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Observation of lightning-induced signals on the summit of La Grande Montagne: HF measurements

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Abstract. A ground-based version of the IME-HF analyzer, developed for the French TARANIS mission, was connected to a magnetic loop antenna and used for broadband measurements of lightning-induced signals in the frequency range from 5 kHz to 36 MHz. A sampling frequency of 80 MHz allows examining submicrosecond timing properties of recorded horizontal magnetic-field waveforms related to different lightning phenomena. The instrumentation 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). We present results of measurements recorded during two years of operation. We concentrate our attention on signals radiated by in-cloud processes which are difficult to detect in situ or optically. We also analyze a fine structure of the magnetic-field waveforms from different types of return strokes in order to investigate currents flowing in the lightning channels. After the launch of the TARANIS satellite the ground-based measurements will complement the observations from space.

1. Introduction

The source of the lightning discharge is an electrified thundercloud – cumulonimbus. The mechanism of the electrification of the thundercloud involves two main processes: 1) a small-scale process of charging the individual hydrometeors (various liquid or frozen water particles in the atmosphere), and 2) a process that spatially separates these particles by their polarity and thus creates charged regions in the cloud. This mechanism is still not completely clear. Non-inductive collisional charging is a generally accepted electrification mechanism.

The majority of discharges (∼75%) don't reach the ground. Discharges transporting the cloud charge to the ground are referred to as cloud-to-ground (CG) discharges. The downward negative discharge (∼90%) is the most common type of lightning.

The in-cloud process called preliminary breakdown lasts from a few milliseconds to several tens of milliseconds and generates the conditions for the formation of the stepped leader. The stepped leader forms the conductive path between the cloud and the ground. When the leader approaches ground, one or more upward connecting leaders are initiated. The connection between the downward and upward moving leaders is called the attachment process, which usually occurs several tens of meters above

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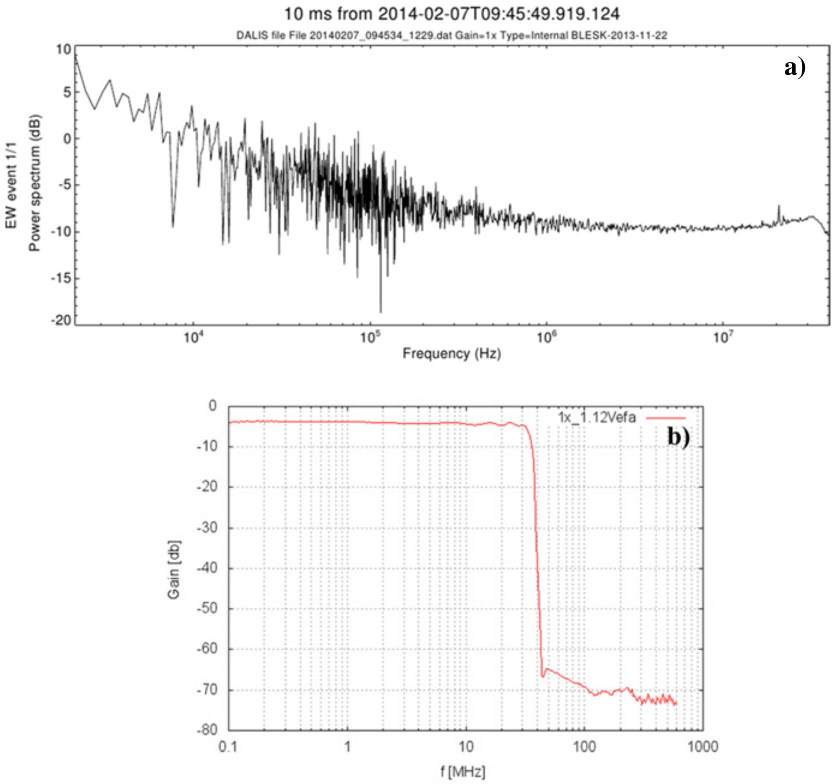

Figure 1. Noise frequency characteristic (a) and frequency response (b) of the broadband analyzer.

the ground. The attachment process is in fact the first stage of the return stroke. The return stroke transports the charge stored in the in the thundercloud to the ground [1].

Various lightning processes radiate electromagnetic signals. Their frequencies differ according to the speeds of the associated lightning processes. The analysis of the remote measurements of signals radiated by different lightning phenomena can serve us as a useful tool for their investigation. Such type of analysis can therefore bring new insights into understanding of physical characteristics of the observed thunderstorms.

2. Instrumentation

For our measurements we use a magnetic-field antenna coupled with a ground-based version of a broadband high-frequency analyzer IME-HF (Instrument de Mesure du champ Electrique Haute Fréquence) which was developed in the Institute of Atmospheric Physics in Prague for the French TARANIS spacecraft [2]. The TARANIS mission (Tool for the Analysis of Radiations from lightNIng and Sprites) is a CNES microsatellite mission, which will carry a unique set of instruments dedicated for observations of transient luminous events and terrestrial gamma ray flashes from space [3]. The satellite is scheduled to be launched in the end of 2016.

The noise frequency characteristic and the frequency response of the analyzer are plotted in Fig. 1a,b. The timing for the ground-based measurements is done by a GPS receiver connected to the analyzer. The locations, the polarities, and the peak currents of analyzed return strokes are provided by the French lightning location network MÉTÉORAGE. The accuracy of these detections is described in [4].

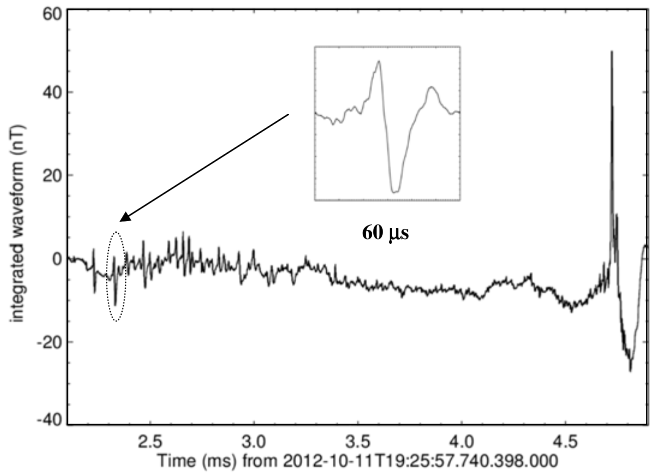

Figure 2. Example of a waveform showing the pre-stroke pulse activity and the corresponding return stroke.

Our records were completed by data of the Lightning Mapping Array (LMA) [5], which was deployed in France in 2012 in the frame of the SOP1 campaign of the HyMeX program [6].

3. Observations

3.1 Pre-stroke pulse activity

We analyze 15 magnetic-field pulse trains occurring prior to first return strokes of negative cloud-to-ground lightning flashes. An example of the pre-stroke pulse activity and the corresponding return stroke are plotted on Fig. 2.

The waveforms of the magnetic-field derivative were recorded during a thunderstorm which occurred on the 11th of October 2012 at distances from 12 to 44 km from the receiving station in Rustrel. The waveforms were numerically integrated.

3.2 Return strokes

Optical observations show that the geometries of the lightning current channels belonging to different types of cloud-to-ground (CG) lightning strokes substantially differ [7, 8]. 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. 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 [9].

We analyze a fine structure of 40 μs-long B waveforms from 50 return strokes occurring on 19th of June 2013 at distances between ∼65 and 258 km from the receiving station in Rustrel. We separately investigate 5 positive CG flashes, 11 negative single-stroke CG flashes, 18 first strokes from multi-stroke negative CG flashes, and 16 subsequent strokes from multi-stroke negative CG flashes. Two examples of submicrosecond structure of 800-μs long magnetic-field waveforms of single-stroke cloud-to-ground negative (a) and positive (b) return strokes are plotted in Fig. 3.

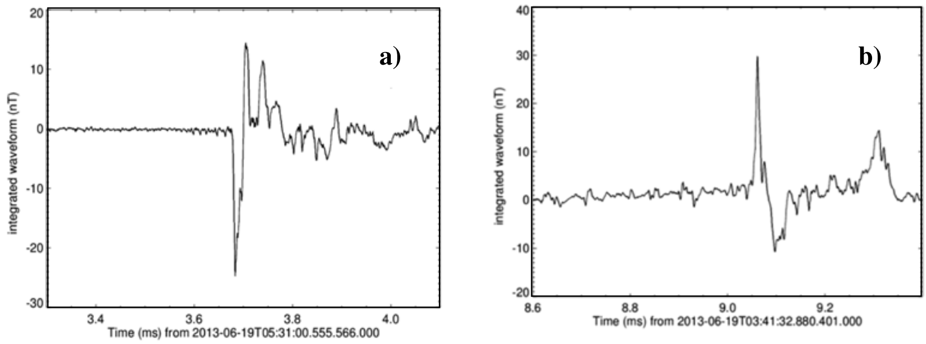

Figure 3. Magnetic-field waveforms of single-stroke cloud-to-ground negative (a) and positive (b) return strokes.

4. Results and conclusions

The magnetic-field amplitudes of preliminary breakdown pulses reach up to 50% of the corresponding return stroke peak value and typically decrease by ~40% during the trains. We observe an unusually short duration of the pre-stroke activity (1–7 ms) reported for the first time during a summer thunderstorm. We explain this observation by a low height of lightning initiation (3–4 km) and a very fast propagation velocity (~10^6 m/s) of the entire pre-stroke process.

We normalized each individual waveform by setting its peak value to unity. We centered the waveforms at their maxima and perform superposed epoch analysis separately for different RS types. We found that 1) the rising times of normalized dominant peaks of different types of negative RSs don't differ; 2) the rising times of normalized dominant peaks are increasing with the peak current only for positive CG, and 3) the width of normalized RS dominant peaks seems to increase with the peak current.

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