Lightning discharges registration by the electric field mill

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Abstract. Analysis of opportunities of use of the electric field mill for lightning discharges detection on the basis of data of an experiment is carried out in the work. Data of joint registration of lightning discharges by the lightning location systems and by the electric field mill are presented. The option of improvement of single-station system characteristics due to joint working of the electric field mill and the lightning direction and range finder is offered.

Introduction

Storm activity monitoring systems [1], the base of which is the lightning discharge electromagnetic radiation reception, have a considerable operation range and allow, as a rule, with a sufficient accuracy to determine the lightning coordinates. The multi station lightning location systems realizing a difference in time of arrival method have the best characteristics. Expansion of a system of distant sensors is connected with the solution of questions in providing a stable communication, time synchronization, etc. As local sensors of storm activity which are not demanding creation of a data transmission network, the systems of time synchronization and fee of third parties the direction and range finders (DRF) [2] allowing determining with an acceptable accuracy coordinates of the lightning discharges in a radius up to 100 km are used. Also as local lightning sensors the electric field meters [6] allowing before the first MR to realize preliminary warning of the coming thunderstorm are widely used.

Single-Station Systems

Single-station systems of passive location of thunderstorms allow determining lightning coordinates on the basis of estimates of azimuth and range. Azimuth estimation in such systems is calculated on the basis of the analysis of amplitudes of the electric and magnetic components of lightning discharge radiation. The error of definition of an azimuth in the DRF does not exceed units of degrees that meets requirements for accuracy at considerable ranges.

Range, or distance, to lightning discharge in a DRF is determined in the time domain (with use of so-called anti-route filters) or frequency domain (with use of differences in phase spectra of electric and magnetic atmospheric components). In the zone limited by a radius of 56 km range the amplitude methods [3, 4] for interval estimations can be used. Radius of the DRF operation area, when using E-H algorithms, does not exceed 100 km, and an error of distance estimation is 10-15% at distances of 20-80 km. At the same time a considerable increase of an error in intervals less than 20 km and from 80 to 100 km is typical. In the first case it is connected with the polarization errors caused by a
deviation from a vertical of the lightning channel. In the second case errors are caused by nuances of the method realization and are caused by a contradiction of industrial network noise filtration requirements (up to 300 Hz) and the need of analysis of this part of a phase range of E and H components of the received signal.

The problem of the accuracy increase in the range of 80-100 km can be solved by combined use of a number of measures, such as: recording with the subsequent subtraction of a noise from the received signal; use of digital filters of a big order for the disturbing spectral components deletion; and analog-digital converters with big bit depth. It is possible to eliminate polarization errors by refusal of magnetic frame antennas and by usage of the interferometer system consisting of the multichannel radio-receiving device and an antenna array for determination of the atmospheric direction. Herewith the range determination can be realized only by an amplitude method which is not providing sufficient accuracy in the frequency range of the antenna system having reasonable dimensions.

At the same time there is a possibility of range estimation to the lightning discharge by the data analysis of electric field meters known in literature as electrostatic fluxmeters [10]. Automation of processes of collecting and processing of data received from these devices allowed, on the base of charge distribution models in convective clouds in the form of a point charge or a point dipole [5], to create dangerous atmospheric phenomena warning systems. Fluxmeters provide preliminary, before the first discharge, identification of presence of considerable charges at the atmosphere. A shortcoming is a small range of one sensor, the operation area of which does not exceed 20 km [6].

Source Data
For the experiment realization the data on locations of lightnings discharges taking place in July, 2017 in the area limited with a radius of 100 km relatively the sensor of electric field (Figure 1) were used. Data on lightning coordinates were determined by the Blitzortung system [9]. As the electric field mill it was used fluxmeter "Ryabina" [7, 8], DRF was located on a roof of the academic building of Saint-Petersburg State University in Peterhof (about 23 km from the electric field meter). Data on lightning discharges coordinates recorded on 13.07.2017 by the Blitzortung system are provided in Figure 2. In the center of circles the device of measurement of electric field is located. Radiuses of circles are multiple of 25 kilometers.

Figure 1. Electric field mill "Ryabina"
Figure 2. Coordinates of separate lightning discharges recorded by a system “Blitzortung” on 13.07.2017 in the Leningrad Region

Experiment Results

On the basis of data of the Blitzortung system the two-dimensional arrays including time and range to lightning discharges (up to 80 km) were formed for determination of the maximum radius within which an identification of the dangerous phenomenon is possible. Joint presentation of information on values of electric field and lightning discharge range allows estimating visually the possibilities of a fluxmeter in lightning discharge detection.

Values of electric field strength along with distances to lightning discharges determined by Blitzortung and DRF systems are presented in Figure 3. From the graph in Figure 3 it is traced the dependence of amplitude of jump of electric field on distance to lightning discharge (by the Blitzortung system data) determined according to model of a point charge by the known [5] expression:

\[
\Delta E = \frac{\Delta Q H}{4\pi \varepsilon_0 \left(R^2 + H^2\right)^{3/2}},
\]

where \(\Delta Q\) is the charge value neutralized as a result of lightning discharge, \(H\) – height to the charge area, \(R\) – distance to an Earth surface projection of a charge.
Figure 3. Dependence of amplitude of jumps of a gradient of electric field on distances to lightning discharge (⋆ – Blitzortung system data, × – DRF data)

Electric field mill data showing possibilities of the device on detection of atmospherics at distances over 60 km are provided in Figure 4. The analysis of data of an experiment allows drawing a conclusion on high sensitivity of the electric field mill to all types of lightning discharges in a radius up to 50 km that is extremely important at identification of a state preceding a storm.

Figure 4. Electric field strength at a distance more than 50 km from the lightning discharge

Summary
Electric field strength sensors allow to identify surely the fact of the lightning discharges of any type at distances up to 50 km. Direction and range finders having the sufficient accuracy of lightning location in a zone of 20-80 km are capable to provide forecasting of the direction of the movement and development of the storm front, but in a case of formation of a storm cell in vicinity of an object are inefficient until detection of the first discharge. Fluxmeter eliminates this lack, and the influence of all electric processes in a cloud on a field structure allows noting a state preceding a storm with a high probability. Joint usage in the storm activity monitoring single-station systems of a direction and range finder and an electric field mill will allow to increase the detection probability of storm danger before the first flash and to reduce errors of range determination in a zone less than 20 km.

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