ELSEVIER

Atmospheric Research 84 (2007) 302 – 310

ATMOSPHERIC RESEARCH

www.elsevier.com/locate/atmos

Waveshapes of continuing currents and properties of M-components in natural negative cloud-to-ground lightning from high-speed video observations

Leandro Z.S. Campos, Marcelo M.F. Saba*, Osmar Pinto Jr., Maurício G. Ballarotti

National Institute for Space Research — INPE, Av. dos Astronautas, 1758, S. José dos Campos, SP, P.O. Box 515–12201–970, Brazil

Received 19 May 2005; received in revised form 14 September 2006; accepted 14 September 2006

Abstract

Continuing current is a continuous mode of charge transfer to ground in a lightning flash. The extent to which the continuing current contributes to the total negative charge lowered to earth is large. In order to study the waveshape of the continuing currents of natural flashes, we developed a computational algorithm that analyzes the pixels of the images obtained by a high-speed camera and plots luminosity-versus-time. Tower measurements have shown that during the continuing current phase of the flash the luminosity of the channel is directly proportional to the current that flows through it. Using this information it was possible to infer the continuing current waveshape for 63 natural discharges and classify them into six different types. Statistics on some characteristics of 345 M-components (that occurred during the same 63 events) are also presented. As far as we know, this is the first study on waveshapes of continuing currents for natural lightning.

Keywords: Continuing current; Waveshape; M-component; Lightning; High-speed video

---

1. Introduction and review

As described by previous works (Rakov et al., 2001; Rakov and Uman, 2003), there are three possible modes of charge transfer to ground associated with the strokes in negative lightning discharges: the return stroke, the continuing current (CC) and the M-component. As the last two modes are the subject of this study, a brief description of them is presented.

1.1. Continuing current

Kitagawa et al. (1962) and Brook et al. (1962) defined “long” continuing current (CC) as indicated by a steady electric field change with a duration in excess of 40 ms. Shindo and Uman (1989) defined “short” CC as indicated by a similar field change with a duration between 10 ms and 40 ms, and “questionable” lasting 1 to 10 ms. Ballarotti et al. (2005), based on data from a high-speed video system, and avoiding contamination from what could just be return stroke pulse tails, introduced the term “very-short” defining continuing currents with a

---

* Corresponding author. Av. dos Astronautas,1758-P.O. Box 515–12201–970,S. José dos Campos, SP, Brazil. Tel.: +55 12 3945 6768; fax: +55 12 3945 6810.

E-mail addresses: leandro.zanella@gmail.com (L.Z.S. Campos), msaba@dge.inpe.br (M.M.F. Saba), osmar@dge.inpe.br (O. Pinto), mgballa@dge.inpe.br (M.G. Ballarotti).

0169-8095/$ - see front matter © 2006 Elsevier B.V. All rights reserved.
doi:10.1016/j.atmosres.2006.09.002

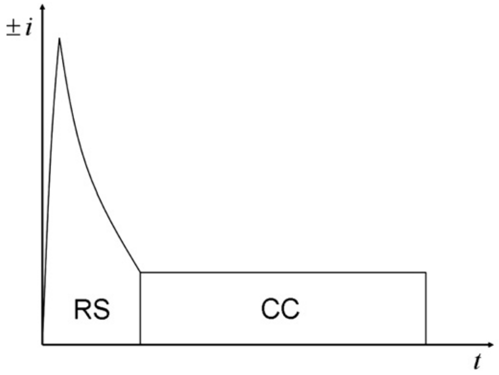

Fig. 1. The continuing current rectangular waveshape used in protection standards (RS indicates the return stroke and CC the continuing current).

duration less than or equal to 10 ms but greater than 3 ms. According to Ballarotti et al. (2005), 28% of the strokes in a flash, including single stroke flashes, are followed by some kind of continuing current (long, short or very short). Continuing currents are responsible for most serious lightning damage associated with thermal effects, such as burned-through ground wires and optical fiber ground wires (OPGW) of overhead power lines, blowing fuses used to protect distribution transformers, holes in the metal skins of aircraft, etc (Chisholm et al., 2001; Fisher and Plummer, 1977; Rakov and Uman, 1990).

The value of the current is usually estimated to be 100 A, with a range from 30 to 200 A and the charge transfer is typically between 10 and 20 C (Brook et al., 1962; Williams and Brook, 1963; Shindo and Uman, 1989). These parameters (commonly reported and used in lightning protection applications) are calculated assuming that continuing currents have a constant current value with time. Fig. 1 illustrates the rectangular shape of the continuing current used in the standards for protection application (IEC, 2006). As far as we know, Fisher et al. (1993) is the only study on the waveshapes of continuing currents, which is based on direct measurements from triggered lightning. They analyzed 30 continuing currents having durations exceeding 10 ms and found that they exhibit a variety of waveshapes that were grouped into four categories.

In the present study a similar analysis is done, for the first time, for natural lightning continuing currents. This study is based on the video observation of the channel luminosity variation with time in a millisecond scale.

1.2. M-components

The M-component, first described by Malan and Collens (1937) is observed as an increase in luminosity of the channel during the occurrence of a continuing current event. The intensity of the light pulses as a function of time is more or less symmetrical. The increase in luminosity is associated with current pulses with amplitudes of typically some hundreds of amperes and rise times of some hundreds of microseconds as observed from triggered lightning measurements (Thottappillil et al., 1995). They are distinctly different from return stroke current pulses, which occur only after the cessation of any preceding current through the channel base and which typically exhibit submicrosecond rise times (Fisher et al., 1993). M-components may have current peaks in the kiloampere range (one magnitude order greater than the usual values), making them sometimes comparable to current peaks of smaller return strokes. They typically produce a charge transfer to ground of 0.1–0.2 C, one order of magnitude smaller than that of a subsequent return-stroke pulse (Rakov and Uman, 2003). Most of these parameters were obtained for rocket-triggered or tower-initiated lightning. For natural flashes, few statistics on the characteristics of M-components were made and, most of them were based on the electric field changes technique, which limits the observation to very close range ground flashes. Table 1 summarizes previous recent work on these two subjects (Thottappillil et al., 1990, 1995; Rakov et al., 1992; Fisher et al., 1993) in comparison to the present study.

In the present study, a statistical distribution of M-component characteristics is made for a larger number of

Table 1
Review of continuing currents (CC) and M-components recent studies

Work (triggered or natural lightning)	Analyses		# of CC	# of M	Observation method	Distance range (km)
	CC waveshape	M-components				
Thottappillil et al., 1990(natural)		X	–	88	Electric field change	2.5 to 12
Rakov et al., 1992(natural)		X	–	118	Electric field change	2.5 to 27
Thottappillil et al., 1995(triggered)		X	–	158	Channel base current	–
Fisher et al., 1993(triggered)	X		30	–	Channel base current	–
Present study (natural)	X	X	63	345	High-speed video	2 to 53