URSI GASS 2020, Rome, Italy, 29 August - 5 September 2020

High Frequency Radio Emission from a Thundercloud: A Case Study

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Abstract

The results of observation of radio frequency emission from a close thunderstorm of June 22, 2016 are presented. Radio frequency emission from a thundercloud existed on time intervals of a fraction of a second separated by intervals of the same length. The emission was predominantly pulsed with sub-microsecond duration of bipolar pulses separated by time intervals of tens of microseconds, and occurs suddenly showing no gradual development. Emission existed not only during development of lightning discharges, but also in the gaps between them. Two indicators were used to highlite pulsed emission: the ratio of the root mean square and median absolute values, and the kurtosis of the distribution of the received signal at time intervals of a fraction of a millisecond. Statistical characteristics of pulse amplitudes and interpulse intervals are investigated. A possible connection of the observed submicrosecond pulsed radio emission with runaway breakdown caused by the passage of extensive air showers through the region of strong electric field inside thundercloud is discussed.

1 Introduction

Recent years, much attention has been paid to the study of radio emission at the initial stage of the lightning discharge which precedes the stepped leader and the return stroke. The main interest is manifested to the groups of pulses associated with the onset of the intracloud phase of the discharge and called preliminary breakdown [1]. The study of the amplitude characteristics and polarity of such pulses makes it possible to make some assumptions about the charge structure of the cloud, in particular, to emphasize the role of the lower positive charge in the development of the cloud-to-ground discharges of different polarity [2]. It was also noted that the sequence of pulses characterizing the preliminary breakdown in a thundercloud does not always followed by a return stroke [3]. The HF radio emission of lightning discharges in a wide frequency range with high temporal resolution was studies in [4, 5]. It was found that radio emission of lightning begins sharply with a sequence of bipolar submicrosecond radio pulses. Further investigation of lightning radio emission showed that during the preconditioning and initiating stages of the cloud-to-groud lightning it consists of a large number radio pulses [6]. Wideband radio emission with high temporal resolution measurements were carried out in [7, 8] also. All those observations were connected with registration of radio emission over short periods (about a second maximum) only during lightning discharges.

In this papeer we present quasi continuous observations of electromagnetic emission from a thundercloud during almost the whole time of its existence in a wide frequency range with a high temporal resolution allowing to investigate the waveform of received signals.

2 Instrumentation

Observations of radio emission of nearby thunderstorms were conducted at the receiving point with coordinates of 56.15N, 44.32E (Nizhny Novgorod region) using waveform recording installation covered frequency range from 50 kHz to 30 MHz. One of the antenna modules of the system similar to described in [4, 5] was used. The receiver was constituted of one of the loop antennas with matching amplifier, and was connected to the recording unit consisting of 14 bits analog-to-digital converter with a conversion rate of 50 MHz and 4 hard drive RAID computer system. This system allowed to record single channel data quasi-continuously for several hours with a loss of approximately 3–5% of the data. The loss was rather random but of blocks of 16 MB approximately corresponded to 160 millisecond intervals of missed data. The record can be long enough to cover a whole duration of thunderstorm. The continuity of the record (positions of intervals of missed data) was monitored during data processing by signals of the RWM radio station that transmits the reference frequency and time. Additionally, signals from several continuous wave (broadcasting) radio stations were used for this purpose. Radio station signals were extracted directly from the obtained record by appropriate filtering.

3 Observations

Observations presented here were carried out on June 22, 2016 during a local thunderstorm. Its temporary behaviour is presented in the Figure 1 based on the data of World Wide Lightning Location Network (WWLLN, green line) and Nizhny Novgorod Regional Lightning Location Network (NNRLLN [9], blue line). Numbers of events registered by both networks in the 100 km vicinity of the receiving point in 5-minute intervals are shown, and WWLLN data are multiplied by 4 in order to maintain scale. It should be mentioned an absense of NNRLLN data at some intervals where the number of events value is zero.

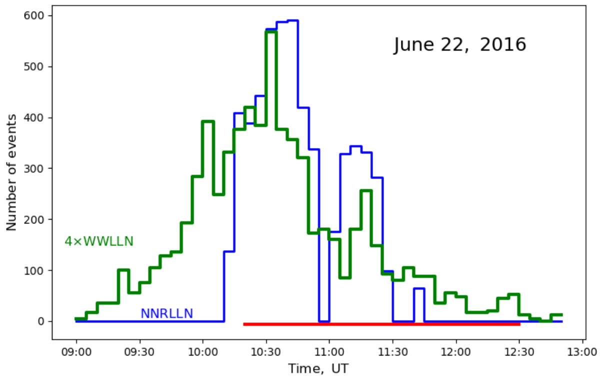

Figure 1. Temporary behavior of thunderstorm intensity according to the worldwide (WWLLN, green) and regional (NNRLLN, blue) lightning location networks. The number of events recorded in 5-minute intervals in the 100 km vicinity of the observational point is given. In order to maintain scale the data of the WWLLN is multiplied by 4. The interval of quasi-continuous recording is shown by the red line along the time axis.

Radio frequency emission data were recorded for more than two hours starting at approximately 13:20:43 Moscow time (UT+3h) which approximately coincides with the local time. The recording was started at the stage of the development of a thunderstorm preceded its maximum intensity, and ended with the almost complete cessation of thunderstorm activity. Its interval is shown in the Figure 1 by the red line along the time axis.

The length of the record was approximately 2 hours, 9 minutes and 46 seconds, and data were lost for about 4 minutes and 53 seconds (about 3.76%) in total. The Figure 2 shows the behavior of the root mean square value of the received signal calculated at intervals of 1 millisecond for the whole time of observations.

A test was conducted during the recording to ensure that recorded signal comes from the antenna but not from the (rather long) cable that connects the antenna with the recording unit. For this purpose the power to the matching amplifier of the antenna was turned off during the recording for about 5 minutes (corresponds to a dip in the signal in the Figure 2). As a result, it was found that crosstalk on the cable is below the signal level from the antenna by at least 40 dB.

A continuous part of the record covered 10 seconds of observations and started at 10:20:45.000 UT is shown in the upper panel of the Figure 3. It presents typical behavior of thundercloud radio emission during the whole thunderstorm. It can be seen from the Figure 3a that the emission exists at time intervals with a characteristic length of a fraction of a second separated by intervals of approximately the same length when the emission (at the sensitivity level of the receiving unit) is absent. Free of emission intervals became longer to the end of the thunderstorm reaching several seconds. The beginning of radiation is always sudden and does not show gradual development.

It should be noted that WWLLN registered three lightning discharges in the corresponding region during the time interval shown in the Figure 3a. Discharges are marked by large downward triangles and occured at 13:20:47.759899, 13:20:50.701673 and 13:20:54.381755 LT at distances of about 50, 90, and 90 km from the receiving point correspondingly. More discharges were found by the NNRLLN showed by small downward triangles. All recorded events are accompanied by thundercloud radio emission. But enhancements of the radio emission similar to others at 4 and 8 seconds were not connected to any registered lightning discharges.

A part of the record corresponded to the beginning of the first period of strong radio emission shown in the Figure 3a is presented in the further panels b)–d) of the Figure 3 at different temporal resolutions. These panels demonstrate sudden beginning of the emission, its pulsed nature, and bipolar character of pulses at this stage. Short bipolar pulses have large amplitudes from the very beginning and are separated by rather long interpulse periods. Typical length of the pulses is about few tens of nanoseconds while interpulse periods varies from several to few tens of microseconds.

4 Pulsed thundercloud emission

An analysis of the radio emission from thunderclouds was carried out with a view to determine periods of existence of the submicrosecond pulse component. It is proposed to use two indicators of the presence of a pulsed component in the radio emission with intervals between pulses significantly exceeded their duration: 1) the ratio of the root mean square (RMS) and median absolute deviation (MAD) of the measured radio signals, and 2) the kurtosis coefficient of the distribution of the values of the received signal at different time intervals. Both indicators are sensitive to the presence of pulsed component in the received signal. In order to extract submicrosecond pulses separated by intervals of one and tens of microseconds characteristic for radio emission from lightning discharges the calculations should be performed at the intervals of fractions of a millisecond.

The first indicator is based on the fact that the pulse component increases the RMS value of the received signal practically without changing its MAD.The RMS to MAD ratio for Gaussian noise is equal to $(\sqrt{2}\mathrm{erf}^{-1}(1/2))^{-1} \approx 1.4826$, for a harmonic signal it is 1, and for rare pulses in the absence of noise tends to infinity. Thus, the high value of this relationship can testify the pulse nature of the signal. This indicator can be used when the energy of pulsed radi-

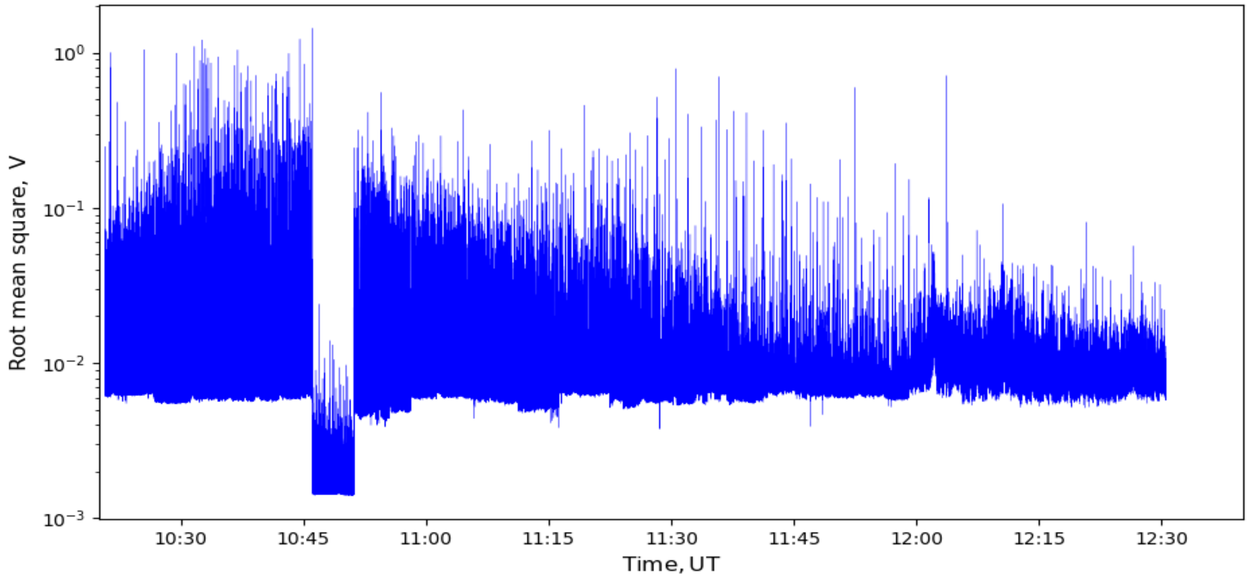

Figure 2. Quasi-continuous record of radio frequency emission from the thundercloud. The dip between 13:45 and 13:50 corresponds to turn off of the antenna matching amplifier.

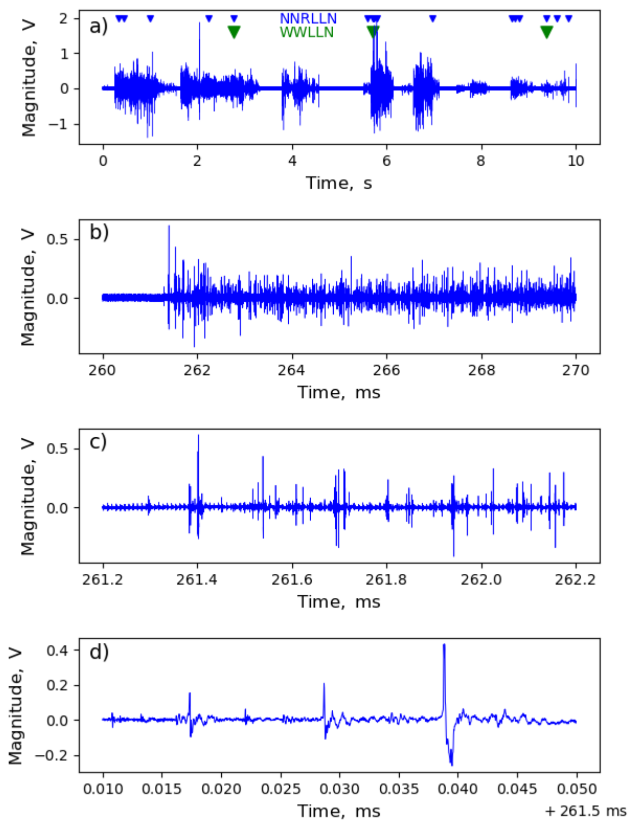

Figure 3. a) The continuous 10 s part of the record of the radio emission from a thunderstorm cloud started at 13:20:45.000 local time. Large green downward triangles show lightning discharges registered by the WWLLN, small blue triangles correspond to discharges registered by the NNLLN. b)–d) A part of the record of the radio emission presented in the panel a) at different temporal resolutions.

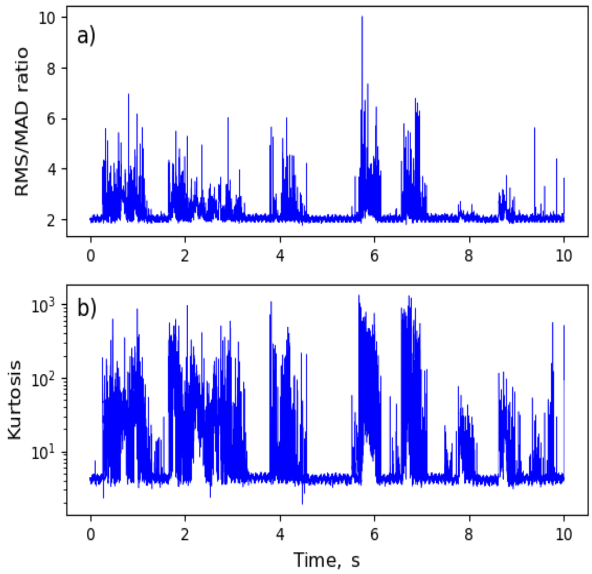

Figure 4. a) The root mean square (RMS) to median absolute deviation (MAD) ratio for the part of the record shown in the Figure 3a. b) Kurtosis coefficient for the same part of the record.

ation is an appreciable fraction of the total energy of the received signal, and also characterizes the energy distribution between the pulsed and quasi-continuous (noise) emission of a thundercloud. Figure 4a shows RMS to MAD ratio for the radio emission from a thunderstorm presented in the Figure 3a.

The second indicator is based on the higher order statistics and is characterized by greater sensitivity to the presence of the pulsed component in the radiation. This coefficient characterizes the severity of the distribution function. For Gaussian noise it is equal to 3, and 1.5 for a harmonic signal. For a pulsed signal a significant increase in this coefficient is expected. Kurtosis analysis allows to detect rare but strong pulses that does not contribute to the received radio wave energy essentially. Figure 4b shows kurtosis coefficient for the radio emission from a thunderstorm presented in the Figure 3a.

A comparison of Figures 4a and 4b shows that the kurtosis coefficient is a brighter indicator of pulsed radiation while RMS to MAD ratio can be used to determine a part of the radiated energy lying in the pulsed component.

The length of pulses varied from less than 100 to several hundred nanoseconds while interpulse periods lasted from few to several hundred microseconds.

5 Conclusion

For the first time quasi-continuous observations of radio emission of thunderclouds over a wide frequency range with a submicrosecond temporal resolution during the whole time of a thunderstorm existence are presented. It is shown that thundercloud radio emission always begins suddenly without any gradual development. It exists on time intervals with a characteristic length of a fraction of a second, separated by intervals of approximately the same length, when the radiation (at the sensitivity level of the receiving device) is absent. The thundercloud emission is primarily a sequence of short bipolar pulses. Although such radiation always occurs when lightning is initiated and develops, it also appears in the intervals between them. At the initial stage there is no essential difference between thundercloud emission preceded and was not followed by a lightning (return stroke).

The shape and duration of the observed pulses, as well as their intensity, correspond to the theory of breakdown on runaway electrons during the passage of wide atmospheric showers caused by cosmic rays through the intense electric field inside a thunderstorm cloud in the presence of hydrometeors [10]. However, this process does not in all cases lead to the occurrence of a lightning discharge, but is a necessary prerequisite for it. The sudden appearance of the emission may indicate that the entire process is initiated by the passage of a particle of rather high energy that can be estimated as of order of 10^{16}eV, and is subsequently maintained by extensive atmospheric showers caused by particles of significantly lower energies $\geq 10^{14}$eV passing through the already ionized region of the thundercloud.

6 Acknowledgements

This work was supported by the Russian Science Foundation through the grant #19-17-00183.

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