Analysis of the spatial-temporal distribution of lightning discharges in the North Caucasus

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Abstract. The organization of lightning protection measures is based on information about the nature of the distribution of lightning discharges, their number and the current value in the region of the location of the protection objects. Therefore, the most relevant direction of the study is to clarify the existing recommendations in the field of lightning protection. In the article, based on the data of long-term measurements of the LS 8000 lightning direction finding system located in the North Caucasus, the analysis of the registration of lightning parameters is carried out. The revealed regularities of the distribution of lightning discharges over the territory in different periods of the year are the basis for the approximation equations developed by the authors, which are used to describe the space-time density of lightning. Maps of the distribution of the number of lightning discharges per square kilometer obtained from the initial data and constructed according to the developed equations are presented, and the relevance of the results obtained is evaluated.

1. Introduction

Lightning discharges even by themselves, in isolation from dangerous weather events accompanying the development of thunderstorms, can cause fires, damage to power lines, breakdowns, disruption of communication networks and failure of electronics, etc. When lightning is discharged into an object, the current exerts thermal, mechanical, and electromagnetic effects. They are associated with the appearance of electromotive forces and potential differences on various metal structures, wires and pipelines that were not directly exposed to a direct lightning strike near buildings and structures or inside them, as well as due to the introduction of high potentials, for example, through underground and ground metal communications, pipelines, electrical cables, underground overpasses, overhead communication lines, power lines, bus lines, alarm systems, etc. Secondary manifestations of a lightning strike are divided into electromagnetic and electrostatic induction. The inductive voltage drop during a lightning discharge depends on the rate of change of the current - the steepness of the lightning front. Under a thundercloud, electric charges accumulate in the ground and in all ground objects, equal in magnitude and opposite in sign to the charges of the cloud and the charges embedded in the future lightning channel. Since the growth of cloud potentials is quite slow, induced charges appear even on objects that have good insulation relative to the ground (wires of overhead lines, metal roofs of wooden buildings, etc.) [1].

Therefore, for the organization of lightning protection measures as a set of protective measures against lightning discharges, ensuring the safety of people, the safety of buildings and structures, equipment and materials from explosions, fires, and destruction, data on the spatial and temporal distribution of lightning discharges, their type, polarity, number, and other parameters, such as the current value, the steepness of the current pulse front, and the duration of the pulse decline [2] are required. To estimate the distribution of these parameters, it is necessary to study the nature of thunderstorm processes over a long period of time. In this regard, the direction of creating and using equipment for determining the location of thunderstorms has become widespread. For operational monitoring of thunderstorms, thunderstorm direction finding systems are being developed and put into practice in many countries of the world [3, 4]. Lightning direction finding technology significantly reduces the risks of lightning strikes, and also takes into account thunderstorm activity when designing and placing buildings and structures. It is aimed at minimizing serious disruptions in the work of
industry, the electric power industry, mass accidents and damage to power lines, which, in turn, determines its high economic efficiency.

The purpose of the research was to analyze the spatial and temporal distribution of lightning discharges in the North Caucasus for the development of systems for detecting the time of occurrence and spatial position of thunderstorms, assessing the degree of their danger and the direction of further development.

2. Materials and methods
The material for the research was long-term archival data of operational records of lightning discharge parameters, obtained on the basis of data from the LS 8000 lightning direction finding network (Vaisala, Finland, USA) installed in the North Caucasus in 2009. The system consists of eight receivers, separated from each other at a distance of 100 to 350 km, connected by communication lines with the monitoring center at the HMGI (High-Mountain Geophysical Institute) (figure 1).

The receivers of the LS 8000 system, which is a ground-based multi-point lightning position detection system of the LPATS (Lightning Position And Tracking System) type, include high-frequency sensors that operate at frequencies of 1-350 kHz and 110-118 MHz. Sensors allow on-site generation of primary data for offline processing and archiving, provides storage of data, including the forms of discharges in its memory when communication with the server is lost, they provide registration of cloud-to-ground and cloud-to-cloud lightning, as well as intra-cloud discharges. The probability of detecting electromagnetic radiation from lightning discharges is more than 90%. The minimum number of network points is 4. The error in measuring the coordinates of lightning discharges inside the network boundaries is less than 1.5 km, outside from 2.5 to 5 km. The height of the mast can vary from 2 to 15 meters, depending on the installation location.

The data acquisition and display system uses navigation satellite data to synchronize time with nanosecond accuracy. With the help of the system, you can determine the latitude and longitude, that is, the coordinates of the location of the lightning strike, the polarity and the amplitude of the lightning current between the cloud and the earth (figure 2) [5, 6].

![Figure 1](image1.png)

**Figure 1.** Placement of sensors of the LS 8000 lightning direction finding network against the background of the map of the specific lightning impact of 1 km² of the surface of the territory of the North Caucasus for the year.

3. Results and discussion
Thunderstorm activity on the territory studied by the thunderstorm direction finding system varies greatly depending on the climatic conditions. The main types of meteorological processes are largely determined by the features of orography, namely the presence of high mountains, foothills and plains. The development of thunderstorms in the Caucasus is associated, among other things, with the heterogeneity of the relief of this region, which includes a flat zone, foothills and a mountain range of the Greater Caucasus, consisting of a number of parallel ridges. The influence of the mountain ranges of the Greater Caucasus on air currents affects
up to heights of about 6 km, depending on the direction of movement of air masses, thunderstorm-hail processes either increase or weaken. Orographic storm clouds usually develop under the influence of an orographic occlusion front in the form of a ridge, often located along the Main Caucasian Ridge. In the foothills of the Caucasus, conditions are developing that contribute to an increase in thunderstorm activity. And although in mountainous areas the amplitude of lightning currents is about half as large as in the plains, nevertheless, positive lightning is significantly more energy-intensive than negative ones, and the general trend of increasing the number of lightning discharges, including those occurring between clouds, shows an increase in the balance of discharge currents [7-10].

The space between the Main Caucasian Ridge and the Rocky Ridge (Pasture Ridge) is filled with spurs, cut by deep canyons. As the data show, when these spurs are crossed by thunderclouds, the specific density of lightning discharges sharply increases. Thus, the features of the underlying surface have a significant impact on the heterogeneity of thunderstorm activity and the distribution of the density of lightning discharges. The highest specific density of lightning is observed along the crests of the Greater Caucasus and Rocky ridges, and it is quite high on the Black Sea coast, in addition, there are areas of increased specific density of discharges along the path of frontal thunderstorm-hail processes, in places where powerful convective clouds exit from the foothills to the plain, where they sharply increase. More than 60% of all thunderstorm processes here are characterized by the presence of a large number of interacting and isolated convective cells, as well as strong thunderstorm activity. The value of the long-term average density of lightning discharges varied from 1 to 43.5 strikes/km².

The lowest values of the density of lightning discharges were related to less humid areas, where the underlying surface is not sufficiently saturated with moisture, creating unfavorable conditions for the development of convective clouds. This is mainly the case on plains, plateaus, in intermountain river valleys and basins, as well as near mountain peaks at altitudes of more than 4000 m above sea level. The significant focality of thunderstorm activity in a flat area is due not only to the latitude of the place, but rather even to local terrain features, the direction of air flows, the state of the underlying surface, and other similar factors. In the study area, there are relatively small-scale foci of increased thunderstorm activity and areas with a low discharge density.

Mountain coniferous and broad-leaved forests are most susceptible to lightning. Areas where there are layers of high-conductivity soil are selectively affected by lightning discharges, areas with poorly conducting soils, where extended metal communications (cable lines, metal pipelines) are laid, are also often affected by metal objects rising above the ground surface (towers, chimneys). Therefore, when assessing the specific density of discharges in a particular area, it is important to take into account, in addition to the spatial distribution of the density, the maximum possible values of the density of lightning discharges into the ground [1]. Spatial-temporal statistical analysis of lightning discharges, taking into account their territorial and temporal parameters, allows you to determine the places of the most intense damage and identify the "weak points" of the lightning protection system, which in turn makes it possible to plan targeted measures to improve it. All this [11-23] shows the relevance and current high demand for such work.
For the primary spatiotemporal analysis of lightning registrations in order to identify patterns of distribution of lightning discharges across the territory in different periods of the year, corresponding maps of the distribution of discharges were constructed (figure 2-3).

The most common areas affected by lightning are zones with a specific discharge density of 0.5-5 strikes/km² per year, which is about 10-100 times less than the maximum possible values for the region under consideration. A year characterized by high thunderstorm activity is usually followed by several years of relatively low thunderstorm activity [24]. The maximum density of lightning discharges into the ground is usually observed in June, it is slightly lower in July and August, followed by May and September [25]. The average number of lightning discharges per hour during the June processes by 16:00-18:00 can reach values of 350 strikes per hour. In June, the number of lightning discharges exceeds the annual average by 45%.

Figure 3. Map of the specific density of lightning discharges per area of 1 km², averaged for each month separately.

The obtained results are the basis for the approximation equations developed by the authors, which are used to describe the space-time density of lightning. Figure 4 shows as an example the distribution maps of the number of lightning discharges per square kilometer obtained from the initial data and constructed according to the developed equations. Thus, for each moment of time, processing is performed and the coordinates and amplitude of the three Gaussians are found, the number of which was determined as optimal according to the results of testing the clustering algorithm, using the exploration algorithm in the k-means method:

\[
n = \sum_{i=0}^{3} A_i \cdot e^{-\left(\frac{(x-x_i)^2 + (y-y_i)^2}{2\sigma_x^2}\right)}.
\]
Figure 4. Map of the specific average annual density of all lightning discharges occurring in an area of 1 km².

In the example presented, the resulting values have the following form:

\[ \begin{align*}
A_0 &= 10.265, \quad x_0 = 41.2548, \quad y_0 = 42.8213, \\
A_1 &= 4.541, \quad x_1 = 41.4019, \quad y_1 = 47.0704, \\
A_2 &= 4.006, \quad x_2 = 38.1306, \quad y_2 = 52.6118, \\
\sigma_x &= 3.6153, \quad \sigma_y = 1.6572.
\end{align*} \]

4. Conclusion

Against the background of a decrease in the average long-term thunderstorm activity in the flat part of the territory under consideration, in general, the location of the main foci remains in the North Caucasus. It can be noted that along with the preservation of the spatial patterns of thunderstorm propagation, where the average value of thunderstorm activity has hardly changed or has changed slightly, it is possible to distinguish areas where thunderstorm activity has changed significantly. First of all, this is the Stavropol Territory. The most dangerous areas are the foothills of the Elbrus, as well as the Krasnodar Territory, relatively less active in this regard are the eastern regions of Dagestan and the north-eastern regions of the Stavropol Territory. During 11 years of remote observations, it was found that thunderstorms in 76% of cases developed during the passage of frontal sections of air masses, in 15% of cases they were recorded during intramass development, and only in 9% of cases thunderstorms were observed from orographic clouds.

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