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Characteristics of cloud-to-ground lightning in warm-season thunderstorms in the Central Great Plains

Stacy A. Fleenor [a], Christopher J. Biagi [a,b], Kenneth L. Cummins [a,c], E. Philip Krider [a,*], Xuan-Min Shao [d]

[a] Institute of Atmospheric Physics, University of Arizona, Tucson, AZ, USA
[b] University of Florida, Gainesville, FL, USA
[c] Vaisala NLDN, Tucson, AZ, USA
[d] Los Alamos National Laboratory, Los Alamos, NM, USA

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ABSTRACT

In July 2005, a field campaign was conducted in the Central Great Plains to obtain 60-field/s video imagery of lightning in correlation with reports from the U.S. National Lightning Detection Network (NLDN) and broadband electric field waveforms from the Los Alamos Sferic Array (LASA). A total of 342 GPS time-stamped cloud-to-ground (CG) flashes were recorded in 17 different sessions, and 311 (91%) of these were correlated with reports from the NLDN. Only 6 of the 17 recording sessions were dominated by flashes that lowered negative charge to ground, and 11 were dominated by positive CG flashes. A total of 103 flashes recorded on video were correlated with at least one NLDN report of negative CG strokes, 204 video flashes were correlated with one or two positive stroke reports, and 4 had bipolar reports. In this paper, we will give distributions of the estimated peak current, I_p, as reported by the NLDN, of negative and positive first strokes that were recorded on video, the multiplicity of strokes that were recorded on video, and the number of ground contacts per flash that were resolved on video. 41 (40%) of the negative flashes produced just a single-stroke on video, and 62 (60%) showed two or more strokes. The observed multiplicity of negative flashes averaged 2.83, which becomes about 3.14 after correcting for the finite time-resolution of the video camera. 195 (96%) of the positive flashes produced just a single-stroke on video, and 9 (4%) showed two strokes; therefore, the observed multiplicity of positive flashes averaged 1.04. Five out of 9 (56%) of the positive subsequent strokes re-illuminated a previous channel, and 4 out of 9 (44%) created a new ground contact. Simultaneous video, LASA, and NLDN measurements also allowed us to examine the classification of NLDN reports during 3 single-cell storms (one negative and two positive). Based on the LASA waveforms, a total of 204 out of 376 (54%) NLDN reports of CG strokes were determined to be for cloud pulses. The misclassified negative reports had $|I_p|$ values ranging from 3.8 kA to 29.7 kA, but only 58 (24%) of these had $|I_p|>10$ kA, and only one misclassified positive report had $I_p>20$ kA. Radar analyses showed that most of the negative and positive CG strokes that were recorded on video were produced within or near the convective cores of storms. The radar imagery also showed that single-cell storms tended to produce one polarity of CG flashes at a time, and that such storms could switch rapidly from negative to positive CG flashes when the reflectivity was near maximum. Multiple-cell storms produced both negative and positive flashes over a broad region, but each polarity tended to cluster near regions of high-reflectivity.

* Corresponding author. The University of Arizona, Department of Atmospheric Sciences, PAS Room 542, 1118 East 4th Street, PO Box 210081, Tucson, AZ 85721, USA. Tel.: +1 520 621 6836; fax: +1 520 621 6833.
E-mail address: krider@atmo.arizona.edu (E.P. Krider).

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1. Introduction

Previous studies of cloud-to-ground (CG) lightning have shown that flashes lowering positive charge to ground represent just a few percent of all CG flashes in warm-season thunderstorms in the U.S. (Fuquay, 1982; Rust, 1986; Reap and MacGorman, 1989; MacGorman and Rust, 1998, pp. 191–2; Orville and Huffines, 2001). Although the majority of CG flashes in the warm-season are negative, positive flashes are of considerable interest because they tend to have high peak currents and large charge transfers (Rakov and Uman, 2003, Ch. 5), and, therefore, they often cause more damage than negative flashes and are thought to play an important role in wildfire ignition (Fuquay et al., 1972; Hall and Brown, 2006).

During the warm-season, positive flashes can be the dominant polarity under the following conditions: (1) in the trailing stratiform regions of mesoscale convective systems (MCSs) (Rutledge and MacGorman, 1988; Engholm et al., 1990; Rutledge and Petersen, 1994) and in the anvil regions of some severe storms (Rust et al., 1981), (2) during the dissipating stage of any ordinary thunderstorm (Fuquay, 1982), and (3) during the mature stages of severe thunderstorms which usually produce large hail and sometimes tornadoes (Rust et al., 1981; MacGorman and Burgess, 1994; Stolzenburg, 1994; Carey and Rutledge, 1998). In the latter case, the positive CG flashes are produced within or near the convective cores of the storms, which is similar to the behavior of negative flashes in ordinary thunderstorms (Krehbiel, 1986; MacGorman and Rust, 1998). Recent studies have shown that a large fraction of the warm-season storms in the Central Great Plains (CGP) and upper Midwest produce a preponderance of positive CG flashes, instead of the more typical negative flashes (Rutledge et al., 1990; Seimon, 1993; MacGorman and Burgess, 1994; Carey and Rutledge, 1998; Carey et al., 2003; Lang et al., 2004). This finding agrees with Orville and Huffines (2001), who found that, on average, more than 20% of the flashes reported by the U.S. National Lightning Detection Network (NLDN) in the CGP and upper Midwest were positive, compared to 6% or less in the eastern and southwestern U.S.

In order to understand better the electrical characteristics of thunderstorms in the CGP, the Severe Thunderstorm Electrification and Precipitation Study (STEPS) was undertaken near the Colorado–Kansas border during the summer of 2000 (Lang et al., 2004). These authors found that at least half of the storms in the CGP produce predominantly positive CG flashes for at least a portion of their life cycle. Krehbiel et al. (2000), Rust and MacGorman (2002), Rust et al. (2005), and Tessendorf et al. (2007) also found that an inverted polarity charge structure was the main reason that some of the STEPS storms produced a high proportion of positive CG flashes. Rust and MacGorman (2002) found 4 single-cell storms that had an inverted polarity near the updraft region, and each of these storms produced a high area density of positive CG flashes. Tessendorf et al. (2007) found one multiple-cell storm in STEPS that exhibited an inverted charge structure. Williams (2005) has suggested that storms that have elevated cloud base heights may tend to produce an inverted polarity charge structure, and other authors have suggested that other meteorological conditions, such as strong updrafts, high liquid water content, and a smaller warm cloud depth, are favorable for inverted polarity charging (Reap and MacGorman, 1989; Smith et al., 2000; Lang and Rutledge, 2002; Carey and Buffalo, 2007).

The CGP was chosen because the studies referenced above have shown that it contains a high proportion of positive flashes in the warm-season. Because the correct classification of CG flashes by the NLDN, or any other lightning locating system, has important implications for meteorological research and applications and for lightning protection (Rakov, 2003; Rakov and Uman, 2003, Ch. 5), a field campaign was conducted in the summer of 2005 in the CGP of eastern Colorado, western Kansas, and southern Nebraska to obtain independent video recordings of CG flashes that were correlated with NLDN stroke reports.

In this report, we will discuss the following findings: a) the number and percentage of negative and positive CG flashes that were recorded on video in the CGP; b) the number of the recording sessions and storms that were dominated by positive CG flashes, and c) the phenomenological characteristics of negative and positive flashes in the CGP. Since the lightning characteristics that will be of interest here depend on the NLDN performance in the CGP, we will also evaluate the NLDN flash and stroke detection efficiencies in this region, the assignment of stroke polarity by the NLDN, and the types of events that the NLDN classified as CG strokes.

2. Data and methodology

2.1. Video recording system

Lightning strokes were recorded using one or two Canon GL1 digital video camcorders with 720×480 pixel resolution. During the data analysis, the standard 30 video frames per second were de-interlaced to provide 60 fields/s that could be viewed on a standard video monitor (Parker and Krider, 2003). The camera exposure time was set to 1/60 s or 16.7 ms to eliminate any dead time between fields. Different strokes that followed the same channel to ground may not have been resolved by our video camera if they had an interstroke interval less than 33 ms. Each video field was time-synchronized to GPS time, and the GPS times were used to correlate video strokes with NLDN reports of CG strokes. A more detailed discussion of the video recording system and the methods of analysis can be found in Parker and Krider (2003) and Biagi et al. (2007).

In this study, a ground stroke was considered to have occurred within a particular video field if that field contained a clearly visible channel between the cloud and the ground. Strokes that remained luminous for two or more consecutive fields were assumed to have a continuing luminosity, and in some cases, the appearance of continuing luminosity may have been produced by an unresolved subsequent stroke. Any increases in the continuing luminosity of the channel were assumed to be M components (Thottappillil et al., 1995).

For this study, a recording session was defined in terms of a specific recording interval at a given camera location. The recording sessions (see Table 1 to follow) did not necessarily coincide with the entire life cycle of the storm, or record all the lightning that occurred in that storm. For many sessions, the recording began in the middle of the lightning activity and/or ended before the lightning activity had ceased. Since