HIGH-SPEED VIDEO OBSERVATIONS OF POSITIVE LIGHTNING FLASHES

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ABSTRACT

Although positive lightning flashes to ground are not as frequent as negative flashes, their large amplitudes and destructive characteristics make understanding their parameters an important issue. This study summarizes the characteristics of 103 positive cloud-to-ground (+CG) flashes that have been recorded using high-speed video cameras (up to 8000 frames per second) in three countries together with time-correlated data provided by lightning location systems (LLS). A large fraction of the +CG flashes (81%) produced just a single-stroke, and the average multiplicity was 1.2 strokes per flash. All the subsequent strokes in multiple-stroke +CG flashes created a new ground termination except one. 75% of the +CG flashes contained at least one long continuing current (LCC) ≥ 40 ms, and this percentage is significantly larger than in the negative flashes that produce LCCs (approximately 30%). The median estimated peak current, (I_p) for 116 positive strokes that created new ground terminations was 39.4 kA. Positive strokes with a large I_p were usually followed by a LCC, and both of these parameters are threats in lightning protection. The characteristics presented here include the multiplicities of strokes and ground contacts, the percentage of single-stroke flashes, the durations of the continuing current, and the distributions of I_p.

1 INTRODUCTION

The highest directly measured lightning currents and the largest charge transfers to ground are produced by positive lightning [1]. Positive flashes are also a major concern for lightning detection and locating systems because their complex waveforms are sometimes rejected.

The first comprehensive statistical data about positive cloud-to-ground (CG) flashes were given by Berger et. [1] who measured the currents in 26 positive CG flashes that struck a tall tower in Lugano (Switzerland). Although more then 30 years have passed since those measurements were conducted (and during this time the measurement techniques have improved significantly), and Berger himself was not sure about whether those flashes were initiated by upward or downward leaders [2], these data are still the basis for all lightning protection standards relating to positive lightning.

Recently, Fleenor et al. [3] have used standard video recordings (60 frames per second), E-fields, and NLDN data to determine to average multiplicity (1.04) of 204 positive flashes in the Central Great Plains (U.S.A.). They also reported the interstroke intervals for nine multistroke flashes that had a mean of 50ms. These authors were the first to document clear evidence of positive subsequent strokes following the same channel as the first stroke.

The development of high-speed CCD video cameras has allowed lightning flashes to be recorded with very high time-resolution [4-6]. With these cameras, almost all of the subsequent strokes that remain in the same channel can be resolved, and the detailed development of leader channels, branches and other processes recorded with relative ease.

Saba et al. [4] have shown that +CG flashes can be initiated by intracloud leaders of either polarity, a behavior which may help us understand why extensive intracloud discharges commonly precede positive CG flashes. Campos et al. [5] and Campos and Saba [6] have given the parameters of M-components and statistics on the continuing current waveshapes in +CG flashes and how these parameters may contribute to the production of transient luminous events by +CG flashes.

Although positive lightning has started to receive more attention in recent years, our knowledge about the physics of positive discharges is not as good as that for negative lightning, and many questions still remain. This paper will summarize the combined results of observations of positive lightning by high-speed video cameras in several locations around the world. Our main object is to provide an up-to-date large dataset that has accurate information on the important parameters of positive CG lightning.

2 INSTRUMENTATION

Six different high-speed digital video cameras (Photron Fastcam 512 PCI, Red Lake Motion Scope 8000S, Phantom v7.1, v310, v12.1 and Basler Pilot piA640-210gm), with time-resolutions and exposure times ranging from 83 microseconds (11,800 frames per second) to 10 ms (100 frames per second), have been used to record images of cloud-to-ground lightning in southern and southeastern Brazil, southern Arizona (USA), South Dakota (USA) and Vienna (Austria) between February 2003 and September 2009. All video imagery was recorded without any frame-to-frame persistence and was time-stamped to GPS.

Information about the amplitude and polarity of the lightning strokes was obtained from Vaisala lightning locating systems that were operating in each country and from electric field measurements. This information was available even if the stroke locations were not computed by the system. When electric field measurements were available, those data were also used to determine the stroke polarity.

The electric field measuring system consisted of a flat plate antenna with an integrator/amplifier, a GPS receiver, and a PC with two PCI-cards (a GPS card Meinberg GPS168PCI and a data acquisition card NI PCI-6110), and a data acquisition box (DAQ BOX NI BNC-2110). The waveform recording system was configured to operate at a sampling rate of 5 MS/s on each channel and the resolution of the A/D converter is 12 bits.

3 RESULTS

3.1 Flash Multiplicity

Figure 1 shows a histogram of the number of strokes per flash for all 103 +CG flashes in our dataset. In this sample, 19 flashes had two strokes and one had three strokes. Although there are some prior reports of positive CG flashes having more than two strokes, there are no prior video recordings of positive flashes with more than two strokes.

The average number of positive strokes per flash in Fig. 1 is 1.2. The percentage of single-stroke flashes is 81%.

Figure 1 shows a histogram of the number of strokes per flash for 101 positive CG flashes. In this sample of 101 flashes, 18 had two strokes and one had three strokes. Positive flashes containing more than two strokes have not been reported previously in the literature. The mean number of positive strokes per flash in Fig. 1 is 1.2.

3.2 Number of Ground Strike Points

It was possible to see the locations of the ground strike points in 98 of the 103 flashes in our dataset. The total number of different strike points was 111; therefore, the average number of strike points per flash was 1.14. There are no prior reports of this parameter in the literature. It is important to note that all but one subsequent stroke in the 20 multiple-stroke positive flashes in our dataset created a new ground termination.

For the multiple-stroke positive flashes where each stroke was located by a LLS, we were able to estimate the horizontal distances between the different ground strike points. The distances range from 2 to 53 km and that most (70%) are greater than 10 km, the default range used by the LLSs to group strokes into flashes.

3.3 Estimated Peak Current

Figure 2 shows the distribution of the estimated peak currents (I_p) for the 116 +CG strokes (out of 124) that were recorded using high-speed cameras and were reported by a LLS. Note that the values of I_p provided by a LLS have never been validated by direct measurement for positive first or subsequent strokes, and that the field-to-current conversion factors that the LLSs uses for positive strokes are the same as for negative strokes.

The median value of I_p for the 116 positive strokes in Figure 2 was 39.4 kA, and the smallest and largest values were 4.8 kA and 142 kA, respectively. Note that the low I_p values are for real CG strokes recorded on video and are not contaminated by LLS reports of cloud discharges. 21% of the positive strokes recorded on video had an I_p that was less than 20 kA, nearly half of which were subsequent strokes.

3.4 Continuing Current

Here, we have measured the durations of CC by visual inspection of the longest lasting luminous segment in the channel above ground. For these measurements, the brightness of the channel was enhanced as needed by changing the image settings of the video player software. Although different cameras were used to record the stroke luminosity at variable distances, and with varying sky backgrounds, all cameras appeared to record faint CCs provided that the events were not too far from the recording site. In order to avoid significant variations due to the sensitivity of the individual cameras, only flashes that were less than 50 km from the recording sites were examined. (Note: positive events that exhibited CCs in Austria were not analyzed because of the lower time-resolution of that camera.)

Only two positive flashes out of the 87 in our dataset did not produce any CC, and at least one long CC event (> 40 ms) was present in 75% of the flashes. 67 (64%) of 104 positive strokes were followed by a long CC. The shortest and the longest CCs had a duration of 5 ms and 800 ms, respectively. Figure 3 shows the distribution of the CC durations in 104 positive first and subsequent strokes. The arithmetic mean and the geometric mean durations are 149 ms and 74 ms, respectively.

Figure 4 shows a plot of I_p vs. the duration of CC for the 70 positive strokes in our dataset that produced a long CC. Note that Figure 4 corroborates a prior finding of Saba et al. [8] based on a smaller sample of only 9 +CG strokes; namely, positive strokes can produce both a high peak current (I_p > 20 kA) and a long CC (> 40 ms), a feature that has not been found in any negative stroke. [Figure 4 includes a plot of 576 newly analyzed negative strokes for comparison, including cases followed by long CC.]. Note also in Figure 4 that the stroke with the largest estimated peak current (142 kA) was followed by the longest CC (800 ms), and this event is marked by an arrow in the upper right corner of the plot.

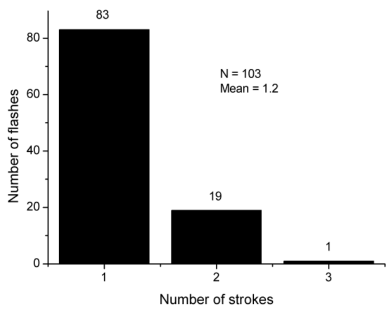

Figure 1. Number of flashes that contained the given number of strokes. The total number of strokes was 124.

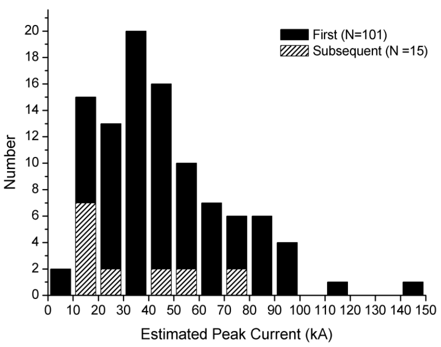

Figure 2. Histogram of the estimated peak currents in positive first and subsequent strokes.

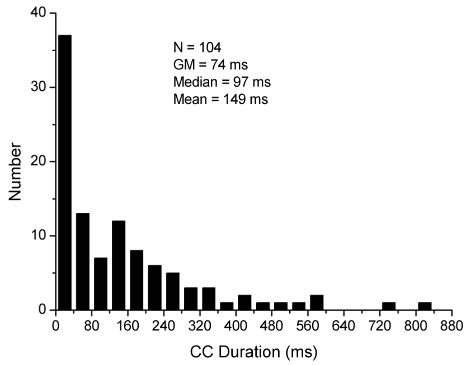

Figure 3. Histogram of the CC durations in 104 positive strokes.

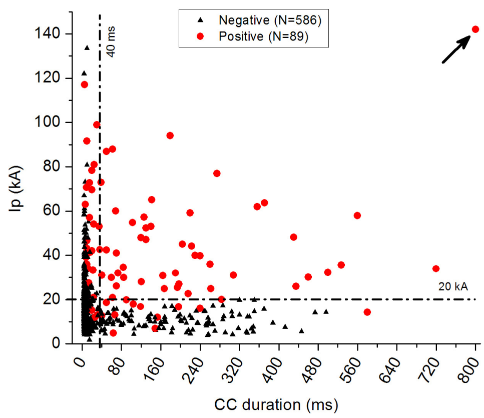

Figure 4. Scatterplot of the estimated peak current, Ip, versus CC duration.

4 DISCUSSION AND SUMMARY

All of the characteristics presented above are based on high-speed video observations and LLS data. To the best of our knowledge, these are the first measurements of +CG parameters using this technique. The distribution of the continuing current durations for +CGs in Fig.3 is the first that has been based on high-speed video measurements. Only two positive flashes out of the 87 in our dataset did not produce any CC, and at least one long CC event (> 40 ms) was present in 75% of the flashes. This is in marked contrast to the low percentage (30%) of negative flashes that contain a long CC [6, 7]. We have confirmed for many more cases than were published by Saba et al., [8] that positive strokes followed by long CC do not exhibit any dependence of the estimated peak current of the stroke.

Most (75%) of the distances between strokes in flashes with multiple ground contacts are greater than 10 km which is the distance presently used by LLS to group strokes into flashes. This is probably because positive flashes often have extensive horizontal channels, and this in turn may affect the LLS counts of positive flashes.

The facts that a) almost all the subsequent strokes in multiple-stroke +CG flashes create a new ground termination; b) positive strokes are frequently associated with flashes that exhibit extensive horizontal channel development; c) subsequent strokes can make a new ground contact even during the continuing current of the previous stroke; and d) the large distances between the different ground contacts in +CG flashes, all indicate a very low interdependence of positive strokes on each other. This leads us to conclude that the temporal and spatial criteria that are commonly used in lightning locating systems to group negative strokes into flashes may not be valid for +CG flashes. This use of the same grouping criteria may also contribute to the low positive stroke multiplicities that are often reported by LLSs [e.g. 9]. The very concept of a lightning 'flash' being a group of strokes that are co-located in space (and time) should be reconsidered for positive flashes to ground.

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