Submicrosecond structure of magnetic-field waveforms of different types of return strokes

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1. Introduction

Optical observations show that the geometries of the lightning current channels belonging to different types of cloud-to-ground (CG) lightning strokes substantially differ [1, 2, 3]. The positive CG stroke channels are quite smooth [4, 5]. The lightning channel geometry of negative CG strokes depends primarily on the order of the stroke in the flash. The channels of first negative CG strokes are branched. Subsequent negative CG strokes copying the channel of the first stroke are similar to that of the first stroke but without branches. The newly created subsequent stroke channels are usually also branched. The channels of other subsequent strokes belonging to the same flash and sharing the same channel sometimes slightly differ, probably due to temporal changes of the lightning channel geometry during the development of the flash [6].

The relation between the optical emissions of a return stroke and the corresponding stroke current is not well known, and direct measurements of current waveforms are quite complicated. The analysis of remote measurements of electromagnetic signals radiated by return strokes can serve as a useful tool for the investigation of currents flowing in the lightning channels [7]. Since the length of the rising edge of a return stroke dominant peak is related to the propagation velocity of this stroke, a slower stroke creating a new channel can be distinguished from a faster stroke which uses an existing channel by the comparison of their dominant peak rise times [8]. Moreover, the fine structure of the magnetic-field waveforms that are radiated by return strokes is related to the geometry of the corresponding lightning current channel. Subsidiary peaks in return stroke waveforms are probably related to the presence of branches [9]. Two distinct peaks in the return stroke waveforms which are separated by tens of microseconds or less can indicate a forked lightning channel with two ground terminations [10, 11]. The degree of the similarity of the *dB/dt* and *B* waveform shapes of the strokes in the same flash tells us if the subsequent stroke followed the existing channel or if it created a separate channel with a new ground termination.

2. Instrumentation and data set

For our measurements we use a ground-based version of a broadband high-frequency analyzer which is developed for the TARANIS spacecraft. The analyzer is coupled with a magnetic-field antenna equipped with an integrated preamplifier. Broadband waveforms of the magnetic-field derivative from lightning return strokes are measured in the frequency range 5 kHz – 37 MHz. A sampling frequency of 80 MHz allows us to examine the submicrosecond timing properties of the onset and the decay of the return stroke dominant peak. The waveform data have been collected during two thunderstorms occurring at a distance of ~ 65 - 258 km from our receiving station in Rustrel, France (43.9410N, 5.4836E) on 19th of July 2013. Our data set consist of 13 positive CG flashes, 22 negative single-stroke CG flashes, 23 first strokes and 26 subsequent strokes from multi-stroke negative CG flashes. We have completed our measurements by the return stroke data obtained from the French lightning detection network MÉTÉORAGE.

3. Analysis of waveform shapes

We analyze a fine structure of the *dB/dt* and *B* waveforms from return strokes separately for positive CG flashes, negative single-stroke CG flashes, first strokes from multi-stroke negative CG flashes, and subsequent strokes from multi-stroke negative CG flashes. We compare the shape, the length of the rising edge, the amplitude of the dominant peak, and the amplitude of the opposite polarity overshoot for different types of return

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strokes. We performed a superposed epoch analyses of return stroke waveforms in order to reveal waveform properties typical for different types of return strokes. We examine the possibility to identify the type of return strokes without optical observations. This analysis can have implications for lightning protection and lightning test standards.

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5. References

1. M. M. F. Saba, M. G. Ballarotti, O. Pinto Jr., Negative cloud-to-ground lightning properties from high-speed video observations. *J. Geophys. Res. 111*, 2006, D03101. doi:10.1029/2005JD006415.

2. W. C. Valine, and E. P. Krider, Statistics and characteristics of cloud-to-ground lightning with multiple ground contacts, *J. Geophys. Res. 107*, 2002, 4441, doi:10.1029/2001JD001360.

3. L. Z. S. Campos, M. M. F. Saba, T. A. Warner, O. Pinto Jr., E. P. Krider, and R. E. Orville, High-speed video observations of natural cloud-to-ground lightning leaders – A statistical analysis, *Atmospheric Research 135-136*, 2014, 285–305, http://dx.doi.org/10.1016/j.atmosres.2012.12.011.

4. A. Nag, and V. Rakov, Positive lightning: An overview, new observations, and inferences, *J. Geophys. Res. 117*, 2012, doi: 1029/2012JD017545.

5. C. Schumann, M. M. F. Saba, R. B. G. da Silva, Electric field changes produced by positive cloud-to-ground lightning flashes, *J. Atmos. Sol.-Terr. Phys.92,* 2013, 37-42, http://dx.doi.org/10.1016/j.jastp.2012.09.008

6. A. Nag, V. A. Rakov, W. Schultz, M. M. F. Saba, R. Thottappillil, Ch. J. Biaggi, A. O. Filho, A. Kahmad, N. Theethayi, and T. Gotschl, First versus subsequent return-stroke current and field peaks in negative cloud-to-ground lightning discharges, *J. Geophys. Res. 113*, 2008, D19112, doi:10.1029/2007JD009729.

7. J. C. Willet, D. M. Le Vine, and V. P. Idone, Lightning-channel morphology revealed by return-stroke radiation field waveforms, J. *Geophys. Res. 100,* 1995, 2727-2738.

8. J. C. Willet, E. P. Krider, and C. Leteinturier, Submicrosecond field variation during the onset of first return strokes n cloud-to-ground lightning, *J. Geophys. Res. 103,* 1998*,* D8, 9027-9034

9. Ch. D. Weidmann, and E. P. Krider, The fine structure of lightning return stroke waveforms, *J. Geophys. Res. 83*, 1978, 6239-6247.

10. X. Z. Kong, X. S. Qie, Y. Zhao, and T. Zhang, Characteristics of negative lightning flashes presenting multiple-ground terminations on a millisecond-scale, *Atmospheric Research 91,* 2009, 381–386, doi:10.1016/j.atmosres.2008.03.025

11. M. A. da Silva Ferro, M. M. F. Saba, O. Pinto Jr., Time-intervals between negative lightning strokes and the creation of new ground terminations, *Atmospheric Research 116*, 2012, 130–133, doi:10.1016/j.atmosres.2012.03.010