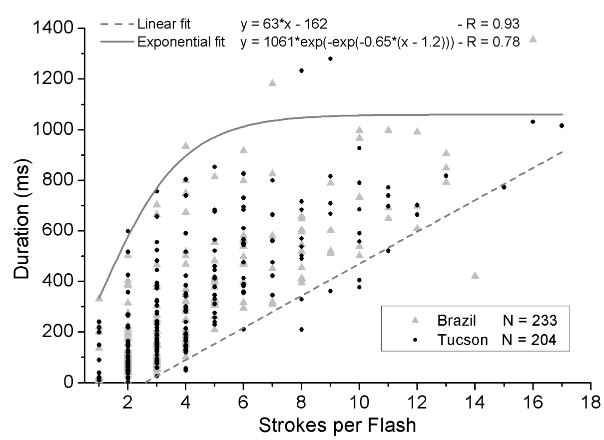

Figure 7. Scatterplot showing the relation between the flash duration and the number of strokes per flash. The black circles are data from Tucson and the gray triangles are from Brazil.

Also, Figure 7 shows that an exponential fit to the maximum durations intercepts the linear fit to the minimum values at a time of about 1 second and a multiplicity of 19 strokes per flash. These values can be viewed as upper limits for most CG flashes. In fact only 5% of the flashes had a duration greater than 1 second, and none had a multiplicity greater than 18 in both datasets.

The mechanism for this "maximum duration" effect has yet to be studied in detail. One possible explanation could be that as the leader inside the cloud propagates to collect more charge for the subsequent strokes, the lightning channel gets longer. Because longer channels are more unstable, the occurrence of extra strokes (discharges) becomes less probable (Heckman, 1992).

3.5 Comparisons between storms

We have compared the flash properties from three different storms on August 10^{th}, 13^{th} and 15^{th}, 2007 These days were chosen because of their large sample sizes. The results of the geometric means of the characteristics are shown in Table 1. Although there are only three cases , it's possible to see the high variability of the flash characteristics from storm to storm, which reinforces the idea that lightning from a large number of different storms needs to be observed in order to make reliable global statistics of lightning properties.

TABLE 1. Flash properties for a subset of 3 thunderstorm days in Tucson, AZ.

Day	# of flashes	% of single strokes	Multiplicity (AM)	Interstroke Interval (GM)	Flash Duration (GM)
10/08	49	18	4.3	61 ms	206 ms
13/08	36	28	4.1	54 ms	197 ms
15/08	23	13	3.5	57 ms	232 ms

4. CONCLUSIONS

In this work, we have analyzed the characteristics of negative CG lightning that occurred in Tucson, AZ, during the summer of 2007. According to Rakov and Huffines (2003) the multiplicity and percentage of single stroke flashes are sensitive to the stroke identification process. This is one of the reasons why we compared the characteristics from the campaign in Arizona, USA with São Paulo, Brazil. In both locations, with different hemispheres and latitudes, the same technique was used. The comparison showed that most of the characteristics are similar in both locations.

Some of the characteristics shown here were also measured by Biagi et al. (2007) in Tucson, and they obtained a flash multiplicity of 3.7, a value similar to our results. On the other hand, Valine and Krider (2002) obtained a flash multiplicity of 2.8. The Valine and Krider study was based on standard video (30 fps) observations, whereas Biagi et al. de-interlaced the frames to obtain 60 fields-per-second resolution, and this produced a 2-year average video-based multiplicity of 3.34. The higher multiplicity obtained by Biagi et al (2007) is partially due to the use of a correction factor (11%) based on simultaneous electric field measurements during one storm.

Both the present study and the work of Biagi et al. found great variability in the properties of CG lightning from storm-to-storm in the Tucson area. Future analyses will try to determine if the small sample size of each storm maybe the sole cause for such high variability, or if there are important difference from storm to storm. It is interesting to note that the average video multiplicity measured by Biagi et al. in 2003 (3.52 for 448 flashes) and in 2004 (3.16 426 flashes) differed by more than 10%.

The parametric curves that fit the maximum and minimum flash duration values indicate that there should be a maximum multiplicity for negative CG flashes. We still need more observations of flashes with multiplicity above 10 to increase the precision of these fits and confirm that the maximum multiplicity is 19. These fits also show that some multiplicity values can occur with a wider range of flash durations. The multiplicity value associated with the widest range of flash durations is 4, which is the mean multiplicity observed in this and other work.

5. REFERENCES

Biagi, C. J.; Cummins, K. L.; Kehoe, K. E.; Krider, E. P., National Lightning Detection Network (NLDN) performance in southern Arizona, Texas, and Oklahoma in 2003-2004. *Journal of Geophysical Research,* Volume **112**, Issue D5, 2007.

Ballaroti, M. G.; Saba, M. M. F.; Pinto Jr., O. High Speed Camera Observations of Negative

Ground Flashes on a Millisecond-Scale. *Geophysical Research Letters*, vol. **32**, 2005.

Heckman, S. Why does a lightning flash have multiple strokes? PhD Thesis Department of Earth, Atmospheric and Planetary Sciences, Massachusetts Institute of Technology. 1992.

Mazur, V., Krehbiel, P. R., Shao, X.-M. Correlated High-speed Video and Interferometric Observations of a Cloud-to-ground Flash, *J. Geophys. Res.,* **100***,* 25,731-25,753, 1995.

Mazur, V., Shao, X.-M., and Krehbiel, P. R., Spider lightning in intracloud and positive cloud-to-ground flashes, *J. Geophys. Res.,* **103***,* 19,811-19,822, 1998.

Rakov, V. A.; Huffines, G. R. Return-Stroke Multiplicity of Negative Cloud-to-Groud Lightning Flashes. *Journal of Applied Meteorology*, Vol. **42**, Issue 10, pp.1455-1462 Oct. 2003.

Saba, M. M. F., Ballarotti, M. G., Pinto Jr., O. Negative cloud-to-ground lightning properties from high-speed video observations. *Journal of Geophysical Research,* Volume **111**, 2006 (a).

Saba, M. M. F., Pinto JR., O., Ballarotti, M. G. Relation between lightning return stroke peak current and following continuing current. *Geophysical Research Letters,* Volume **33**, Issue 23, 2006 (b).

Saba, M. M. F.; Ballarotti, M. G.; Pinto Jr., O.; Miranda, F. J.; Naccarato, K. P. Simultaneous electric field and high-speed video observations of lightning, in *Proceedings of the Ground'2004 International Conference on Grounding and Earthing & First International Conference on Lightning Physics and Effects,* pp. 38-42, Belo Horizonte, Brazil, 7-11 November, 2004.

Saba, M. M. F.; Cummins K. L.; Warner, T.; Krider, E. P.; Campos, L. Z. S., Ballarotti, M. G.; Fleenor S. A.; Pinto JR., O. Positive Leader Characteristics from High-Speed Video Observations. **In press**, *Geophysical Research Letters*, Jan. 2008.

Valine, W. C.; Krider, E. P. Statistics and characteristics of cloud-to-ground lightning with multiple ground contacts. *Journal of Geophysical Research (Atmospheres)*, Volume **107**, Issue D20, pp. AAC 8-1, 2002.