

A comparative study of negative cloud-to-ground lightning characteristics in São Paulo (Brazil) and Arizona (United States) based on high-speed video observations

A. C. V. Saraiva,¹ M. M. F. Saba,¹ O. Pinto Jr.,¹ K. L. Cummins,² E. P. Krider,² and L. Z. S. Campos¹

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[1] There are only a few prior reports that detail accurate measurements of the number of strokes in natural negative cloud-to-ground (CG) lightning flashes. These are known as “accurate-stroke-count” studies, and they have been performed using various instruments and techniques. Here, we will examine the lightning characteristics produced by warm-season thunderstorms in two different climate regimes (southern Arizona, United States, and São Paulo, Brazil) using the same instrumentation. The lightning parameters were obtained from high-speed video recordings and time-correlated data provided by lightning locating systems (LLS). The use of these instruments has allowed us to measure the number of strokes in each flash and their polarity, the interstroke intervals, the number of different ground contacts, and the durations of the continuing currents. Altogether 209 negative flashes were recorded on video in the United States and 223 in Brazil (containing a total of 1681 strokes), and the majority of these flashes had at least one stroke reported by a LLS. Statistical analyses of these data sets as a whole did not show any significant differences in the characteristics of negative CG flashes from warm-season thunderstorms in both locations. The mean values for all data are as follows: video multiplicity, 3.9; single-stroke flashes, 19.5%; flash duration, 226.5 ms; interstroke interval, 61.5 ms; long continuing current, 17.5%; multigrounded flashes, 49.5%. Those characteristics were very similar to the well-accepted values for negative flashes in other regions. However, there were large storm-to-storm variations.

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1. Introduction

[2] Lightning has been the object of many studies since the end of the nineteenth century, beginning with recordings using still cameras [Hoffert, 1888], followed by the use of time-resolved photography, instrumented towers, video cameras, lightning locating and mapping systems, triggered lightning facilities, and, more recently, satellite optical sensors. Lightning characteristics based on these techniques have been published by many authors [e.g., Rakov *et al.*, 1994; Diendorfer *et al.*, 1998, 2002; Valine and Krider, 2002; Pinto *et al.*, 2003; Rakov and Huffines, 2003; Schulz *et al.*, 2005; Hussein *et al.*, 2006; Miki *et al.*, 2006; Pinto *et al.*, 2006; Biagi *et al.*, 2007; Pinto *et al.*, 2007; Flache *et al.*, 2008; Pinto *et al.*, 2009]. Recently, high-speed video cameras have added much to our understanding of

natural downward lightning physics [e.g., Ballarotti *et al.*, 2006; Kong *et al.*, 2008; Saba *et al.*, 2008; Campos and Saba, 2009; Saba *et al.*, 2009]. Observations with high-speed cameras were initially made on isolated events [e.g., Mazur *et al.*, 1995, 1998], and more recently they have been used to determine the characteristics of cloud-to-ground (CG) flashes for a larger numbers of events [Saba *et al.*, 2006a, 2006b; Campos *et al.*, 2007; Lu *et al.*, 2007; Saraiva *et al.*, 2008; Campos *et al.*, 2009; Ferro *et al.*, 2009].

[3] It has been found that different observation techniques will result in different lightning parameters, especially if those techniques are sensitive to the stroke identification process [Rakov and Huffines, 2003]. For example, Rakov and Huffines [2003] and Biagi *et al.* [2007] have compared video recordings and electric field measurements with data from the U.S. National Lightning Detection Network (NLDN), and they found large differences in the fraction of single-stroke flashes and the number of strokes per flash. Saba *et al.* [2006a] have used a high-speed camera to record 233 negative CG flashes, and the results were compared with the so-called “accurate stroke count studies” [Rakov and Huffines, 2003]. When comparing the results, similarities

¹National Institute for Space Research (INPE), São Jose dos Campos, São Paulo, Brazil.

²Institute of Atmospheric Physics, University of Arizona, Tucson, Arizona, USA.

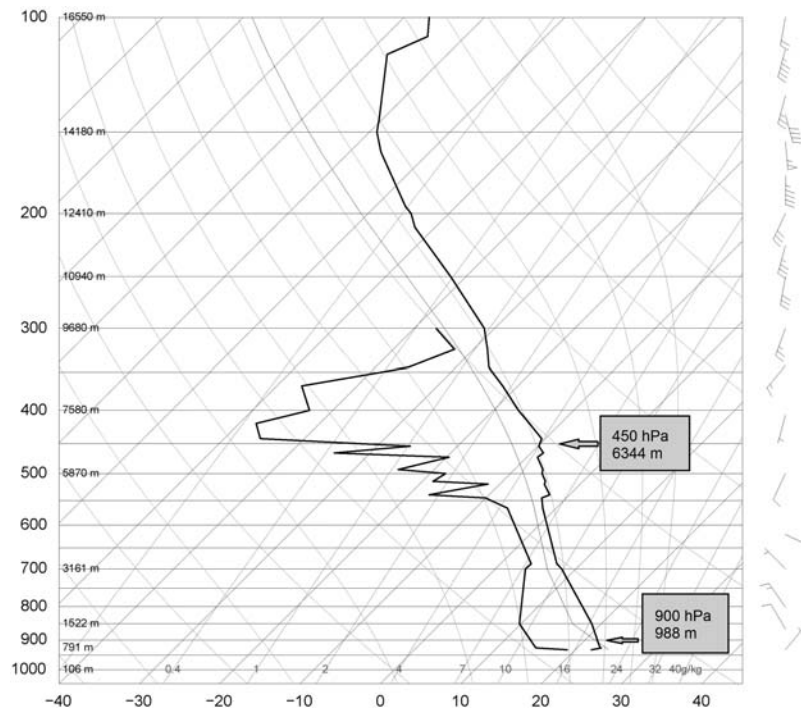


Figure 1. Skew T – log P diagram in São Paulo at 1200 UT on 7 March 2003. The height of cloud base (988 m) and the altitude of -15°C (6344 m) are marked on the image.

were found in some of the lightning characteristics, but there were still differences, which could be due either to different instrumentation or to real differences in the lightning from place to place. Rakov *et al.* [1994] compared various lightning parameters, based on accurate stroke count studies, in New Mexico and Florida and found them to be very similar.

[4] It remains unclear whether climate variations between regions are responsible for the observed regional differences in lightning parameters, or whether differences in the measurement methods are the primary source of the observed differences. In an effort to clarify this issue and minimize the effects of instrumentation, two observation campaigns were conducted on warm-season thunderstorms using the same instrumentation in distinct geographic regions: São José dos Campos (23.212°S , 45.867°W) and Cachoeira Paulista (22.686°S , 44.984°W), in São Paulo, Brazil, and in Tucson ($32^{\circ}13'47.64''\text{N}$, $110^{\circ}57'14.22''\text{W}$), Arizona, United States.

[5] Here, we will give statistics on the characteristics of negative CG flashes recorded in Arizona and in São Paulo, based on data obtained from high-speed cameras and lightning location systems, with the eventual goal of measuring the effects of differences in climate on the characteristics of lightning. We will also compare our results with previous studies in Arizona [Valine and Krider, 2002; Biagi *et al.*, 2007] that used different instrumentation.

2. Climate Regimes

[6] Both regions have substantially different geographic latitudes and climates. According to Köppen-Geiger climate classification [Kottek *et al.*, 2006], Arizona is classified as desert climate (Bwh), with low humidity and small precip-

itable water content (between 300 and 800 mm). On the other side, São Paulo is classified as humid subtropical climate (Cfa) which is characterized by hot, humid summers and cool winters, with significant amounts of precipitation occurring in all seasons. The heights of the cloud bases and of the -15°C isotherms are generally different, and therefore the altitudes where the negative charge centers are produced and where the leaders are initiated are likely to be different as well. The skew T – log P diagrams in Figures 1 and 2 show temperature soundings on typical warm-season thunderstorm days in São Paulo and Tucson, respectively. It can be seen that the typical cloud bases in Tucson are almost 4 times higher than in São Paulo (~ 3700 m in Tucson and ~ 1000 m in São Paulo), and the altitudes of the -15°C levels (~ 7000 m in Tucson and ~ 6000 m in São Paulo) are different as well. This means that it is possible that the overall charge structure of the clouds in these regions may be different, but it is not clear if these differences will affect the basic lightning parameters such as the multiplicity of strokes, the presence and duration of any continuing luminosity (or current), the number of different ground contacts, etc.

[7] The meteorological conditions that produce lightning in each region are also different. Tucson is located in southern Arizona, in the northern portion of the so-called “North American monsoon” [Pytlak *et al.*, 2008]. This phenomenon starts in mid-June and gets weaker in September, and thunderstorms are associated with heating and orographic interactions with local mountainous terrain. Cloud top temperatures are occasionally colder than -70°C , and there is often abundant lightning [NWSF, 2006].

[8] In southeastern Brazil, most thunderstorms occur during the warm season between November and March

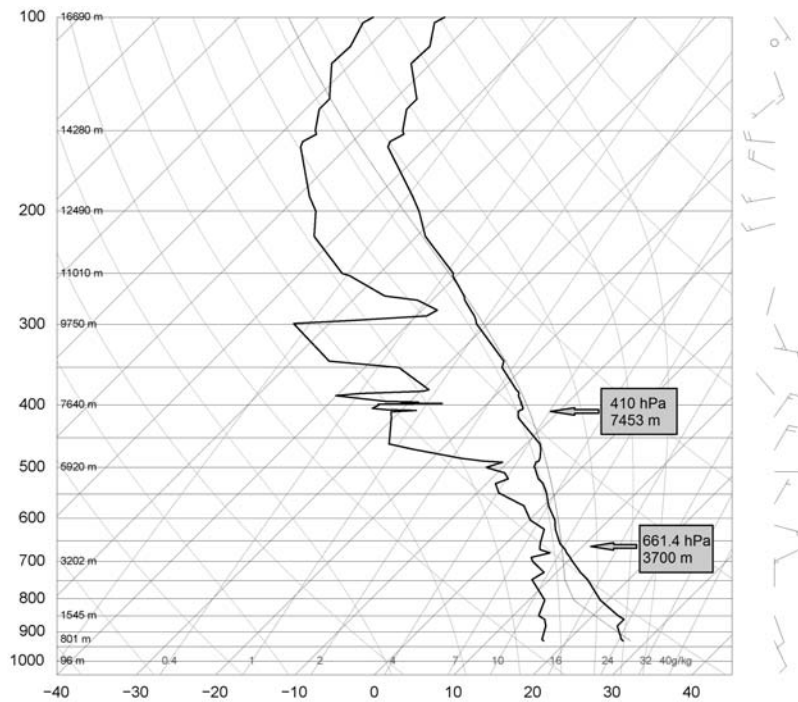


Figure 2. Skew T – log P diagram in Tucson, Arizona, at 1200 UT on 10 August 2007. A comparison with 1 shows that there is a more prominent difference in the height of the cloud base than in the height of the -15°C isotherm.

and are produced by local convection and the passage of cold fronts [e.g., *Nascimento*, 2005]. The observation regions for these studies are indicated by the red stars in Figures 3 and 4.

3. Instrumentation

[9] The data for this study were acquired during the summers of 2003 and 2004 in São Paulo, and during the summer of 2007 (July–August) in Arizona. The same camera was used in both campaigns, but in Arizona, an additional high-speed camera was added in order to record some lightning flashes from different angles. To ensure that

no bias was introduced by the addition of the extra camera, we analyzed 35 flashes (out of 209) that were recorded by both cameras from the same viewing direction. The analysis of these videos did not show any fundamental differences in the luminous characteristics that were recorded by both cameras. The use of a high-speed camera with a time resolution of 1 ms (or less) between frames minimized the likelihood of missing subsequent strokes that occurred at very short interstroke intervals. Occasionally, a strong M-component that occurred during a continuing luminosity may have been misclassified as a subsequent stroke if that luminosity was blocked by heavy rain [*Saba et al.*, 2006a].

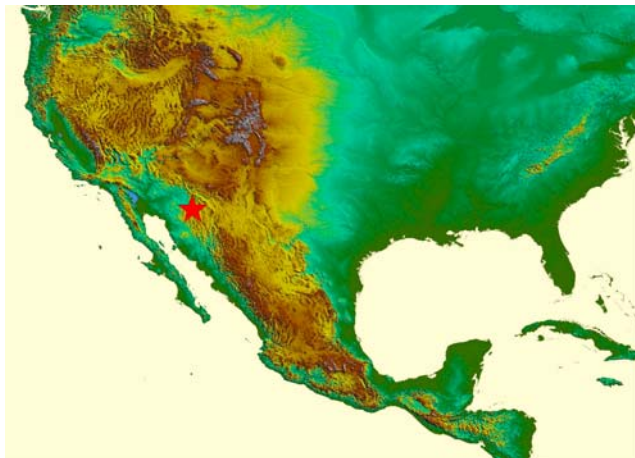


Figure 3. The location of the observation site in Arizona, United States.

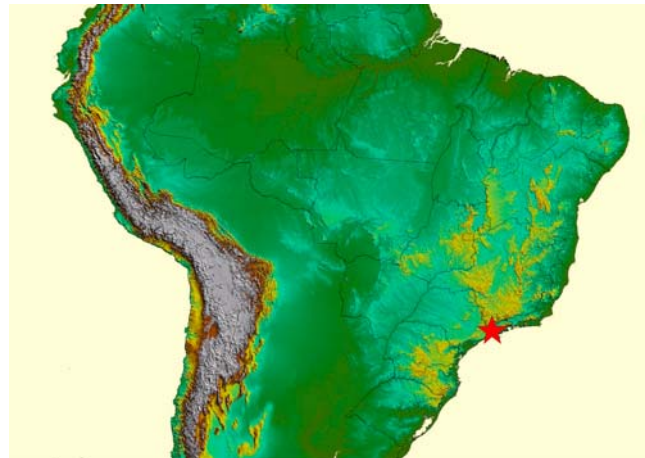


Figure 4. The location of the observation site in São Paulo, Brazil.

Table 1. Comparison of Lightning Characteristics Over Tucson, Arizona, and São José dos Campos, São Paulo, Brazil^a

	Arizona, United States, AM/GM (SD/GSD)	Sample Size	São Paulo, Brazil, AM/GM (SD/GSD)	Sample Size
Flash multiplicity (AM)	3.9 (0.2)	209	3.9 (0.2)	223
Single-stroke flashes	19%	40	20%	44
Interstroke interval (GM)	61.4 (1.03) ms	598	61.6 (1.03) ms	624
Flash duration (GM) ^b	216 (1.1) ms	169	229 (1.1) ms	179
Continuing current (CC)	7% long CC	28/400	6.5% long CC	34/523
Percent of multigrounded flashes	48%	99/206	51%	70/138
First stroke peak current ^c	−22.3 (0.8) kA	146	−26.3 (1.5) kA	132

^aNumbers in parentheses indicate the sample size for each measurement. AM, arithmetic mean; SD, standard deviation of the mean; GM, geometric mean level; GSD, geometric standard deviation of the mean.

^bTo compute the mean value of the flash durations, only multiple stroke flashes were used.

^cThis value of estimated peak current is the trimmed mean of each flashes first stroke peak current. All values considered were above 12 kA, as the addition of lower peak currents are more influenced by instrumental factors between NLDN and BrasilDAT.

[10] The camera used in both locations was a Redlake MotionScope 8000S. This camera is capable of recording videos at frame rates ranging from 60 frames per second (fps) to 8000 fps. During the campaigns, the camera was set up to operate at 1000 fps with an image resolution of 240×210 pixels. The second camera, used only in United States, was a Photron Fastcam 512 PCI. It was set to run at 4000 fps with image resolution of 512×256 pixels; some flashes were also observed at 8000 fps (image resolution of 512×128 pixels). All video recordings had a total duration of 2 s, including the pretrigger time.

[11] The video frames of both high-speed cameras were GPS time-stamped with an accuracy that was better than 1 ms. This synchronization allowed a comparison of each stroke with data from a lightning locating systems (LLS). The detection efficiency (DE) of the U.S. National Lightning Detection Network (NLDN) on negative CG flashes is about 93% and about 68% on all strokes [Biagi *et al.*, 2007]. The BrasilDAT (Brazilian Lightning Location Network) uses sensors that are similar to the NLDN and has a DE on negative CG flashes of 87% and 57% on strokes near the observation sites [Ballarotti *et al.*, 2006; Pinto *et al.*, 2007]. Both of these networks report the time, location, polarity, and estimated peak current of each located stroke, as well as supplementary quality parameters. They also group CG strokes into flashes and provide an estimate of the multiplicity of strokes in each flash. For additional details about LLS parameters and their accuracy, see Cummins and Murphy [2009].

[12] More details about the observations made in São Paulo during the summer of 2003–2004 are given by Saba *et al.* [2006a], and more information about the campaign in Arizona is given by Saraiva *et al.* [2008] and Cummins *et al.* [2008].

4. Analysis and Results

[13] The total number of CG flashes that were analyzed in this study was 432; 223 in São Paulo (27 thunderstorms), and 209 in Arizona (16 thunderstorms). The polarity of almost all flashes was provided by the LLS, and we analyzed only negative flashes that had at least one stroke reported by the LLS. (This method may lead to misclassification of multiple-stroke bipolar CG flashes, but the percentage of errors was estimated as around 2–3%.)

[14] Single-stroke flashes that were recorded on video but not reported by an LLS, and therefore did not have their polarities identified (nine flashes), were visually analyzed and were regarded as negative if the luminous characteristics (branching) of their leaders were similar to the commonly reported characteristics of negative CG flashes [Rakov and Uman, 2003]. All flashes considered in this study occurred within a radius of about 50 km from the observation site, and this selection criterion tended to avoid the misclassification of M-components as return strokes.

[15] Section 4.1 will compare the multiplicities of strokes, the interstroke time intervals, the flash durations, the number of ground contacts, and the presence and duration of continuing luminosity (current) in Arizona and São Paulo. Table 1 summarizes the information about the lightning parameters in each region and the percentage of flashes with long continuing currents (CC > 40 ms).

4.1. Video Multiplicity

[16] The total number of negative CG strokes recorded on video was 1681; 84 (19.5%) of the 432 flashes were single-stroke, and the average multiplicity was 3.9. It should be noted that the percentage of single-stroke flashes did not vary appreciably between regions.

[17] Figure 5 shows the distributions of the numbers of strokes per flash that were recorded on video in Arizona and São Paulo. Note that the percentage of flashes with a given number of strokes is very similar in both regions. Figure 5 also shows that the most probable value of the multiplicity was 2 in both locations.

4.2. Flash Duration

[18] The flash duration is defined here as the time between the appearance of the first stroke and the end of the luminosity of the last subsequent stroke, or the end of the continuing luminosity (if present). The duration of single-stroke flashes was not computed. The geometric mean (GM) duration of the 169 multiple-stroke flashes in Tucson was 216 ms, and the GM of the 179 multiple-stroke flashes in São Paulo was 229 ms. Figure 6 shows the distributions of the flash durations in São Paulo and Arizona separately. No significant differences were found between the two campaigns. A maximum value of 1.4 s was found in Brazil, but the majority of the durations (~99%) were less than 1 s.

[19] Figure 7 shows a scatterplot of the flash duration versus the measured multiplicity in Arizona and São Paulo,

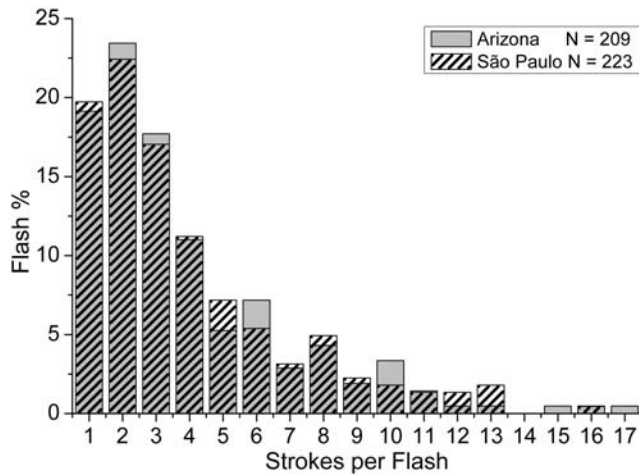


Figure 5. Percentage of flashes versus the number of strokes per flash (or multiplicity) measured on video in Arizona and São Paulo.

and it should be noted that the pattern is similar in both locations. The flash duration tends to increase with the multiplicity, until it saturates at about 1.0 s, and at the larger multiplicities, there is a minimum in the total flash duration. Following *Saba et al.* [2006a], there are two possible reasons for the latter behavior: (1) There is a minimum time required for the channel from the previous stroke to decay to the point where it can no longer support the propagation of a dart leader prior to the next stroke [see, e.g., *Uman and Vosshall*, 1968], and (2) there is a limit to the maximum rate at which cloud charge can be supplied to sustain a subsequent stroke. Both hypotheses complement each other and may explain why the flash duration appears to have a lower limit for a given multiplicity. A linear fit to the minimum duration on combined has a correlation coefficient of 0.93, and the slope is 63 ms.

[20] Figure 7 also shows an exponential fit (solid line) to the maximum durations that intercepts the linear fit (dashed line) at a duration of about 1 s and a multiplicity of 19 strokes per flash. These values can be viewed as upper limits

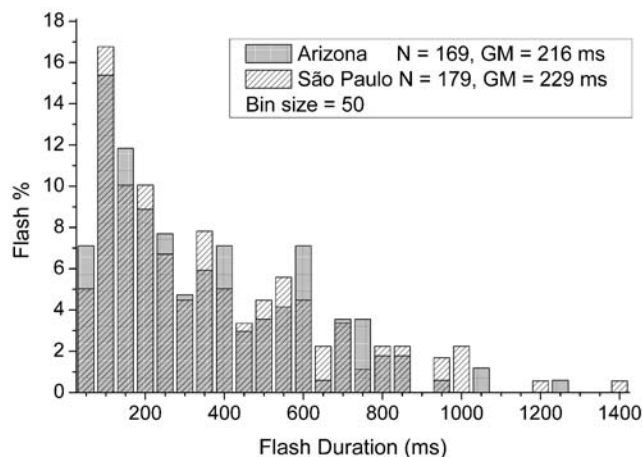


Figure 6. Percentage of flashes versus flash duration in Arizona and São Paulo.

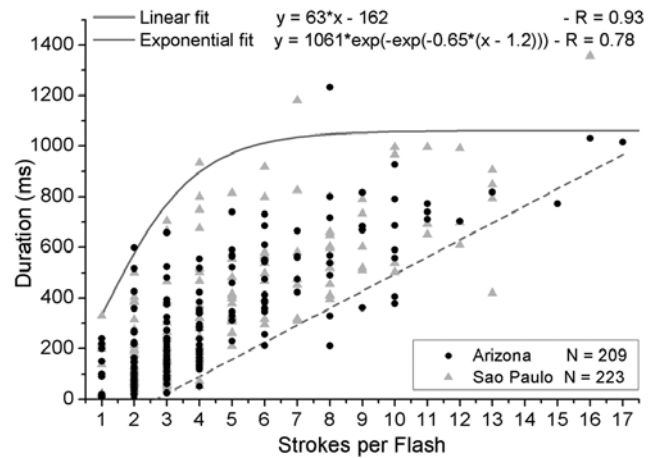


Figure 7. Scatterplot showing the relation between the total flash duration and the number of strokes per flash. The black circles are data from Arizona, and the gray triangles are from São Paulo.

for most -CG flashes. In fact, only 1% of the negative CG flashes had a duration greater than 1 s, and none had a multiplicity greater than 18 in both geographic regions. The only study in the literature that has found a multiplicity higher than 18 is the one by *Kitagawa et al.* [1962], and those authors found higher multiplicities (ranging from 18 to 26) in 3% of 99 documented lightning flashes.

[21] The mechanism behind the apparent “maximum duration” in Figure 7 remains to be investigated. One possible explanation could be that as leaders inside the cloud progressively collect more charge for the subsequent strokes, the length of the total channel gets longer, and because longer channels become unstable, the chances of additional strokes are reduced [*Heckman*, 1992].

4.3. Interstroke Interval

[22] Measurements of 1222 interstroke intervals ranged from hundreds of microseconds to 782 ms. The very short intervals (<1 ms) were associated with forked channel development and multiple ground terminations [*Ballarotti et al.*, 2005], and extremely long intervals were associated with long CCs [*Saba et al.*, 2006a]. The geometric mean interval was 61.5 ms, and this was essentially the same in both locations (see Table 1) and very similar to GM = 60 ms reported for Florida and New Mexico [*Rakov and Uman*, 2003, Figure 4.4]. Figure 8 shows the distributions of interstroke intervals in both Arizona and São Paulo, and it should be noted that both distributions have almost the same lognormal shape with values that are almost the same as those found by *Schulz et al.* [2005] in Austria (GM = 60 ms) for a 10-year study based on data obtained by the Austrian Lightning Detection and Information System (ALDIS).

[23] Two hundred thirty-three (19%) out of the 1222 interstroke intervals in Figure 8 were less than 33 ms, the resolving time of a standard video camera, but considering the percentage of strokes that create a new path to ground, approximately 15% of the total number of strokes would have been missed in standard (30 fps) video recordings,

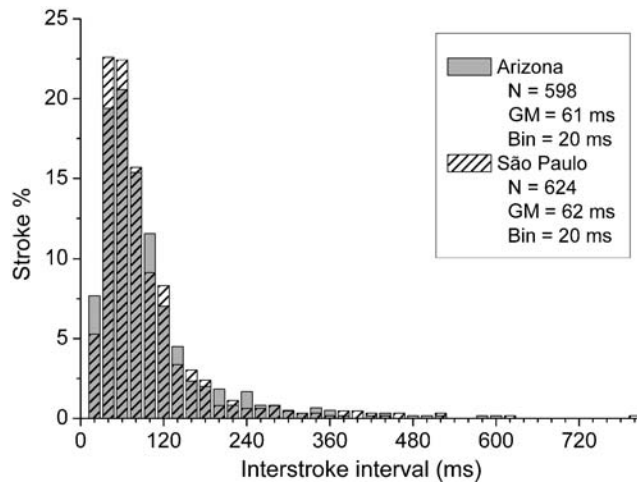


Figure 8. Distributions of interstroke intervals in Arizona and São Paulo.

even using deinterlaced fields of frames (60 fps) [e.g., Thomson *et al.*, 1984; Saba *et al.*, 2006a; Biagi *et al.*, 2007].

4.4. Continuing Current

[24] The duration of the continuing current (CC) can be inferred from the duration of the continuing luminosity in the channel following the return stroke. The CC can last from a few to hundreds of milliseconds, and it can be classified as long (duration greater than 40 ms) [Brook *et al.*, 1962; Kitagawa *et al.*, 1962], short (between 10 and 40 ms) [Shindo and Uman, 1989], and very short (between 4 and 10 ms) [Ballarotti *et al.*, 2005]. Because our measurements of CC are based on the luminosity of the channels in video recordings, the durations may be underestimated at large observation distances or in the presence of rain, or overestimated if there is any residual ionization in the channel after the current ceases.

[25] Figure 9 shows distributions of the very short and short CCs for strokes in Arizona and São Paulo, and Figure 10 shows distributions of the long CCs, which are about 7% of the total data set (see Table 1). The data

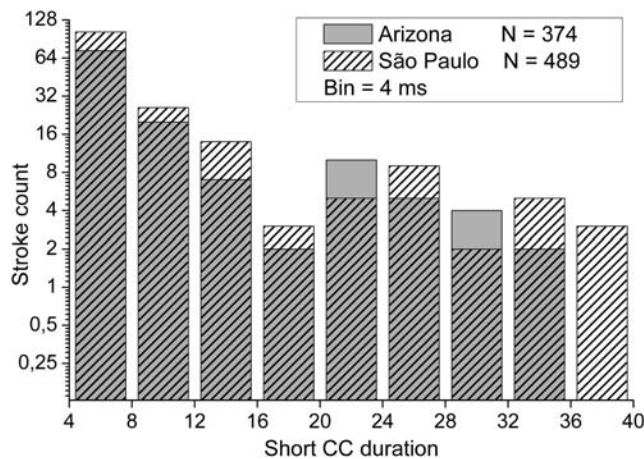


Figure 9. Distribution of continuing (CC) durations below 40 ms in Arizona and Brazil.

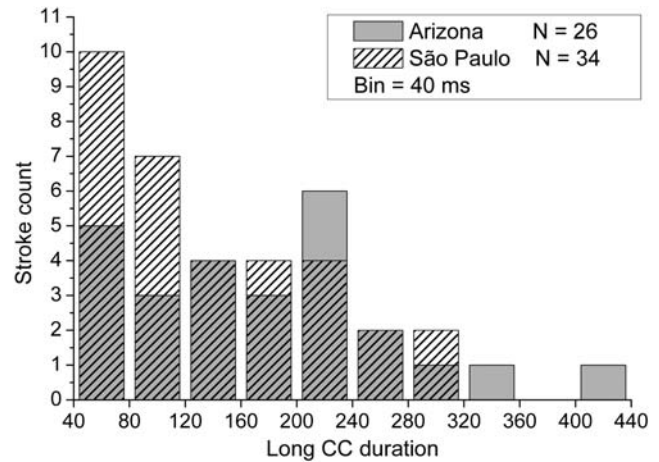


Figure 10. Distribution of long continuing currents in Arizona and São Paulo.

selected for this case are all recorded strokes with visible channel, where it is possible to identify the presence, or not, of the CC. Note that most of the CCs are between 4 and 16 ms (mostly very short) in both locations, and that there are some differences in the short and long CCs in Arizona and São Paulo, probably due to the small sample sizes in this range. The percentage for long CC for flashes is 34% in São Paulo and 27% in Arizona.

[26] Analyzing only the first stroke peak current, the estimated mean for the negative recorded flashes by the LLS in Brazil is 26 kA and in Arizona is 22 kA (as shown in Table 1), the small difference between these values is hard to explain, but probably they are more affected by the configuration and calibration of the sensors than a physical effect. Figure 11 shows a scatterplot of the estimated peak current of all strokes (observed by the LLS and camera) versus the duration of the CC that followed it. Note that this scatterplot shows a so-called “exclusion zone,” as discussed by Saba *et al.* [2006b], in both geographic regions. That is, negative strokes that produce estimated peak currents greater than 20 kA are never followed by a CC longer than

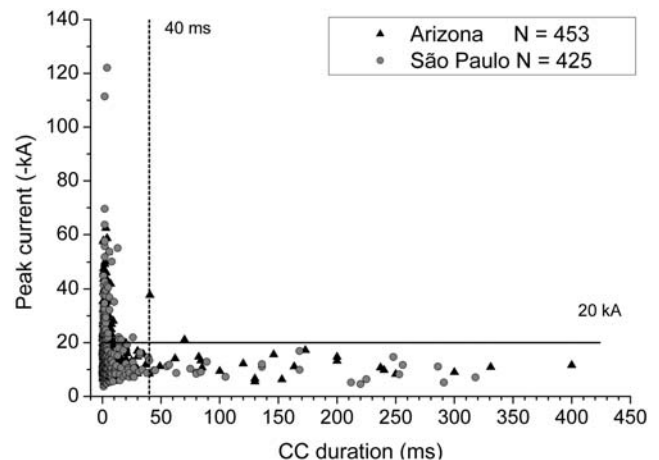


Figure 11. Peak current versus duration of CC for 878 strokes in São Paulo, Brazil, and in Arizona, United States.

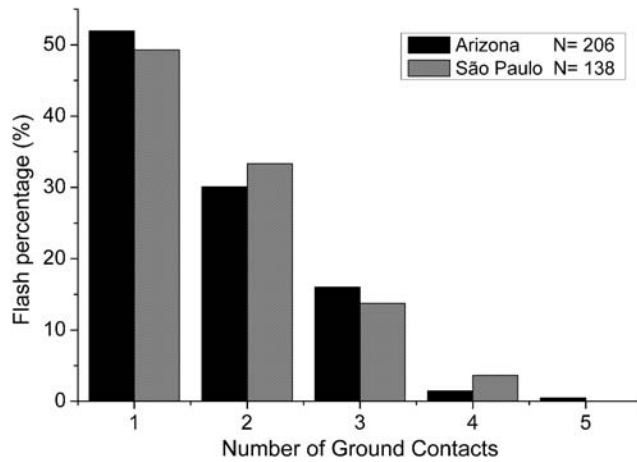


Figure 12. Percentage of flashes that produced a given number of ground contacts in Arizona and São Paulo. In Arizona, one flash was observed to have five ground contacts, although the maximum value reported in the literature is currently seven [Rakov and Uman, 2003].

40 ms, while negative strokes that produce peak currents less than 20 kA can be followed any duration of CC. Sixty-nine percent of the strokes with estimated peak currents less than 20 kA were followed by short or very short CC, as illustrated in Figure 11.

4.5. Multiple Ground Contacts

[27] Approximately half (49%) of all 344 flashes in our data set produced more than one ground termination (see Table 1). Figure 12 shows that there was good agreement between the distributions of the number of ground contacts per flash in Arizona and São Paulo. The average number of ground contacts per flash was about 1.7 in both locations, same as in both Florida and New Mexico [Rakov *et al.*, 1994]. Note that no flash exceeded five ground contacts in our data set, and that flashes with more than three ground contacts occurred only rarely (only 2.6% of the cases).

4.6. Variations Between Storms

[28] A sample of six thunderstorms, three in Arizona and three in Brazil, was used to compare the means of several of the flash parameters listed in Table 2. These days were chosen because they were large samples that contained comparable numbers of data points. Although there are only six storms in Table 2, it is clear that there is a large variability in some of the flash characteristics and low variability in others. Given the small number of observations

and large standard deviations (relative to the means) in Table 2, it is difficult to say that there are significant differences among these storm samples. A few parameters may indicate different underlying distributions, such as 12 February 2004, which exhibit a mean multiplicity that is more likely to be different from other days, or 7 November 2004, when the interstroke interval is also different, or 16 August 2007, and 30 March 2004, whose mean flash duration are way below the value for the other days.

[29] During July 2007, a persistent tropical air mass caused anomalous thunderstorms in Tucson that contained unusually high values of precipitable water and that produced a high percentage of positive CG flashes and intracloud discharges [Pytlak *et al.*, 2008]. Therefore storms from this period have not been included in the cases shown in Table 2.

[30] Table 2 reinforces the idea that in order to make a reliable inference of the climatology of lightning in a given region, a large number of different storms need to be analyzed in that region. It also suggests that another way to characterize any variations in lightning parameters would be to group meteorologically similar thunderstorms together regardless of the geographic region where they occur. A more detailed assessment of just how the characteristics of CG lightning vary from storm-to-storm will be the subject of a future study.

5. Discussion and Conclusions

[31] In order to evaluate the effects of different climate regimes on the average parameters of negative CG lightning, measurement campaigns were conducted in São Paulo, Brazil, and southern Arizona using essentially the same instrumentation in both locations. We found that none of the characteristics that were measured during warm-season thunderstorms differed appreciably between these two locations, when averaged over a large number of storm cases.

[32] Some flash characteristics shown here were measured by Rakov and Huffines [2003] in Florida, and the authors compared their results with similar work by N. Kitagawa in New Mexico, and found out similarities between both locations. Those same flash characteristics were also measured by Biagi *et al.* [2007] and Valine and Krider [2002] in Arizona, who reported average flash multiplicities of 3.7 and 2.8, respectively. Valine and Krider [2002] used a standard video camera (30 fps) for their measurements, whereas Biagi *et al.* [2007] deinterlaced their video frames to obtain 60 fields-per-second resolution and then applied a correction factor (of 11% based on a single storm) to correct for their limited time resolution. We assume that the different values of multiplicity obtained in these earlier

Table 2. Flash Characteristics in a Subset of Six Thunderstorms in São Paulo and Arizona

Day	Location	Number of Flashes	Percentage of Single Strokes	Multiplicity AM (SD)	Interstroke Interval GM (GSD)	Flash Duration GM (GSD)
7 Nov 2004	São Paulo, Brazil	24	33	3.2 (0.58)	76 (1.1) ms	262 (1.2) ms
12 Feb 2004	São Paulo, Brazil	30	10	4.8 (0.73)	58 (1.1) ms	296 (1.2) ms
30 Mar 2004	São Paulo, Brazil	43	9	3.7 (0.32)	55 (1.1) ms	171 (1.1) ms
10 Aug 2007	Arizona, United States	23	13	3.6 (0.72)	55 (1.1) ms	205 (1.2) ms
15 Aug 2007	Arizona, United States	49	25	4.3 (0.5)	59 (1.1) ms	260 (1.2) ms
16 Aug 2007	Arizona, United States	21	0	4 (0.54)	56 (1.1) ms	164 (1.3) ms

Arizona studies compared with the values obtained here were caused by different instrumentation and/or by the limited number of thunderstorms that were analyzed.

[33] The parametric curves that show the maximum and minimum flash duration as a function of multiplicity indicate that there is likely to be a maximum multiplicity for negative CG flashes. More observations of flashes that have a multiplicity greater than 10 are needed to increase the precision of these fits and to confirm that the maximum multiplicity is around 19. These curves also show that some multiplicity values can occur within a wide range of flash durations. The multiplicity that is associated with the widest range of flash durations is 4, which is the mean multiplicity observed in this and the other studies of warm-season storms [Rakov and Uman, 1990; Cooray and Jayaratne, 1994; Cooray and Pérez, 1994; Rakov et al., 1994; Saba et al., 2006a].

[34] The distributions of CC durations in Arizona and São Paulo are very nearly the same, and the relationship between the duration of CC and the estimated peak current of the preceding stroke follows the same pattern established by Saba et al. [2006b] for negative flashes.

[35] We also found that about 50% of the negative CG flashes produced more than one ground termination in Arizona and São Paulo, and the distributions of the number of ground terminations per flash were similar, with means of about 1.7 in both locations. Within our sample of 344 flashes, we found that only 2.6% produced more than three ground contacts. Very similar findings were reported by Rakov et al. [1994] in Florida (50%) and Kitagawa et al. [1962] in New Mexico (49% for multiple stroke flashes only).

[36] Both this study and that of Biagi et al. [2007] found large variations in the characteristics of negative CG lightning from storm to storm; therefore more work is planned to determine which parameters are the most variable and which are not, and the reasons why. A future paper based on high-speed camera measurements and LLS data will examine the effect of different meteorological conditions on the lightning parameters in São Paulo (Brazil) and Arizona (United States).

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L. Z. S. Campos, O. Pinto Jr., M. M. F. Saba, and A. C. V. Saraiva, National Institute for Space Research (INPE), PO Box 515, Av. dos Astronautas, 1758 São José dos Campos, São Paulo, 12201-970, Brazil. (acvsaraiva@gmail.com)

K. L. Cummins and E. P. Krider, Institute of Atmospheric Physics, University of Arizona, Tucson, AZ 85721-0081, USA.