High Frequency Radio Emission from a Thundercloud: A Case Study

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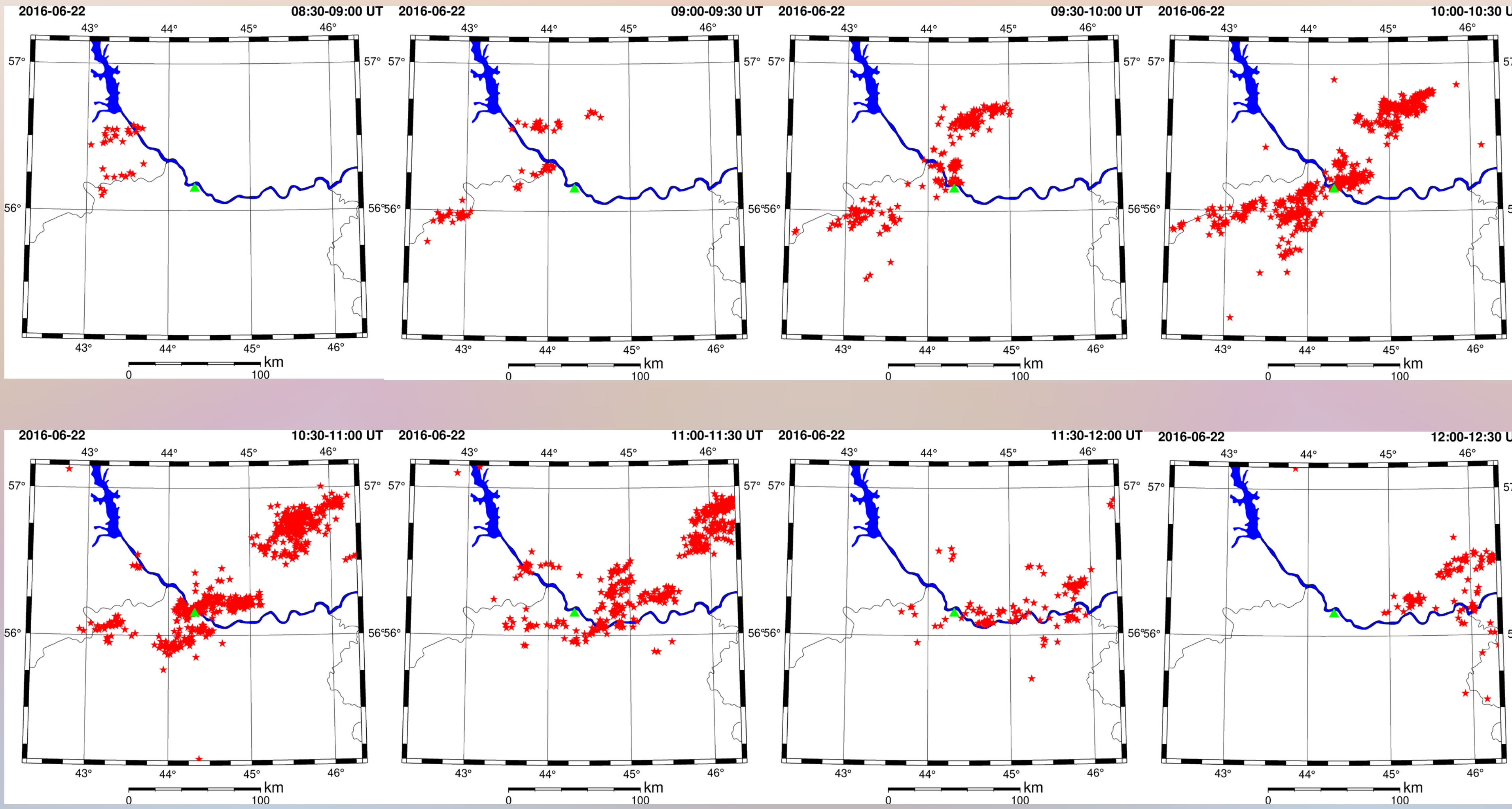
Instrumentation

Receiving point	56.15 N, 44.32 E (Upper Volga region, near Nizhny Novgorod)
Antenna	Rectangular ~40 cm shielded loop
Matching amplifier	Frequency range 50 kHz — 30 MHz, matching to 75 Ω cable of ~50 m length
Analog-to-digital converter	14 bits, 50 MHz conversion rate
Data storage	4 HDD RAID, 4TB

Allows quasi-continuous single channel record of radio emission waveform with 20 nanosecond temporal resolution for ~10 hours with a loss of ~3–5% of data.The loss of data by blocks of 16 MB (~160 milliseconds). Main data continuity checking by signals of RWM radio station (reference frequency and time) filtered from obtained record.

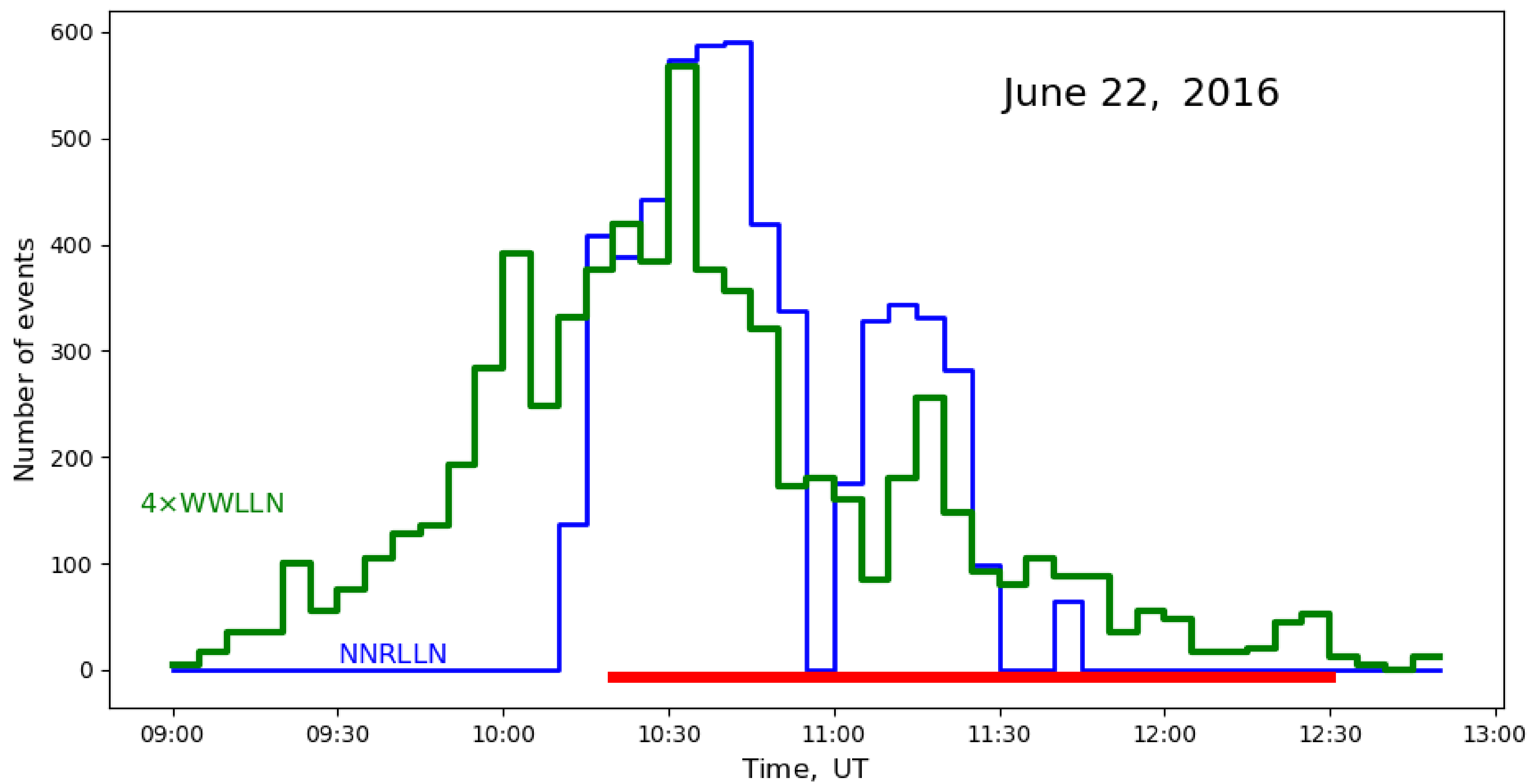
Observations

June 22, 2016 thunderstorm nearby the receiving point (green triangle).
Red stars — registered by WWLLN events (lightning discharges).
The record was started at about 10:20 UT (upper right picture).



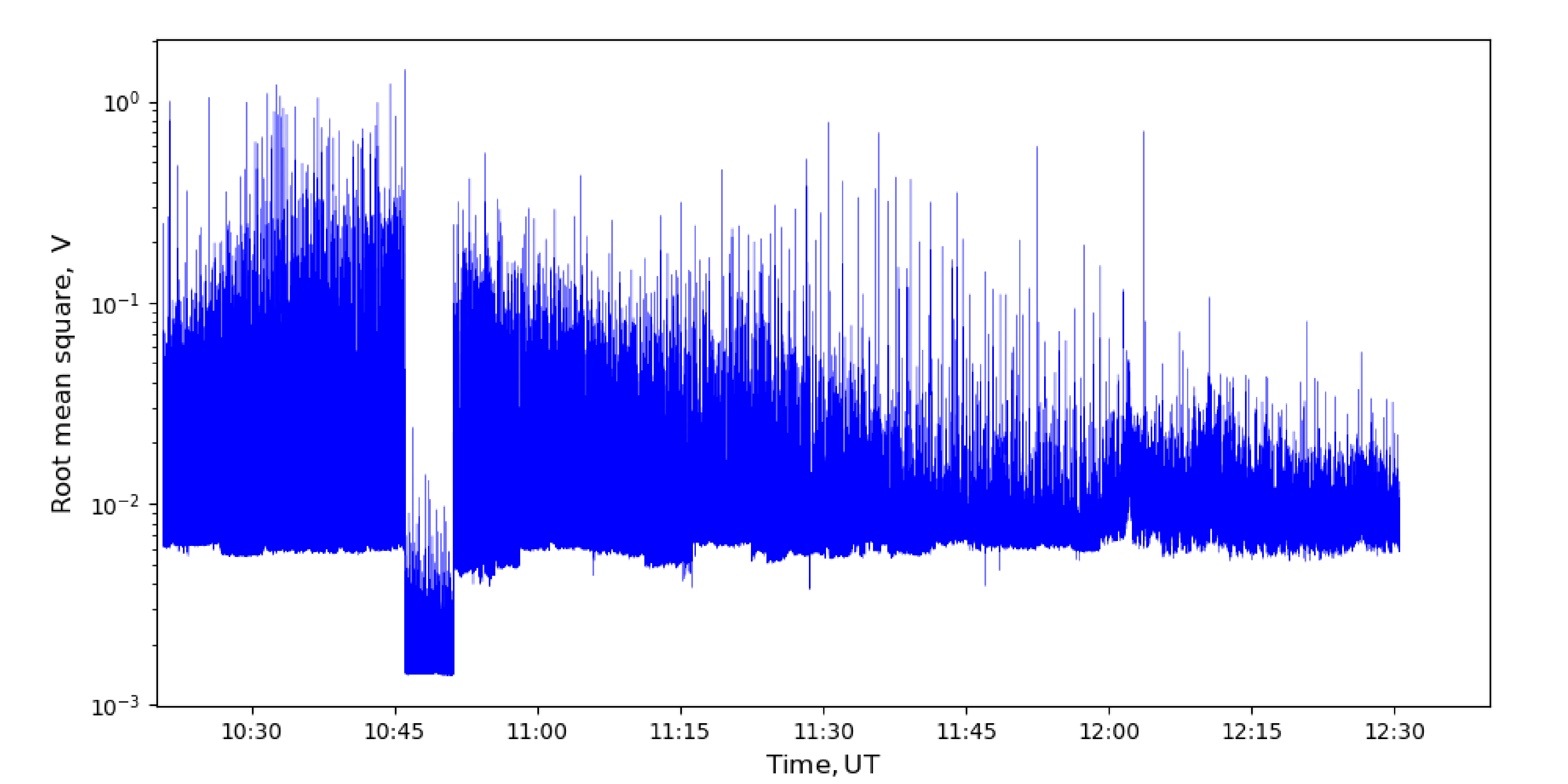
Observations

Temporal behavior of June 22, 2016 thunderstorm occured nearby the receiving point according to worldwide (WWLLN, green) and regional (NNRLLN, blue) lightning location networks. The number of events recorded in 5-minute intervals at distances up to 100 km from the receiving point is shown. Radio emission data recording period is indicated by the red line along the time axis.



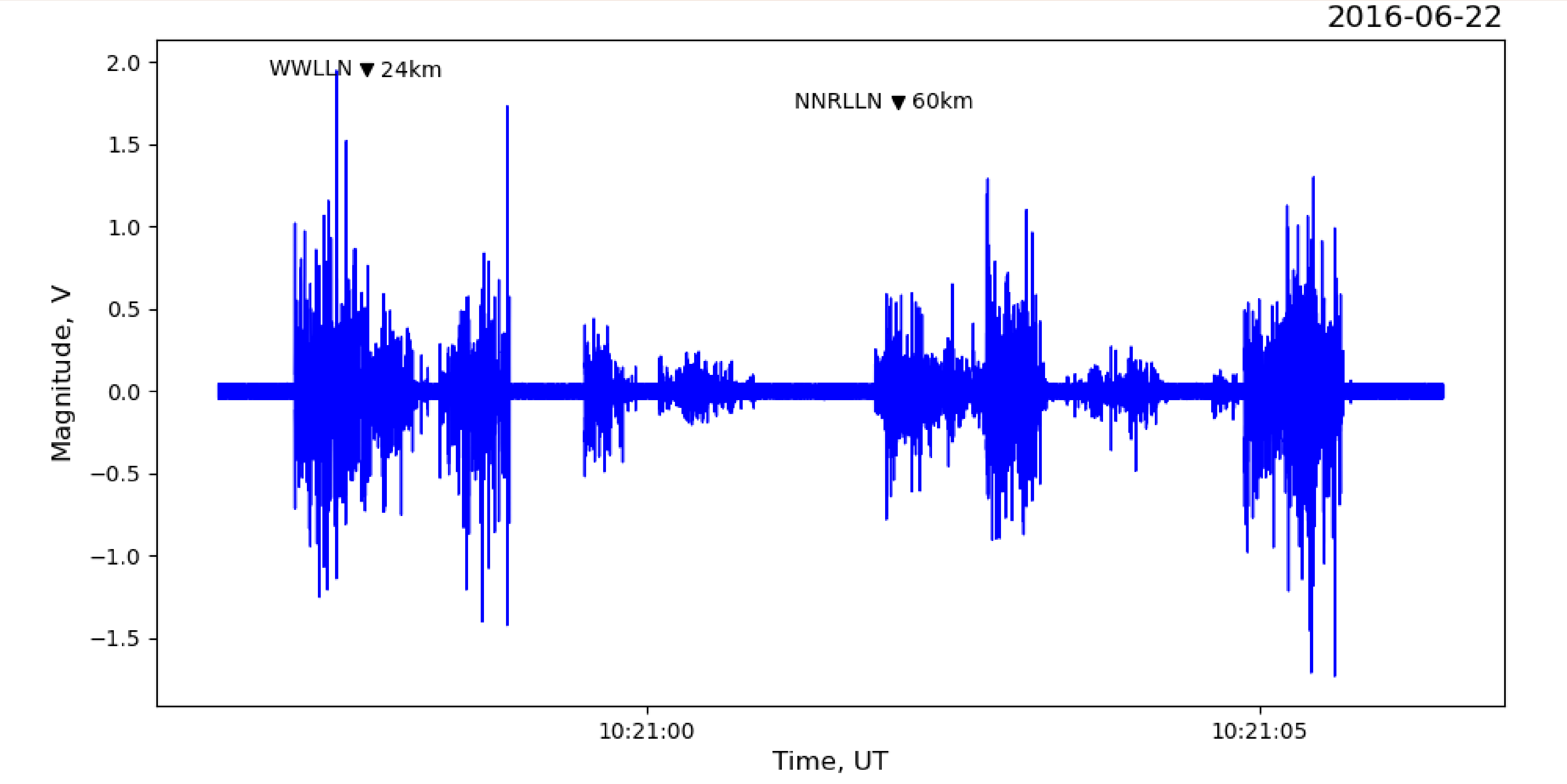
Observations

Radio frequency emission record started at 10:20:43 UT (LT ≈ UT+3h). Root mean square over 1 millisecond intervals is shown. Record length $2^h\ 9^m\ 46^s$, data loss $4^m\ 53^s$ (~3.76%). 10:46-10:51 — switch off matching amplifier power to ensure that signal comes from antenna. Crosstalk on the cable is below the signal level from the antenna by at least 40 dB.



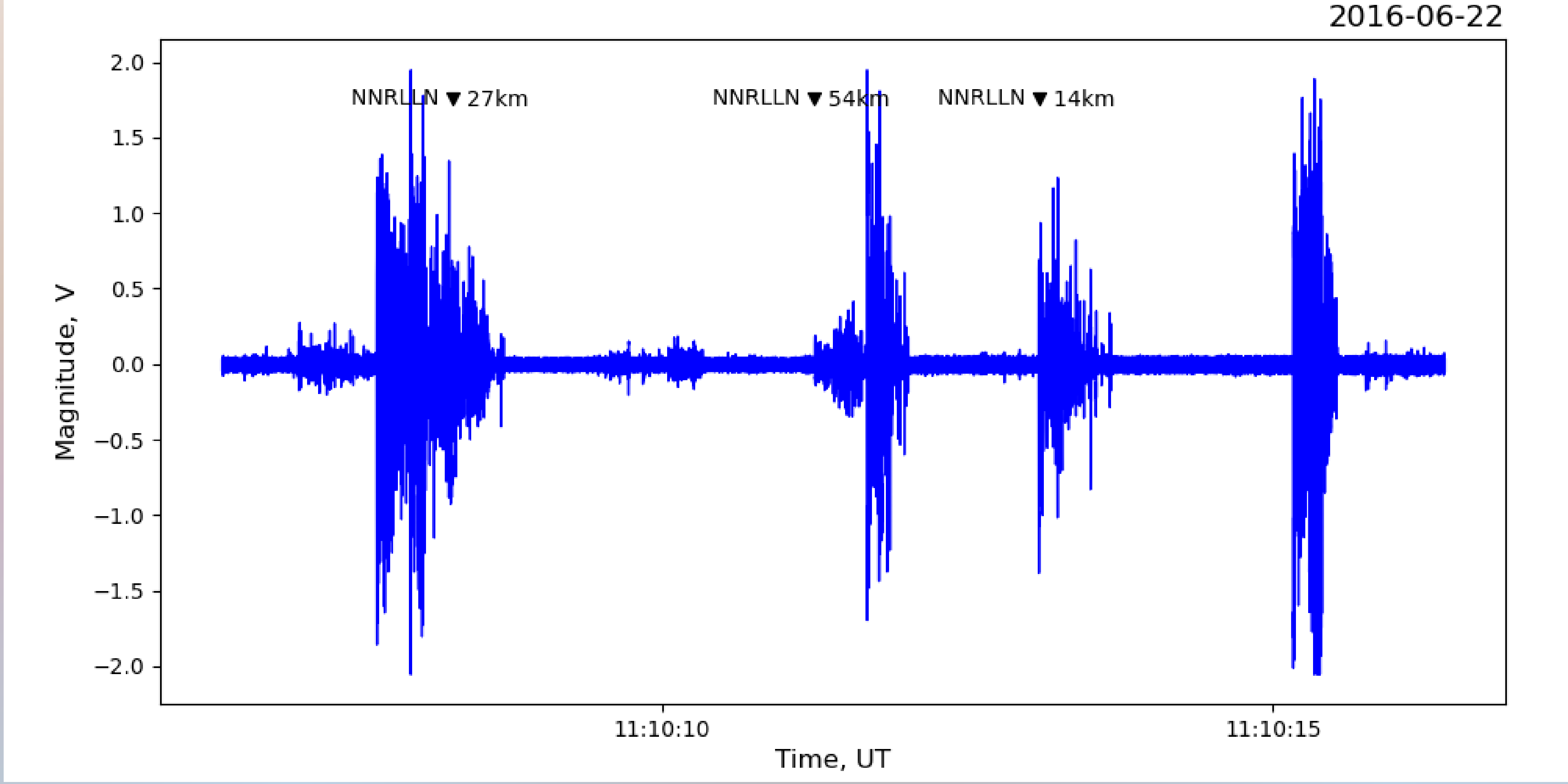
Observations

10-second interval of confirmed continuity part at the beginning of the record — maximum intensity of the thunderstorm. A fraction of a second radio emission intervals are separated by quiet ones of the same order lenghts. Registered by lightning location networks events are shown.



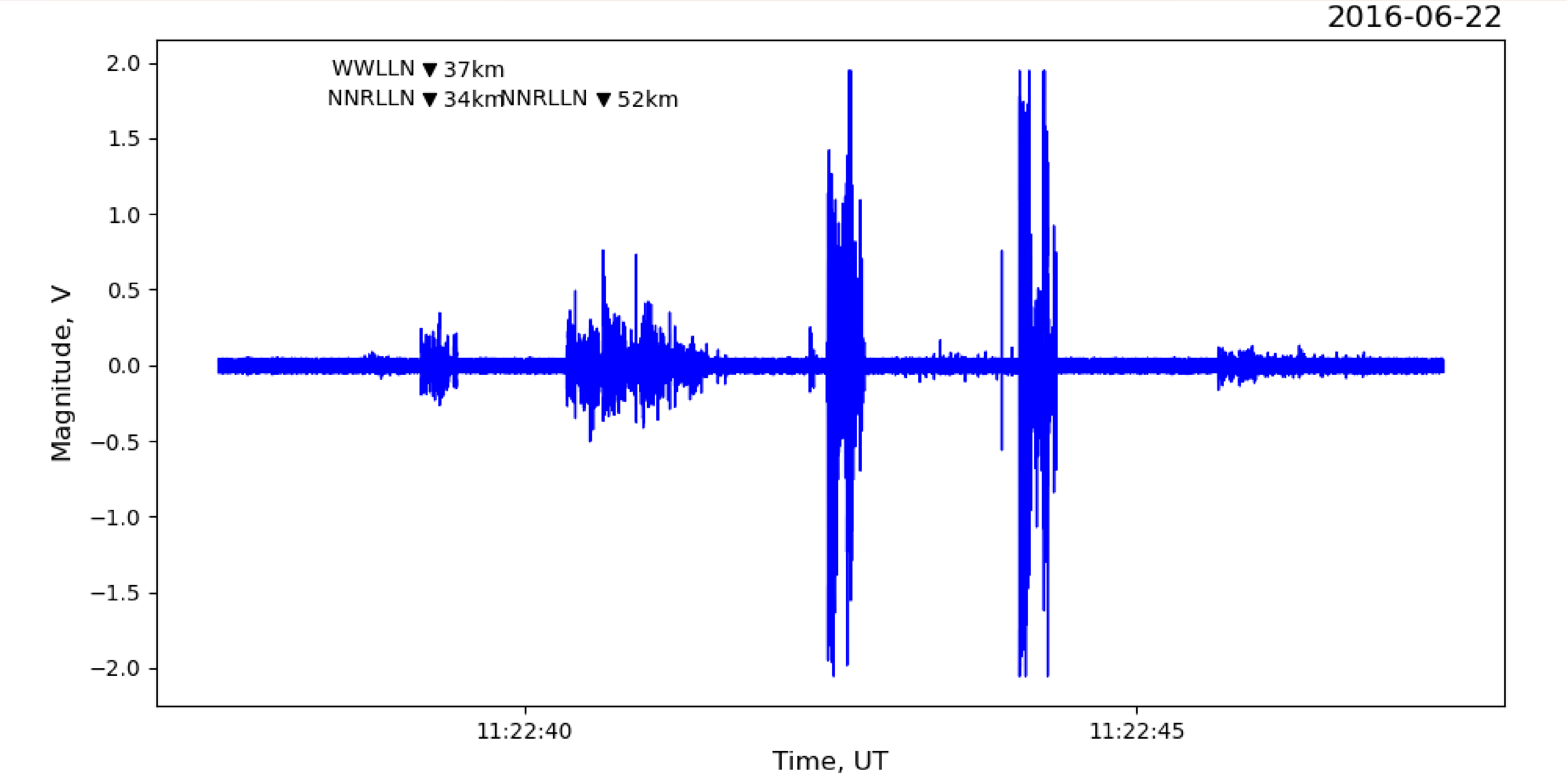
Observations

Another 10-second interval of confirmed continuity part at the middle part of the record — thunderstorm recession. Intervals of radio emission are separated by longer quiet ones. Registered by lightning location networks events are shown for distances up to 60 km.



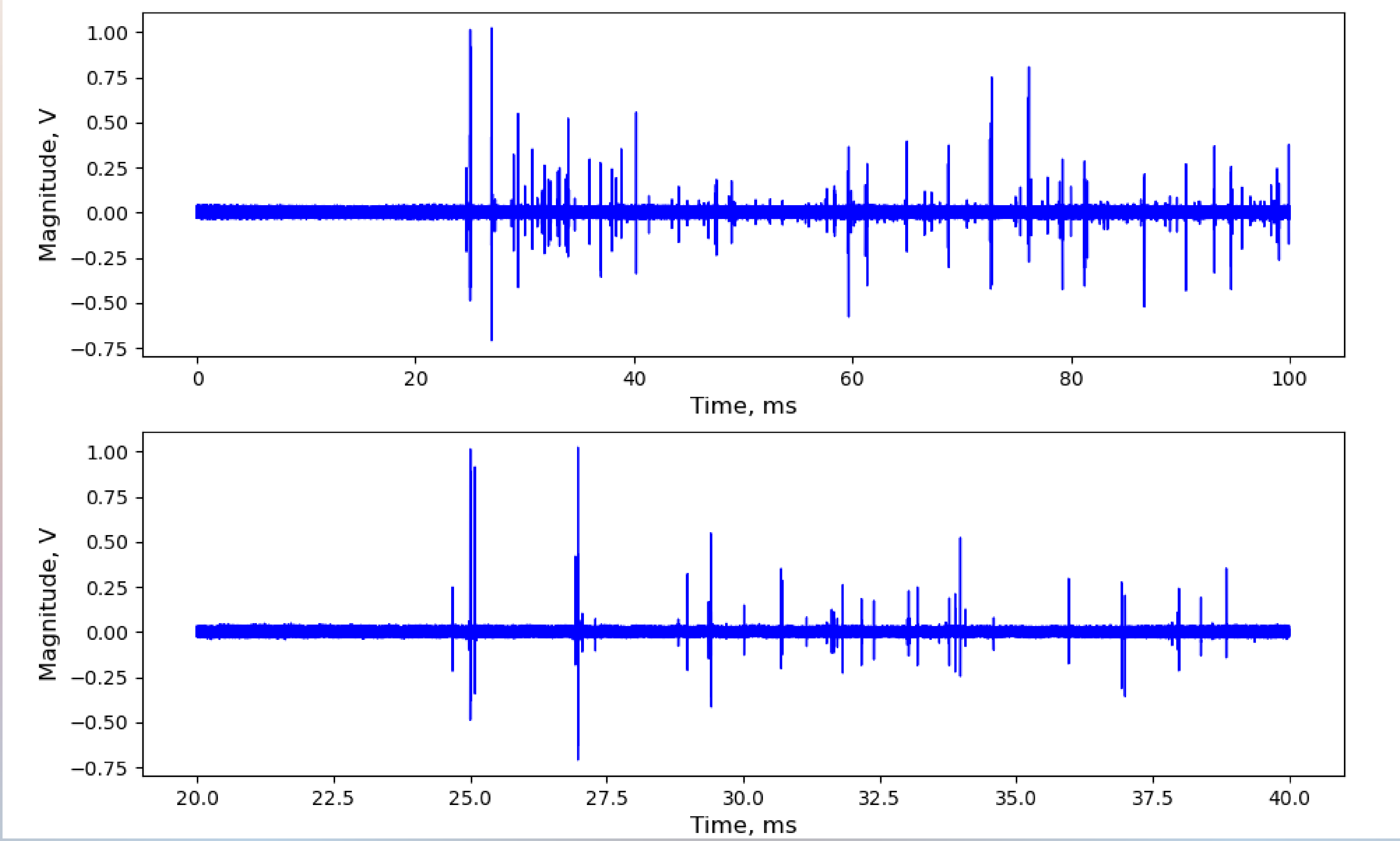
Observations

Other 10-second interval of confirmed continuity part at the middle part of the record — further thunderstorm recession. Registered by lightning location networks events are accompanied by radio emission. But some of the intervals of radio emission are not connected with such events.



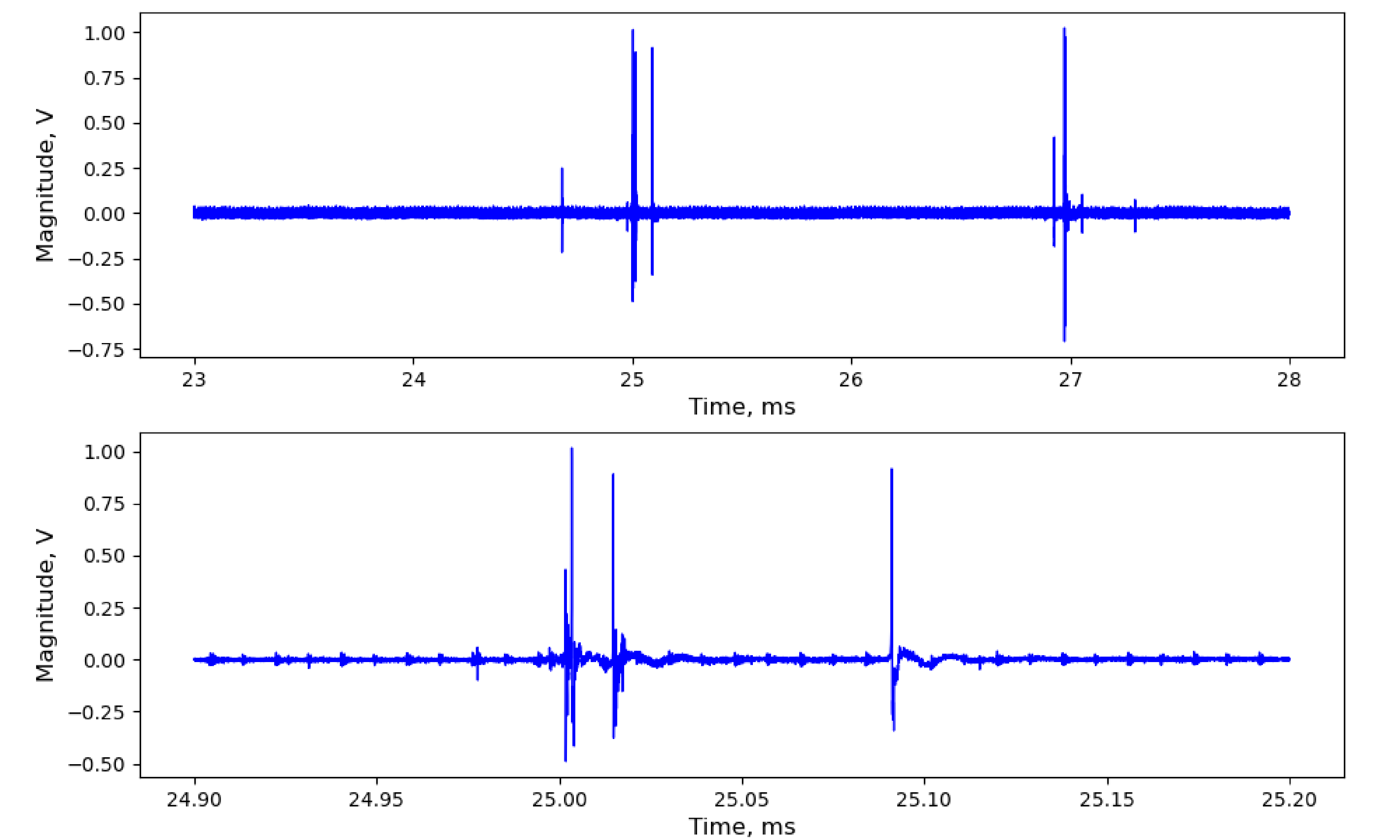
Observations

Scans of the radio emission at the beginning of an emission interval with different temporal resolution. Pulsed structure is clearly seen.



Observations

Scans of the radio emission at the beginning of an emission interval with different temporal resolution — continued.



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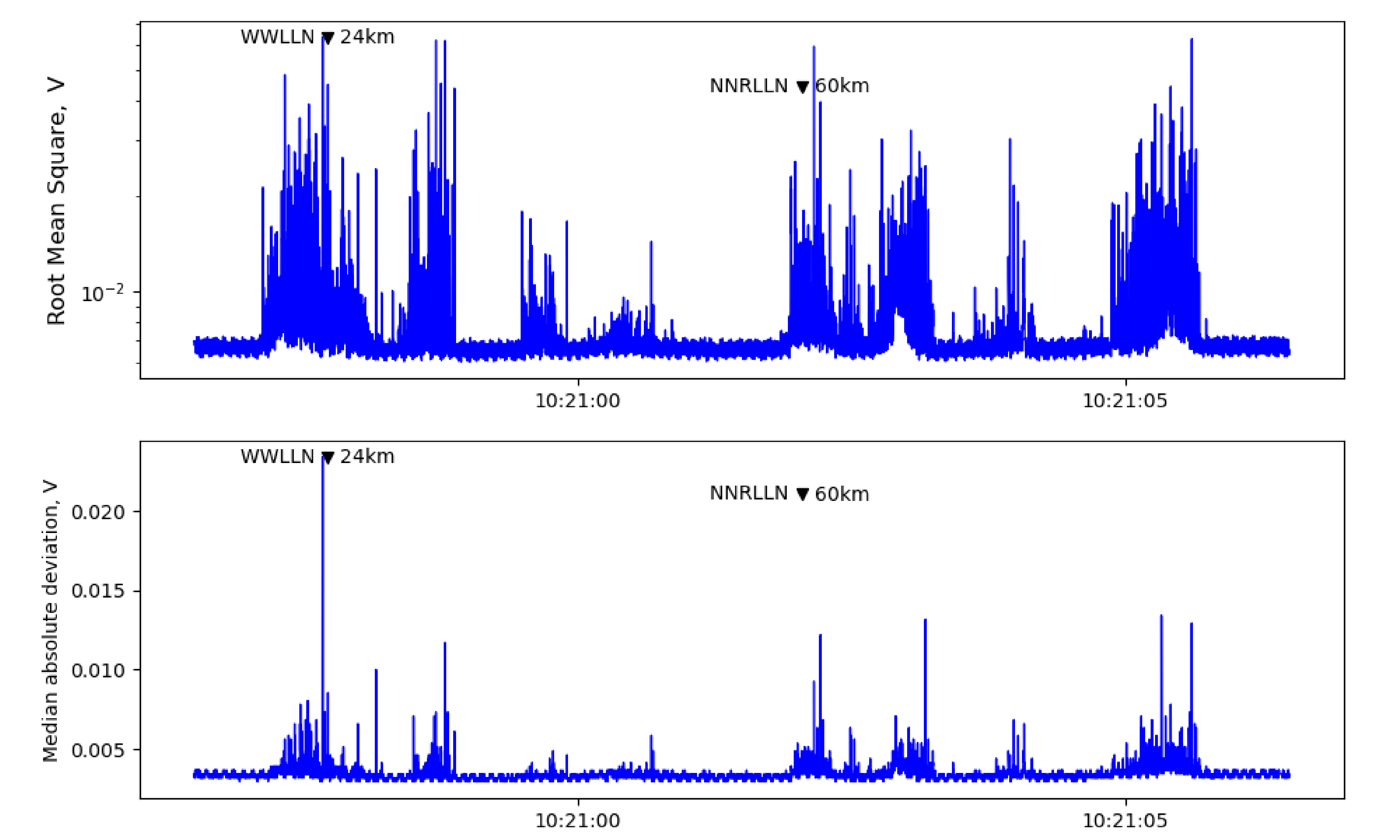
Indicators of pulsed emission

Two indicators are suggested to reveal a pulsed component in the radio emission: the ratio of the root mean square (RMS) and median absolute deviation (MAD) of the measured radio signals and 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.

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 approximately equal to 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 relation can testify the pulse nature of the signal.

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 coeffi cient is expected. Kurtosis analysis allows to detect rare but strong pulses that does not contribute to the received signal energy essentially.

RMS and MAD values calculated on the 1 millisecond intervals for the first shown above 10-second sample of radio emission from the thundercloud. Sudden beginning of the emission is seen on RMS.



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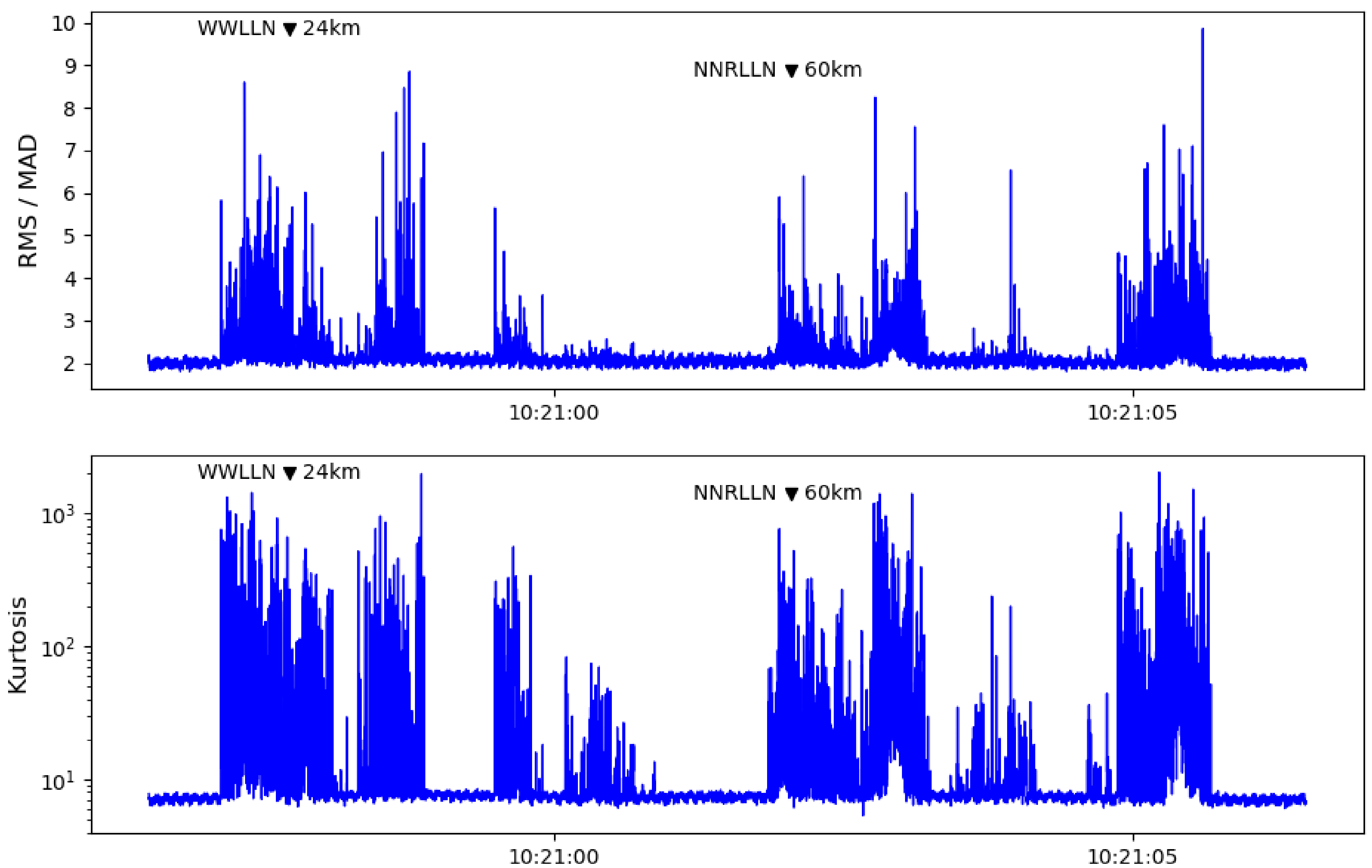
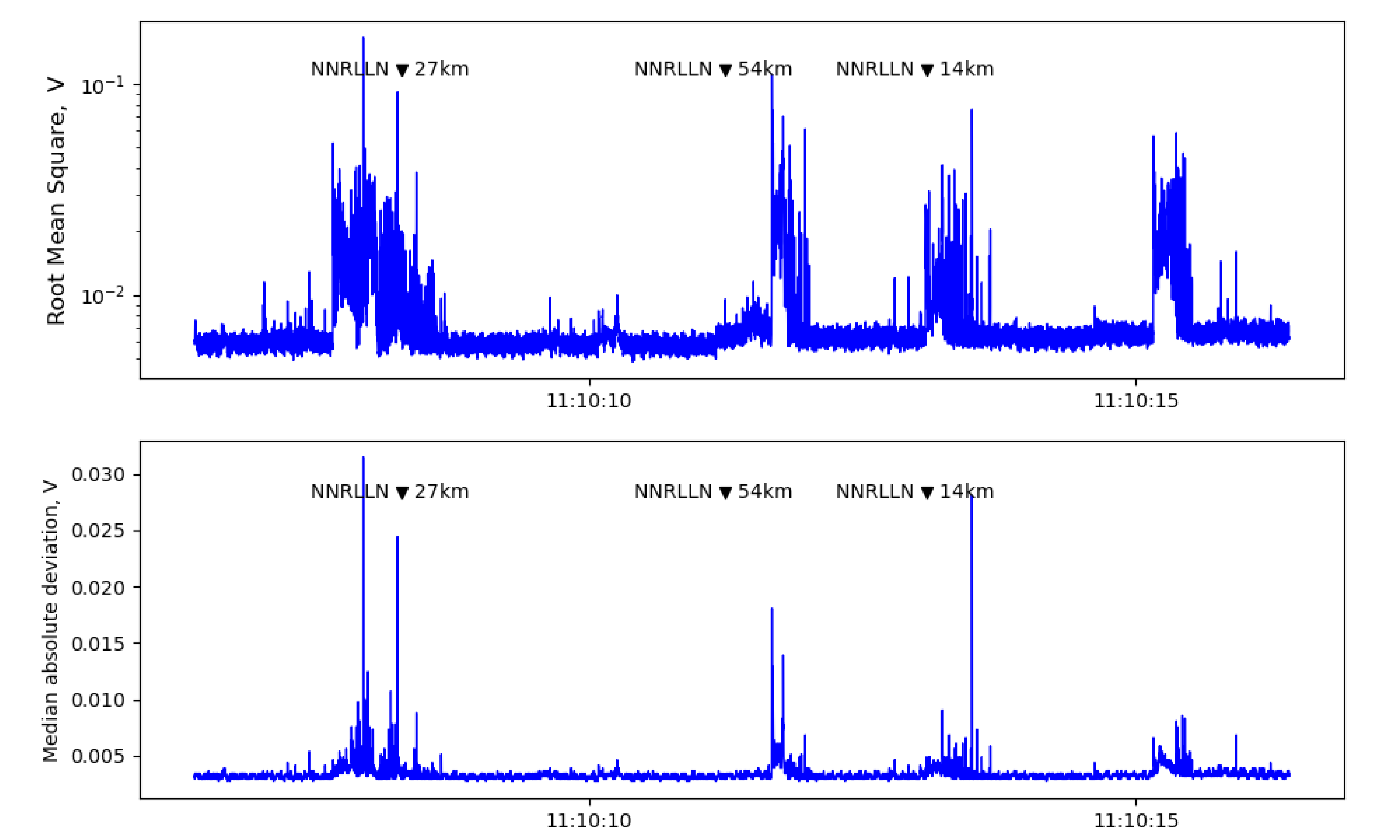
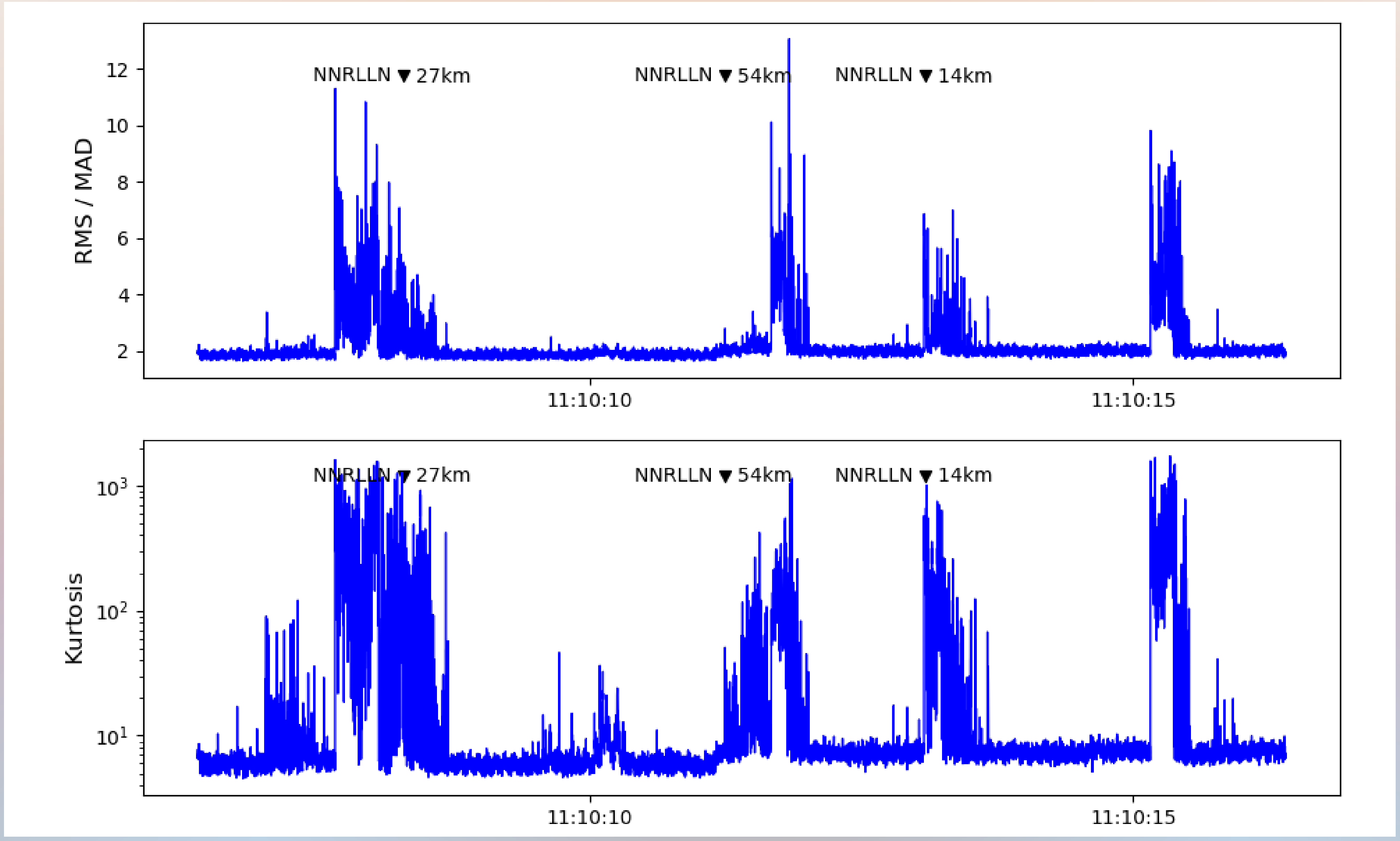
RMS/MAD and kurtosis values for the first shown above 10-second sample of radio emission from the thundercloud. Primarily pulsed nature of the emission is testified by both indicators.



RMS and MAD values calculated on the 1 millisecond intervals for the second shown above 10-second sample of radio emission from the thundercloud.



RMS/MAD and kurtosis values for the second shown above 10-second sample of radio emission from the thundercloud. Extremely high values of kurtosis correspond to the presence of very rear but intense pulses.



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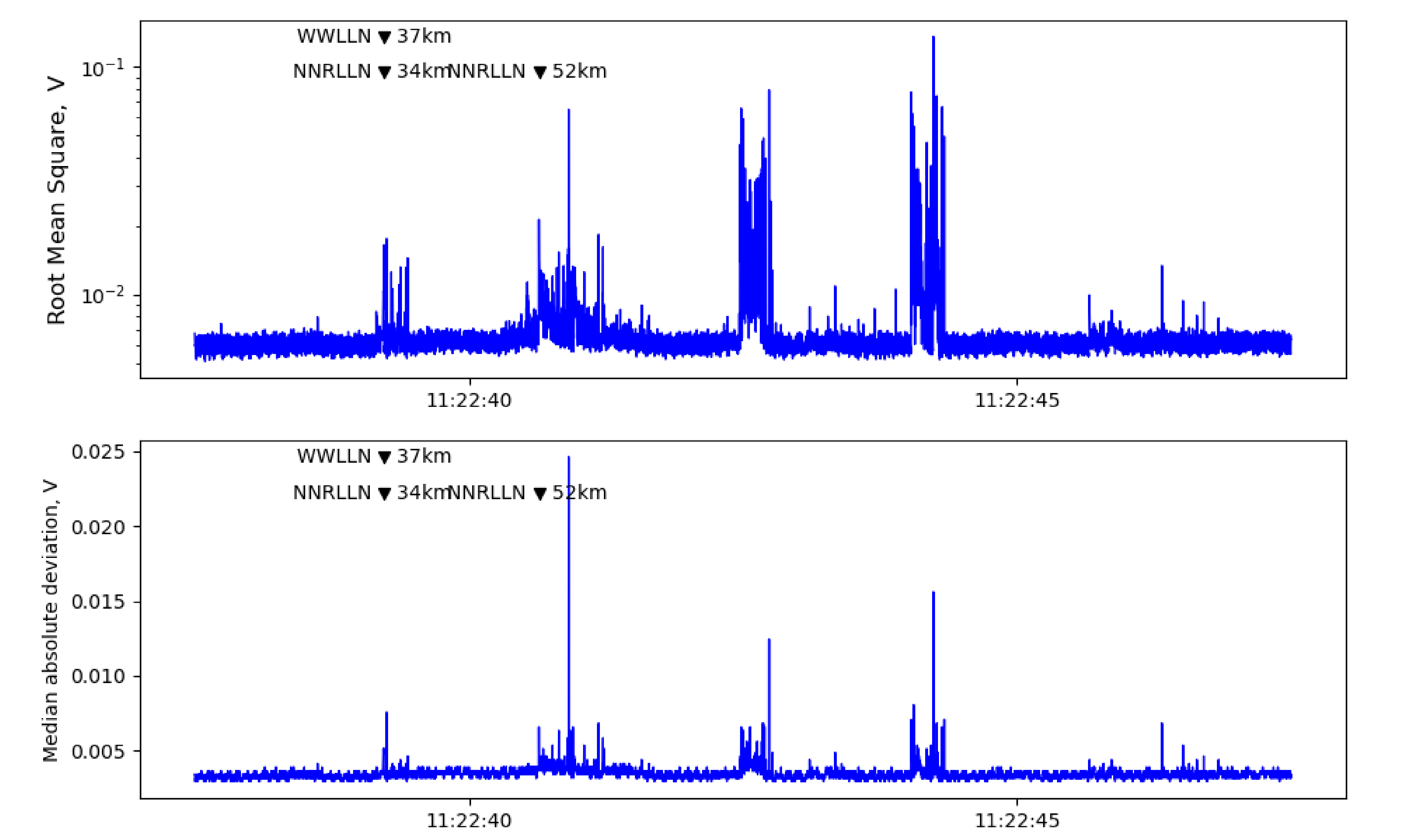
RMS and MAD values calculated on the 1 millisecond intervals for the third shown above 10-second sample of radio emission from the thundercloud.



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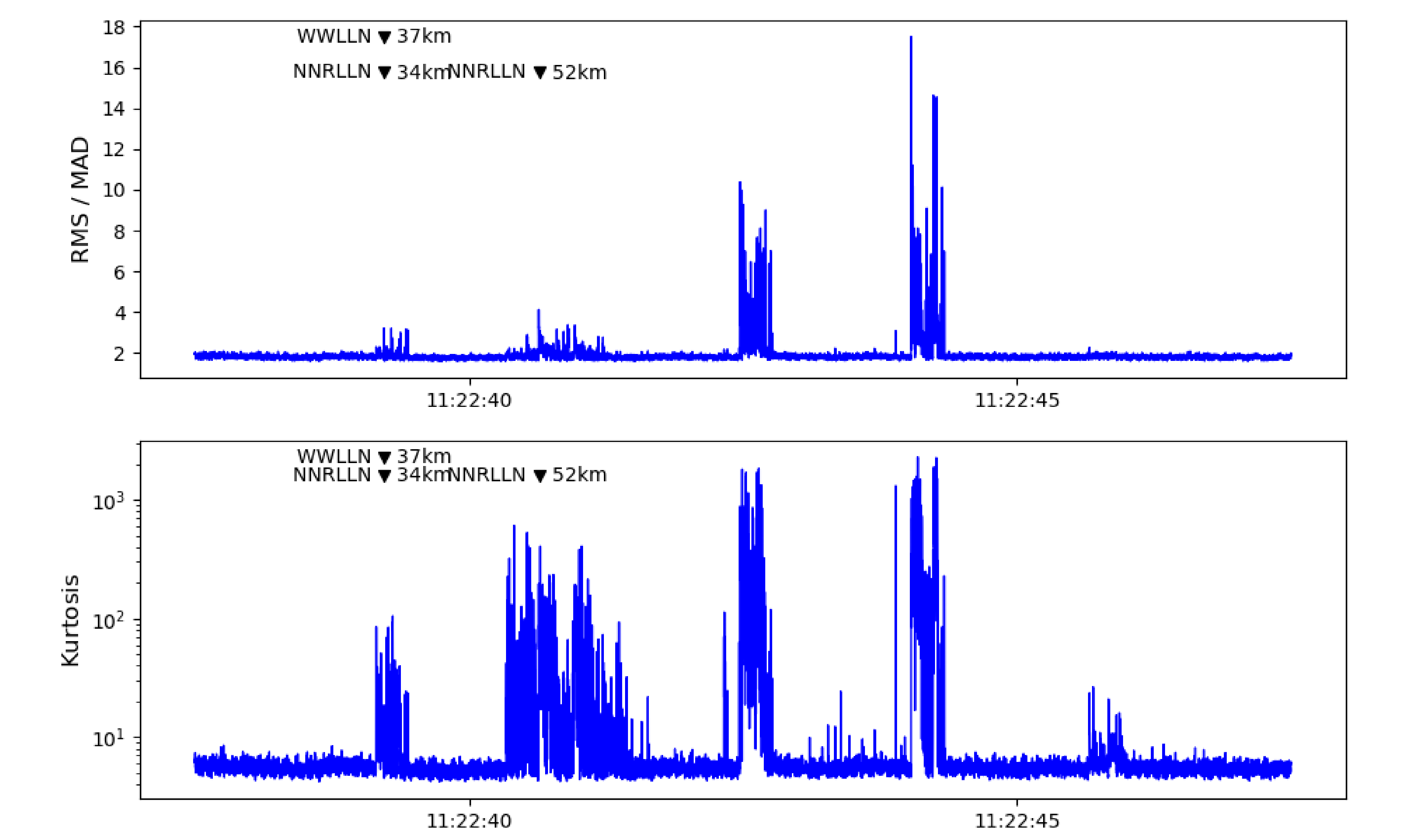
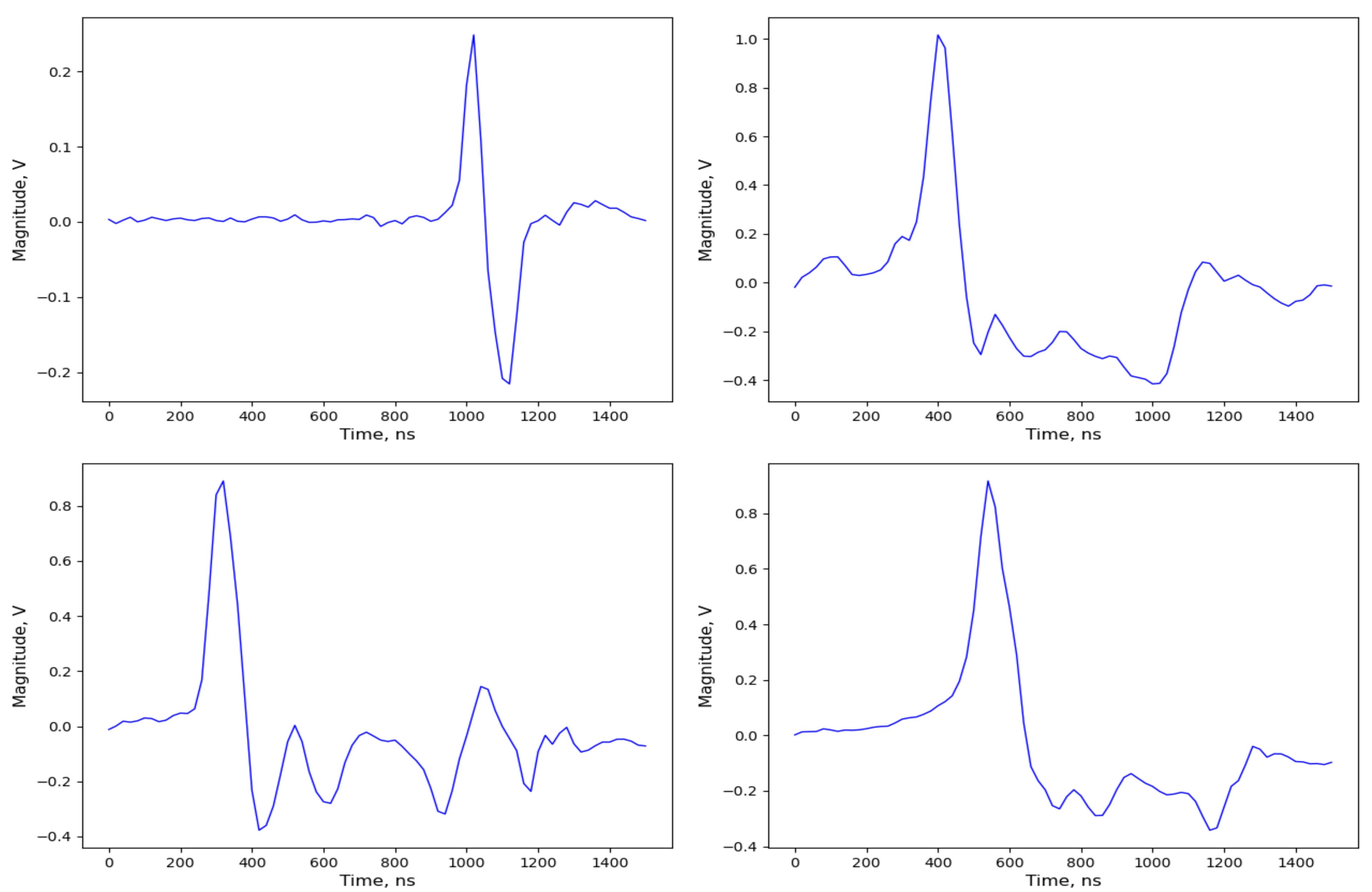
RMS/MAD and kurtosis values for the third shown above 10-second sample of radio emission from the thundercloud. Kurtosis is much more sensitive to the presence of the pulsed component in the emission.

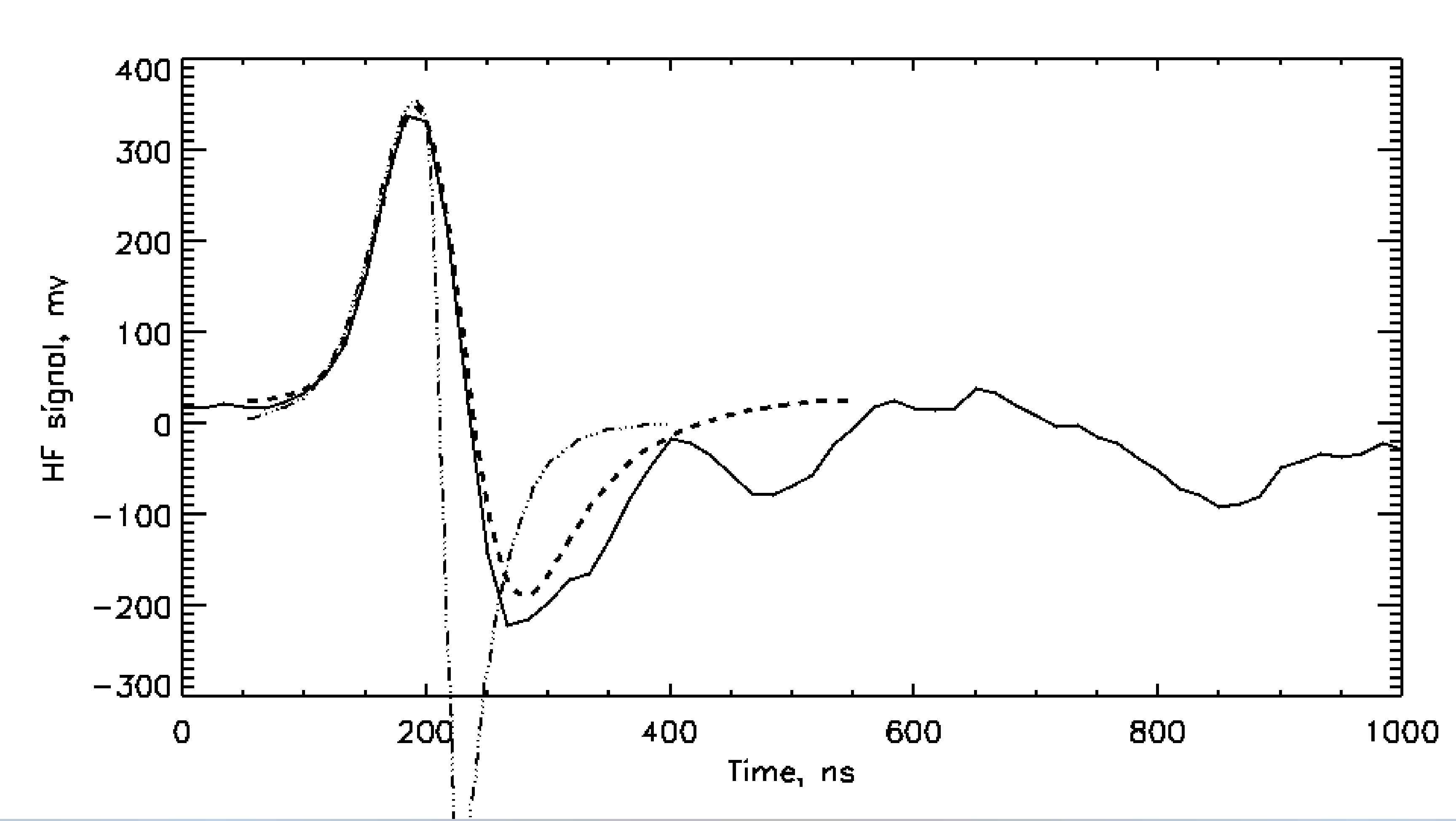


Waveforms of some radio pulses observed at the beginning of the one of the intervals of thundercloud emission.



Comparison of the observed radio pulse form (solid) with the theoretical predictions of radio emission from runaway breakdown process initiated by an extensive atmospheric shower calculated in [A.V. Gurevich et.al., 2004, Phys. Lett. A 325, 389] (dash-dot) and [J.R. Dwyer, M.A. Uman, H.K. Rassoul, 2009, J. Geophys.Res., 114, 6867] (dash).

Borrowed from A.V. Gurevich, A.N. Karashtin, Phys. Rev. Lett., 2013, 110, 185005



Conclusion

Main properties of high-frequency radio emission from a thundercloud:

- Exists on time intervals of a fraction of a second separated by intervals from a fraction of a second to several seconds when it is absent (at the sensitivity level of the receiver)
- Begins suddenly without any gradual development
- Represents primarily as a sequence of short sub-microsecond bi-polar pulses
- Accompanies all registered by lightning location networks events but exists also beyond them
- At the initial stage there is no essential difference between emission preceded and was not followed by a lightning
- The shape and duration of the observed at the initial stage of the emission 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 thundercloud in the presence of hydrometeors (A.V. Gurevich, A.N. Karashtin, Phys. Rev. Lett., 2013, **110**, 185005)

Thank you!