# Radio-physical methods of analysis for thunderstorm field perturbations


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## Abstract


Complex field experiments have been undertaken on the basis of the observational set-up arranged in the Upper-Volga Region during the convective seasons of 2005-2010. Spectral and statistical characteristics of electric field perturbations in the vicinity of thunderstorm clouds have been investigated. Statistical analysis allowed us to relate found peculiarities with different stages of thunderstorm generator dynamics. We develop our fractal simulation code to take into account the spatio-temporal dynamics of a cloud discharge, to compare the results with the observations and to address several actual problems of lightning initiation physics.


## 1. Introduction

In this study we use a database of the field experiments on the remote sensing of the electric field and current, as well as on the registration of radio-emissions from near and far-away thunderstorms occurred in the Upper Volga region during the convective seasons of 2005-2010. Complex field experiments have been undertaken on the basis of the observational set-up arranged in Nizhny Novgorod and Gorodets about 60 km to North-West from Nizhny Novgorod. Radio-emissions from thunderstorms were registered with a portable three component (two components of horizontal H-field and vertical E-field) ELF receiver. The sampling frequency was 20 Hz under fair weather conditions and 20 kHz during one hour after the triggering signal when a thunderstorm is detected. Synchronous four channel registration with time resolution of 50 microseconds (in a fast mode) provided fine structure of lightning-current observations.

We used the data of a 3.2 cm - wavelength radar situated in Nizhny Novgorod with the effective range of about 150 km, and the data of standard aerologic sounding performed in Nizhny Novgorod [1]. As a result of observations a unique database of aeroelectric and magnetic data has been created for extreme meteorological events occurred in summer periods of 2005 - 2010. As bright examples of extreme events over Upper Volga region we present the characteristics of most intensive thunderstorms of 2010 (see Fig.1-2).

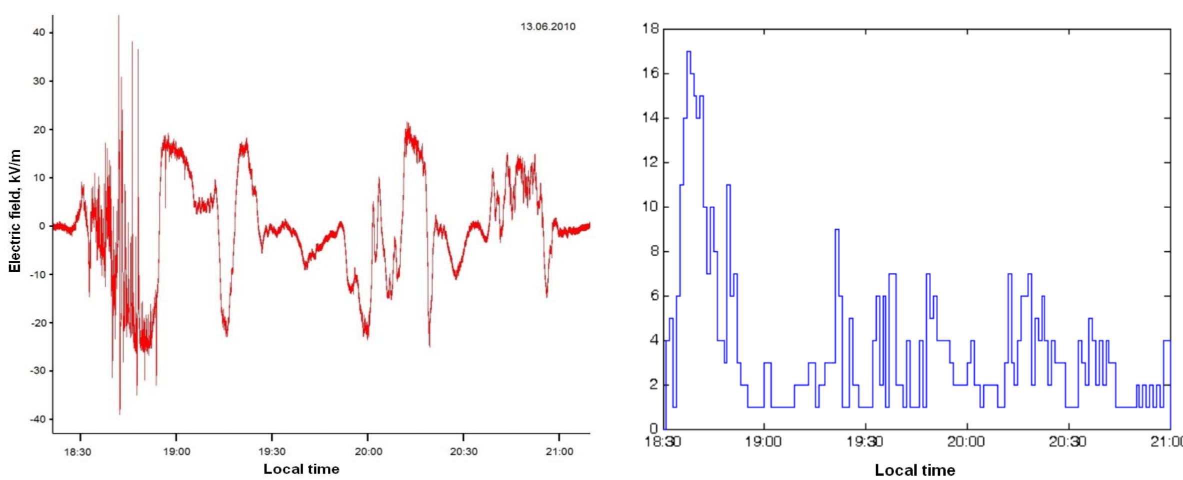


Fig.1. a) Electric field perturbations and b) -number of lightning discharges per minute occur during severe thunderstorm 13.06.2010


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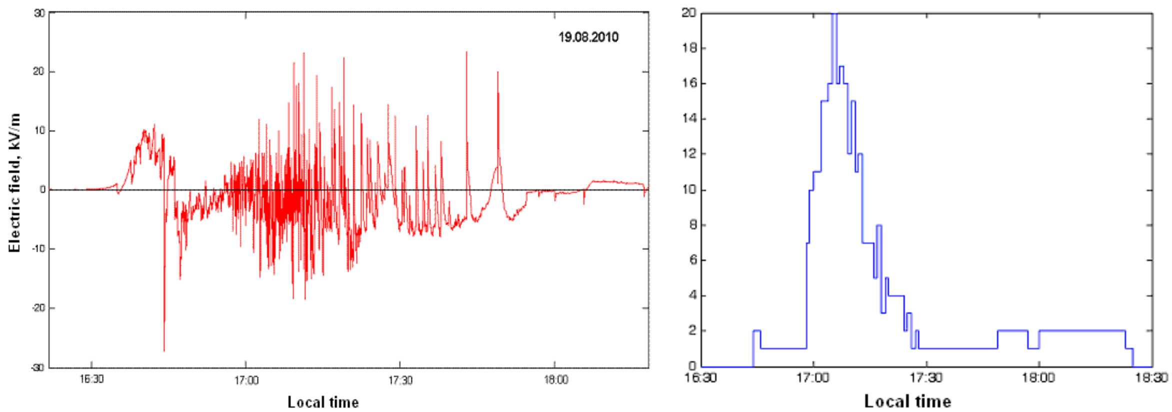



a) b)

Fig.2. a) Electric field perturbations and b) -number of lightning discharges per minute occur during frontal thunderstorm 19.08.2010

## 2. Spectral and statistical characteristics of electric field perturbations

Spectral and statistical characteristics of the electric field perturbations in the vicinity of thunderstorm clouds have been investigated using the data of electrostatic fluxmeters. Observations have been organized at three stations, spaced at the distances from 8 to 60 km each from another, and performed during the convective seasons of 2005-2010. It was found that there are three characteristic bands in the distribution of spectral power density (SPD) for the electric field perturbations. First one, where the SPD weekly depends on the period, corresponds to the fluctuations with time periods exceeding 20 min. In the second band with time periods from 1min to 20 min the SPD falls exponentially. The third band corresponds to the pulse process, where the SPD follows the power law dependence $f^{-2}$ for the frequencies exceeding about $10^{-1}$ Hz. The statistical analysis of time intervals between the pulses showed that for the relatively low flash frequency about 1 flash per min the interval durations are distributed according to the exponential law ~exp($-t/\tau$), which means that there is no correlation between pulses, while the mean interval duration equals to the mean square deviation value $\sigma_{msd.} \approx \tau$. The results of 7 thunderstorm event statistical analysis are shown on Fig.3.

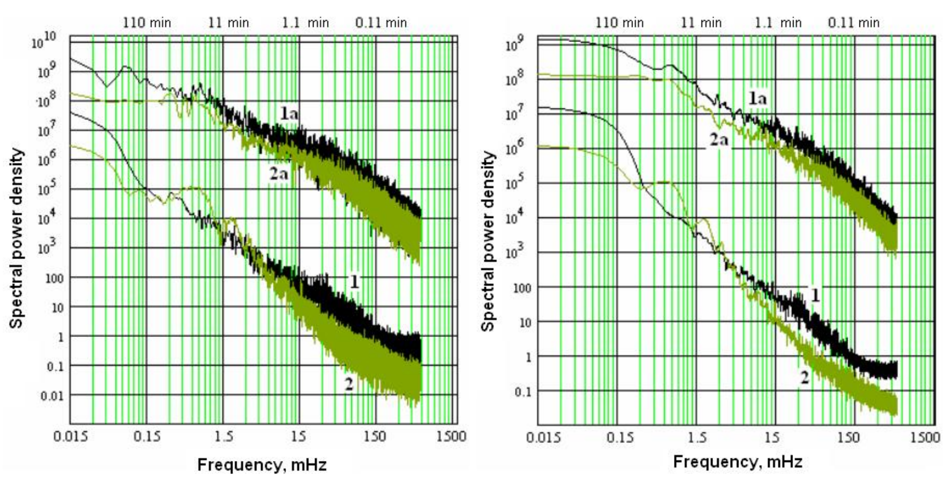


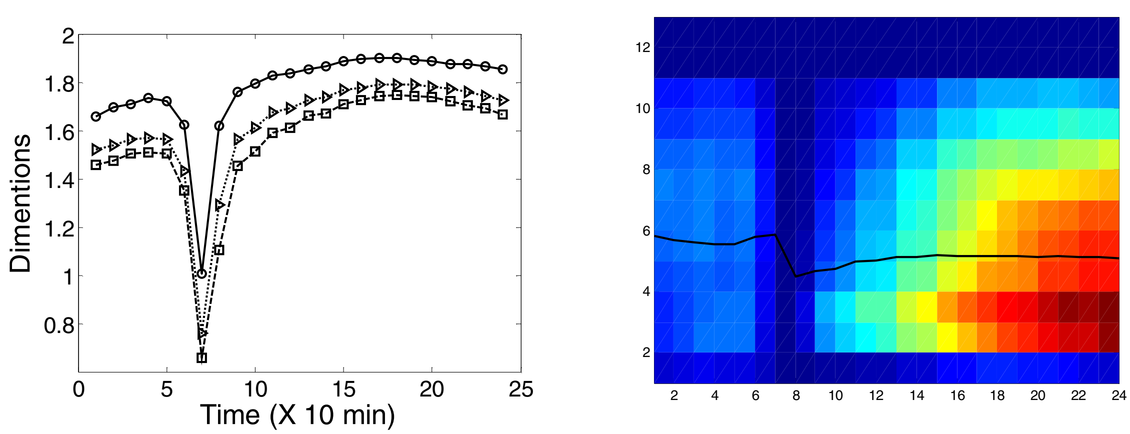

Fig.3. Spectral power densities averaged on 7 thunderstorm events in 2009. 1 and 2 – SPD for pre-thunderstorm conditions, 1a and 2a – SPD for thunderstorms. Numbers are for corresponding observation points. Left picture is for source data, on the right picture SPD for smoothed data.

With the increase of the flash frequency the inequality $\sigma_{ср.кв.} < \tau$ holds so that for the pulse density about ten per min $\sigma_{msd.} \approx 0.5\tau$, i.e. the pulse flow becomes correlated. There is also a clear SPD decrease for short intervals which can be interpreted as a presence of some characteristic "quiet" time interval necessary for a cell regeneration. Rather simple statistical analysis allowed us to relate found peculiarities with different stages of thunderstorm generator dynamics, and derive useful quantitative characteristics of this generator (relaxation time, effective conductivity of a cloud) from the ground-based measurements.

## 3. Fractal models of thunderstorms and lightning

In the course of last decades several fractal models of thunderstorm clouds and lightning discharge were developed [2-5]. A multi-fractal formalism is an adequate instrument for the data analysis (both temporal series and spatial patterns). First of all, it should be noted that a typical pattern of the radar reflectivity for intensive storm events has a multi-fractal nature. The result of fractal modeling of pattern of the radar reflectivity for the thunderstorm on 19.08.2010 is shown on Fig.4. It is obvious that there was a time moment of bifurcation behavior of the radar echo pattern and vertical coordinate of the "mass center" for a thunderstorm system evolution. Note that satellite data demonstrated a typical picture of a mesoscale convective system development for this event.

A fractal description of discharge is achieved through space sampling in the form of a lattice. Discharge is propagated along the bonds of this lattice, and a probability law of discharge initiation from the edge points is introduced, which depends on a local value of electric field and on a critical value, determining the possibility of a streamer formation. Traditionally the local value of electric field was calculated by step-by-step solution of Laplace or Poisson equations (e.g., [3]). However, a strict consideration of lightning dynamics should include generalization of the solution for a separate streamer on the case of many streamers with branching and mutual influence taken into account. The model we suggest allows us to take into account above mentioned effects [4]. We consider an assembly of intra-cloud multi-size particles under the influence of two main processes. The first is the deposition of electrical charges on the particles. The second is the discharge process itself, which restricts in particular the particle charge growth. These two processes have remarkably different characteristic time. The separation of time scales is closely connected with the existence of the corona breakdown threshold. The fine-scale electrical field has to build up enough to pass a certain critical value. This occurs over a much longer period of time than the short breakdown time interval. This is the separation of time scales that turns our system into the self-organized criticality (SOC) -like state. This peculiar state is characterized with avalanche formation that provides transition from corona to streamer discharges and later from streamer to leader discharge. We developed our fractal simulation code and compared the results with the observations. In our model we took into account in more detail the space and temporal dynamics of the cloud discharge, and the fine structure of the electric field and charge in a cloud. It allowed us in particular to understand better the role of the large-scale and fine structure electric field and charge distribution in a thunderstorm cloud, and to recognize some universal features of the breakdown process.




a) b)

Fig. 4. (a) Evolutions of generalized dimensions D0, D1, D2 (circles, triangles, squares). (b) Evolutions of the vertical projection of the radar echo and vertical coordinate of the "mass center" for a thunderstorm 19.08.2010.

## 4. Conclusions

Several radio-physical methods of analysis for thunderstorm field perturbations were applied for the data of complex field experiments have been undertaken on the basis of the observational set-up arranged in the Upper-Volga Region during the convective seasons of 2005-2010. It was found that there are three characteristic bands in the distribution of spectral power density (SPD) for the electric field perturbations. First one, where the SPD weekly depends on the period, corresponds to the fluctuations with time periods exceeding 20 min. In the second band with time periods from 1min to 20 min the SPD falls exponentially. The third band corresponds to the pulse process, where the SPD follows the power law dependence $f^{-2}$ for the frequencies exceeding about $10^{-1}$ Hz. Rather simple statistical analysis allowed us to relate found peculiarities with different stages of thunderstorm generator dynamics, and derive useful quantitative characteristics of this generator (relaxation time, effective conductivity of a cloud) from the ground-based measurements. We developed our fractal simulation code and compared the results with the observations. In our model we took into account in more detail the space and temporal dynamics of the cloud discharge, and the fine structure of the electric field and charge in a cloud. It allowed us in particular to understand better the role of the large-scale and fine structure electric field and charge distribution in a thunderstorm cloud.

## 5. Acknowledgements

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