Correlation of pre-stroke magnetic-field pulses measured by a broad-band receiver with the sources of VHF radiation recorded by LMA

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We analyze broadband magnetic-field measurements of pulse sequences occurring prior to first return strokes of negative cloud-to-ground lightning flashes. We compare our measurements with narrow-band (60–66 MHz) Lightning Mapping Array (LMA) data. We observe an unusually short duration of the pre-stroke activity (1-7 ms) reported for the first time during a summer thunderstorm, with a low height of initiation (3-4 km). A very fast propagation speed (~10^6 m/s) is probably maintained for the entire pre-stroke process. We analyze the time correlation of magnetic-field pulses measured by a broad-band receiver with the sources of VHF radiation recorded by LMA. Our preliminary results show that only a few magnetic-field pulses are accompanied by VHF radiation recorded by LMA and that, on the other hand, some LMA sources cannot be linked to any particular magnetic-field pulse. These results indicate that current-producing processes are only weakly related to the VHF radiation sources.

1. Introduction

A sequence of electromagnetic pulses lasting from a few milliseconds to several tens of milliseconds is often observed prior to the first return stroke of negative cloud-to-ground lightning flashes [1]. This sequence is composed of three parts. It begins with a pulse train whose duration is on the order of 1 ms. These initial pulses are believed to be connected with preliminary breakdown processes. They are usually followed by a relatively low and irregular pulse activity, which lasts from several tens to hundreds of milliseconds. The sequence ends with another short train of smaller pulses which lasts from several tens of microseconds to several hundreds of microseconds, being attributed to the last stages of the stepped leader.

Clarence and Malan [2] believed that the preliminary breakdown pulses (PBPs) are produced by a vertical discharge between the main negative charge centre and the lower positive charge centre inside the thundercloud. *Stolzenburg et al.* [3] introduced a new hypothesis for the generation of PBPs based on the time-correlated high-speed video and electric field measurements. They found that bursts of light recorded by the high-speed video (50000 frames/s) are coincident with the largest PBPs in the electric-field data. *Stolzenburg et al.* [3] hypothesized that each large PBP which is accompanied by a visible light pulse can be caused by a current surge that is a few hundreds of meters long.

In the present study we analyze 15 pulse sequences occurring prior to the first return strokes (RSs) of negative lightning flashes during a thunderstorm on the 11th of October 2012. We analyze the time correlation of magnetic-field pulses measured by a broad-band receiver with the sources of VHF radiation recorded by the Lightning Mapping Array (LMA) [4].

2. Instrumentation

For the broadband measurements we use a magnetic-field loop antenna coupled with a ground-based version of a broadband high-frequency analyzer (5 kHz – 36 MHz) which is developed for the TARANIS spacecraft. The instrumentation is described in detail by *Kolmasova and Santolik* [5]. The analyzer is placed in a quiet electromagnetic environment of an external measurement site of the Laboratoire Souterrain à Bas Bruit (LSBB) on the summit of La Grande Montagne (1028 m, 43.94N, 5.48E) close to Rustrel, France. We compare our measurements with narrow-band (60–66 MHz) LMA data. LMA was deployed in France in spring 2012 in the frame of the HyMeX Special Observation Period campaign. The LMA system was located about 100 km westward from the flashes discussed in this paper. The time assignment is done by GPS receivers.

3. Results and discussion

Using the broad-band magnetic-field waveforms we have estimated the maximum time

separation of the first pulse and the dominant peak of the corresponding RS for all 15 sequences. The results show that time separation of the first PBP and the corresponding RS varies from 0.9 ms to 7.1 ms with the mean value of 2.5 ms.

The LMA detected pre-stroke activity for 14 out of the 15 RSs. The return stroke carries ground potential to the top of the leader channel, which results in very strong electric fields at the top of the channel, and leads to additional electrical breakdown a few microseconds after the RS. The LMA detected sources associated with this subsequent breakdown in 11 out of the 15 original RSs. Fig. 1 shows the LMA sources for one of the 15 RSs, with an expanded view of the initial pre-stroke activity and the subsequent breakdown at the top of the channel.

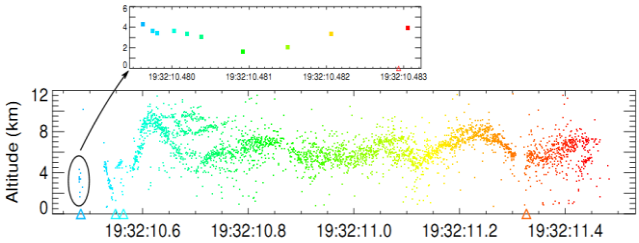

Fig. 1 LMA data from 11th of October 2012, (19:32:10.45 – 19:32:11.50); the triangles are the times of the MÉTÉORAGE detected -CG strokes.

The LMA data shows that the pre-stroke activity in all cases started at an altitude of 3 to 4 km and had durations of 2 to 4 milliseconds. By combining the height of the initiation of pre-stroke activity obtained from LMA data (~3-4 km) and the average duration of the PBP-RS time separation (2.5 ms) we get very fast average speed of propagation of the pre-stroke discharges in the analyzed thunderstorm, starting by in-cloud PBPs and ending by the stepped leader. The duration of these processes (~ 2-4 ms) obtained from LMA data is consistent with the duration of the pre-stroke pulse sequences from broadband records. This confirms that the propagation velocities of the pre-stroke processes were 1×10^6 to 2×10^6 m/s, much faster than typical velocities of stepped leaders prior to a typical CG flash which are on the order of 10^5 m/s [6].

Fig. 2 shows a part of the magnetic-field pre-stroke sequence belonging to the flash from Fig.1. Blue dots represent sources of VHF radiation recorded by LMA. This example demonstrates that only a few magnetic-field pulses are accompanied by VHF radiation recorded by LMA. On the other hand we can find LMA sources which cannot be linked to any particular magnetic-field pulse. These preliminary results show a very weak relation between current-producing processes radiating magnetic-field pulses and the VHF radiation detected by LMA. Investigation of properties of pulses which are linked to the LMA sources can lead us to a better characterization of this relation.

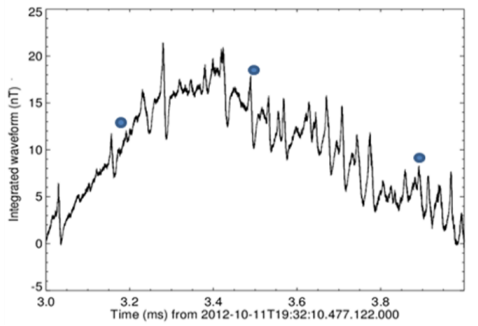

Fig. 2 Part of the sequence belonging to the flash from Fig.1; blue dots represent sources of VHF radiation recorded by LMA.

4. References

[1] Rakov , V. A., and M. A. Uman (2003), Lightning – Physics and effects, *Cambridge University Press*, ISBN:9780521583275.

[2] Clarence, N.D. and D. J. Malan (1957), Preliminary discharge processes in lightning flashes to ground. *Quarterly Journal of the Royal Meteorological Society 83*, 161–172.

[3] Stolzenburg M., T. C. Marshall, S. Karunarathne, N. Karunarathna, L. E. Vickers, T. A. Warner, R. E. Orville, and H.-D. Betz (2013), Luminosity of initial breakdown in lightning, *J. Geophys. Res. Atmos.*, *118*, 2918–2937, doi:10.1002/jgrd.50276.

[4] Rison, W., R.J. Thomas, P.R. Krehbiel, T. Hamlin, and J. Harlin (1999), A GPS-based Three-Dimensional Lightning Mapping System: Initial Observations in Central New Mexico, *Geophys. Res. Lett.*, 26, No. 23, 3573-3576.

[5] Kolmašová, I. and O. Santolík (2013), Properties of unipolar magnetic field pulse trains generated by lightning discharges, *Geophys. Res. Lett.*, *40*, 1637–1641, doi:10.1002/grl.50366.

[6] Heavner, M. J., D. A. Smoth, A. R. Jacobson, and R. J. Sheldon (2002), LF/VLF and VHF fast-stepped leader observations, *J. Geophys. Res. 107*, 4791, doi: 10.1029/2001JD001290.