Research of spatio-temporal variability of the parameters of thunderstorm activity in the North Caucasus according to date of the lightning direction finder

A A Adzhieva*, V A Shapovalov

1 Kabardino-Balkarian State Agricultural Univ. (Russian Federation)
2 High-Mountain Geophysical Institute (Russian Federation)

E-mail: aida-adzhieva@mail.ru

Abstract. In the article, with the help of the data of the system of lightning direction finding established in the North Caucasus on the basis of the analysis of the materials of lightning parameters registration, the regularities of the space-time variability of the parameters of thunderstorm activity are established. Maps of the distribution of the number of lightning discharges and discharge currents per square kilometer are given and the relevance of the obtained technology is estimated.

Introduction

Proper organization of lightning protection measures in many cases allows you to avoid damage or significantly reduce it. The need to monitor the characteristics of thunderstorm activity is dictated by both the increase in material damage and the increase in the incidence of serious injuries and even death from natural hazards that accompany thunderstorm processes. Lightning direction finding is a source of meteorological data that is available in many countries, but is not operating optimally. Modern automated lightning direction systems, in contrast to lightning markers and lightning recorders, in addition to counting the number of digits, also solve the problem of determining the direction and determining the location of discharges.

In the world practice of lightning with the introduction of new technologies, there is an accumulation of actual data on the features of the electrical activity of powerful convective clouds, which, due to certain causal relationships, provide information about the significant microphysical reorganization of the cloud and possible dangerous phenomena with some time in advance [2]. Thus, it becomes an urgent task to study the stability of such relations in different regions. The parameters of lightning discharges are the subject of intensive research by remote sensing methods, due to their danger and inaccessibility for other research methods. Currently, requirements are being changed to improve life safety, lightning and lightning protection [5,8,12]. On the basis of the introduction of lightning systems in our country [1,6,7,13,14] and abroad [9-11], many methodological parameters are refined and adjusted, information is systematically analyzed, methodological support is being developed for the protection of the population and infrastructure.

The importance of complex research and long-term monitoring of thunderstorm phenomena, systematic analysis of data on lightning activity, to search for protective measures and warnings about the development of dangerous thunderstorm processes, is increasing.
Thunderstorms, lightning and other weather events associated with lightning cause dangerous situations and complicate working conditions not only for pilots, but also for airports in general.

In the field of electric power industry, having information about the places of occurrence of atmospheric discharges, you can quickly find the damage caused by a direct lightning strike to the elements of overhead power lines. In the case of the accumulation of statistical data on the territorial distribution of lightning for a long period, it becomes possible on the basis of these data to conduct additional lightning protection measures for objects located in areas with a high density of discharges. For example, by defining places and territories with abnormally high thunderstorm activity, it is possible to correct the rationale for the passage of high-voltage lines to avoid their losses and accidents.

**Methods and research materials**

The list of lightning discharge parameters used in calculations of protection of high-voltage lines and substations against lightning surges includes [1]:

- amplitude and current slope;
- the duration of the discharge front and the duration of the pulse;
- discharge polarity;
- the average annual density of lightning strikes per square kilometer of the earth's surface, etc.

For the occurrence of lightning, it is necessary that in a relatively small (but not less than some critical) volume of the cloud an electric field is formed with a strength sufficient to start an electric discharge (~ 1 MV/m), and in a significant part of the cloud there would be a field with an average intensity sufficient for its maintenance of the begun discharge (~ 0.1–0.2 MV/m). In lightning, the electrical energy of the cloud turns into heat and light.

The frequency of discharges on the ground for moderate thunderstorms is about one in 1 min, and in intensive it can reach several tens per minute. The average charge density in a cloud is $3 \cdot 10^{-9}–3 \cdot 10^{-8}$ C/m$^3$, and their accumulation rate is $3 \cdot 10^{-10}–3 \cdot 10^{-8}$ C/(m$^3$·s). In this case, the duration of the electrical activity of an individual thunderstorm cloud is 30–40 min.

![Figure 1. Cloud discharges - earth (positive and negative) and cloud overhead for thunderstorm process on May 29, 2014](image)

The degree of danger of lightning discharge is determined by the maximum current value in the channel. The magnitudes of the induced overvoltages, as well as the magnitude of the voltage drop across the inductive elements, depend on the current rise rate at the front of the lightning wave.
Field studies on measuring the amplitude of the lightning current using ferromagnetic oscillographic recorders, remote sensing, and other methods [2–4] that have been widely set in the past century have shown that there are differences in the distributions of maximum currents for different regions.

It can be argued that the effectiveness of lightning protection of infrastructure depends largely on the exact knowledge of the values of the maximum and characteristic amplitudes of the currents of lightning discharges for their location [3,8,12].

Lightning direction finding systems are designed to determine the coordinates, time of occurrence, energy parameters of lightning discharges and transfer information to consumers. The operation of lightning systems is based on the registration of electromagnetic radiation that accompanies lightning discharges.

To determine the amplitudes of the lightning current, the duration of discharges and the length of the front of a wave of lightning currents and other parameters of thunderstorm activity, the study used data from a thunderstorm direction system installed in the North Caucasus. The system consists of 8 LS8000 lightning direction-sensors from “Vaisala” and a central point for receiving and processing information from lightning direction-finders [1,2,4].

Since 2009, the LS 8000 thunderstorm recorder, manufactured by “Vaisala” (Finland), has been collecting, processing and archiving information on lightning discharges in the North Caucasus. The LS 8000 is a range finder LPATS system. It consists of eight lightning direction-finders and a central point for receiving, processing and archiving information.

Sensors of the system are installed in the Stavropol Territory, Rostov Region, Kabardino-Balkaria and Karachay-Cherkess Republics. The field of view of the thunderstrip network is about 1.8 million km². The detection efficiency of lightning discharges reaches 90–95%, and the error in measuring the coordinates is 1–2 km (Figure 2).

Each direction finder has two sensors - low frequency (LF) and high frequency (VHF). The LF sensor registers cloud-to-ground (CG) and intra-cloud (IC) discharges, and the VHF-sensor registers intra-cloud discharges. Also in the hardware-software complex includes GPS antennas, which allow to obtain exact time from GPS satellites, which, in turn, allows you to synchronize all the time measurements made by all sensors with time at the central point. Time values are determined with an accuracy of 100 nanoseconds. In case of lightning discharge, the sensors determine the azimuth to discharge, the time of arrival of the signal and the signal strength.

Figure 2. Location of lightning direction-finding systems of the LS 8000 system and distribution of the number of lightning discharges per km² according to the LS 8000 data.
The area of collecting lightning information close to 100% reliability is about $3 \cdot 10^5 \text{ km}^2$. Outside the specified territory, the system records the coordinates of lightning discharges with errors from 10 to 40%. Thus, the lightning recorder receives information about lightning from the entire territory of the North Caucasus, their archiving and the transfer of information to consumers. For this, data from sensors are transmitted via satellite communications to the central information receiving and processing center located in the city of Nalchik, in the building of the High-Mountain Geophysical Institute. The central point for receiving and processing information is a hardware-software complex consisting of 6 computers, “Vaisala” software and satellite communications equipment.

According to the data obtained from the LF and VHF sensors, the system, after being processed by the central processor, provides the following information about the bits:
- Date and time accurate to 100 nanoseconds.
- Coordinates of the discharge (latitude and longitude in the WGS-84 system).
- The strength and polarity of the signal (current in the discharge channel), in kA.
- Type of discharges (cloud-to-earth or inter-cloud and intra-cloud discharge).
- Polarity - classification of discharges into positive and negative.
- The number of sensors used in determining the location.
- The parameters of the ellipse 50% probability (large and small semi-axis, as well as the angle).
- Positional confidence ($\chi^2$-square).
- The rise time of the signal to the peak value, in $\mu$s.
- Signal decay time from peak value to zero, in $\mu$s.
- The maximum value of the rate of increase of the signal (lightning current steepness), in kA/$\mu$s.

The data reception center of the lightning direction network monitors the values of the parameters of lightning discharges, allows monitoring in real time, provides reception of information about lightning from the entire territory accessible to sensors, its archiving and transmission to consumers.

**Data processing results**

According to the data of thunderstorms, an analysis of the features of the development of thunderstorm processes and lightning parameters in various areas of the territory of the South of the European part of Russia is performed.

For the period from 2009 to 2018, 56724108 discharge registrations were received. The volume of the studied sample for positive and negative ground discharges is 5161044 registrations. The number of registrations of positive digits to the earth was 561850, negative - 4599194.

The most frequent (209403, 24434 and 193047 cases) pulse of the measured current is 14, 15 and 6 kA for generalized, negative and positive registrations, respectively. The largest registered amplitude is 750, 750 and 582 kA.

The median variant, located in the middle of an ordered variation range, dividing it into two equal parts is 17, 17 and 14 kA. The average values of the current strength are 23.4, 23 and 26.5 kA, respectively. The dispersion of the studied signals — the degree of scattering around their mean value — is 342.17, 277.7, and 859.2 (kA)$^2$, and the standard deviation is 18.5, 16.66, and 29.31 kA. The weakest measured pulse is 1 kA. Sample Scope - the difference between the maximum and minimum signals received is 1332 kA.

As a rule, thunderstorm activity is more in the south than in the north. It can be noted that the highest specific attack rate by lightning (5 discharges/year-km$^2$) occurs in the area of Sochi along the Black Sea coast, the smallest in the Northeast of the region (up to 2 discharges/year-km$^2$).

High mountain areas of the Caucasus, due to their low level of development, are characterized by a low level of risk, despite the significant danger of thunderstorm processes. The Volgograd and Astrakhan regions, as well as the Republic of Kalmykia, can be attributed to the predominantly low and medium risk zone. At the same time, on the territory of the latter, areas with a low risk of thunderstorms and lightning prevail. Studies show that areas with a high degree of risk include well-developed areas of the Krasnodar and Stavropol Territories, the republics of Adygea, Kabardino-Balkaria, Ossetia, Ingushetia [3].
With increasing altitude above sea level, the value of maximum currents decreases. This is due to the fact that thunderstorm-discharge activity is usually associated with the development of convection and the formation of cumulonimbus clouds. Intensive moisture exchange occurs between the cloud and the underlying surface, on which the terrain has a significant impact.

The greatest lightning currents are recorded in the foothills zone. The average amplitude in the foothill zone is 23 kA, and in the mountainous part it is 14 kA, i.e. with terrain height, lightning currents decrease. This feature should be taken into account in order to develop recommendations for the lightning protection of specific high-voltage lines, buildings and other structures in these areas. Figures 2 and 3 generally describe the overall picture of the territorial distribution of thunderstorm phenomena in the North Caucasus.

The greatest number of days with thunderstorms per year in the North Caucasus takes place in the south - up to 70 and the smallest in the north - 25–30. This conclusion is confirmed both by the data of meteorological stations and by measurements of the thunderstorm-directional network, and indicates the dependence of thunderstorm activity on the latitude of the terrain.

**Figure 3. Discharge current distribution per km² according to LS 8000**

The maximum lightning discharges across the territory of the North Caucasus took place in the month of June, and they amounted to 26,297 - 17 June. The minimum number of digits noted in January - 122 negative and 88 positive for the entire month. The extremum of average values of parameters of thunderstorm activity as a whole for the period under consideration falls in the period from May to June. At the beginning of a thunderstorm season, discharge processes are observed at the beginning on the mountain-sea coast (January-March months), then with the onset of a warm (summer) period thunderstorm processes arise in the northeast of the North Caucasus. In this case, the statistical characteristics of the current during the season change little.

It turned out that the greatest frequency of occurrence of various emergency situations during thunderstorms is observed along the Caucasian ridge and, as a rule, they are associated with accidents on power supply lines.

**Summary**

In recent decades, the problem of atmospheric electricity has increased in particular in the field of practical issues of thunderstorm electricity: warnings of dangerous weather phenomena (heavy rainfall, thunderstorms, hail, squalls, tornadoes) and phenomena associated with them (floods, mudflows and avalanches); prediction of aircraft damage by lightning; improving the protection of power lines and other structures against lightning discharges; clarification of the amount of precipitation when observing zones of thunderstorms with remote sensing methods; storm alert and others.
Based on the analysis of materials for registration of parameters of lightning, it has been established that the parameters of discharges in different areas differ and may change with time. This means that for the effective operation of the lightning protection systems and the implementation of life safety measures during thunderstorms, it is necessary to monitor lightning-like situations in each individual region. The lightning direction system ensures sufficient accuracy in detecting discharges in the area under control.

The years analyzed are years of average thunderstorm activity. At the same time, thunderstorm activity on the territory is uneven.

Lightning direction technology significantly reduces the risk of lightning discharges from line and field personnel, and also takes into account thunderstorm activity when designing power lines. It is aimed at minimizing serious violations in the operation of the power industry, mass accidents and damage to power lines, which, in turn, determines its high economic efficiency. In the world practice of lightning registration with the introduction of new technologies, there is an accumulation of actual data on the features of the electrical activity of powerful convective clouds, which, due to certain causal relationships with some time in advance, provide information about significant microphysical reorganization of the cloud and possible dangerous weather phenomena. At the current stage, the problem of studying the stability of such bonds in various climatic conditions becomes urgent.

References

[1] Adzhiev A Kh and others 2017 Monitoring the characteristics of thunderstorm activity in the south of the European part of Russia (Proceedings of the Southern Federal University. Technical science) 4 (189) 212-223.
[2] Adzhiev A Kh, Stasenko V N, Shapovalov A V, Shapovalov V A, Shapovalov V A 2016 The intensity of the electric field of the atmosphere and thunderstorm phenomena in the North Caucasus (Meteorology and Hydrology) 3 46-54.
[3] Adzhieva A A, Razumova N V, Shagin S I 2009 Thunderstorms and lightning in the south of the European part of Russia (Problems of Regional Ecology) 2 217-220.
[4] Adzhieva A A, Shapovalov V A 2016 Cluster analysis in the automatic detection and maintenance of thunderstorm foci according to the data of a thunderstorm direction-finding network (Don Engineering Engineer) 2 164-171.
[5] Bochkovsky B B, Merzlyakov A S 2012 Determination of the intensity of thunderstorm activity (Energy of the United Network) 3 30-35.
[6] Gorbatenko V P, Ershova T V, Konstantinova D A 2009 Spatial distribution of the density of lightning discharges into the earth over the territory of Western Siberia (Vestn. Tom. state un-that) 329 251-255.
[7] Kozlov V I, Mullayarov V A 2003 Thunderstorm activity in Yakutia (Yakutsk: Publishing House of the Yakut Scientific Center of the Siberian Branch of the Russian Academy of Sciences).
[8] Nikitin D 2010 Systems of lightning direction on guard of the electric grid economy (Energorynok) 6 17.
[9] Defer E, Lagouvardos K, Kotroni V 2005 Lightning activity in the eastern Mediterranean region (Journal of Geophysical Research: Atmospheres) 110(D24).
[10] Pinto I, Pinto Jr O 2003 Cloud-to-ground lightning distribution in Brazil (Journal of Atmospheric and solar-terrestrial physics) 65(6) 733-737.
[11] Pinto O, Naccarato K P, Pinto I R C A 2011 The new Brazilian lightning detection network: First results (Lightning Protection (XI SIPDA), 2011 International Symposium on. – IEEE) 152-153.
[12] Uman M, Rakov V 2002 A critical review of nonconventional approaches to lightning protection (American Meteorological Society) 1809—1820.
[13] Adzhiev A Kh, Stasenko V N, Shapovalov A V, Shapovalov V A 2016 Atmospheric electric field strength and thunderstorms in the North Caucasus (Russian Meteorology and Hydrology) 41(3) 186–192. doi: 10.3103/S1068373916030031
[14] Adzhieva A A, Shapovalov V A, Boldyreff A S 2017 Development of thunderstorm monitoring technologies and algorithms by integration of radar, sensors and satellite images (Proc. SPIE 10424, Remote Sensing of Clouds and the Atmosphere XXII, 104240H (20 October 2017)). doi: 10.1117/12.2299289