Study of the features of the distribution of the intensity of lightning activity during thunderstorms in the North Caucasus

A A Adzhieva¹, V A Shapovalov², H A Tumgoeva³ and A A Tokbaeva⁴

¹Kabardino-Balkarian State Agricultural University, 1 Tarchokova str., Nalchik, Russia, 360000
²High-Mountain Geophysical Institute, 2 Lenina ave., Nalchik, Russia, 360000
³Chechen State University, 32 A. Sheripova str., Grozny, Russia, 364024
⁴Kabardino-Balkarian State University named after H.M. Berbekov, 173 Chernyshevsky str., Nalchik, 360004, Nalchik, Russia

¹aida-adzhieva@mail.ru, ²vet555_83@mail.ru, ³tumgoeva_75@mail.ru, ⁴tok2506@mail.ru

Abstract. Operational and reliable information about thunderstorms and lightning discharge parameters allows you to solve many problems of aviation, meteorology, energy, atmospheric physics, earth electricity and even near-Earth space. This article discusses issues related to the features of the development of thunderstorm processes and the parameters of lightning activity for the territory of the North Caucasus. The features of the risks associated with intense lightning activity are discussed. Information about electrical processes in the clouds and lightning parameters for 2009-2019 was obtained using the Vaisala LS 8000 network of lightning registers. The article gives a picture of the spatial distribution of the foci of the maximum intensity of lightning discharges in the North Caucasus and the distribution of the maximum value of the total absolute current of discharges per minute to the ground. The statistical features of the distribution of the intensity values of the discharges per minute by types of discharges encountered throughout the year were investigated. The performed analysis of these distributions made it possible to select the optimal approximating expressions for practical application in lightning protection. The main factors affecting the obtained characteristics of the spatial distribution of lightning activity are identified. Conclusions are drawn on the prospects for further research in order to obtain comprehensive information about electrical processes in the atmosphere of the region.

1. Introduction
Lightning discharges cause injuries and loss of life, death of livestock, fires in forests, settlements and other objects associated with human activities [1]. They are also the main source of electromagnetic interference, cause power surges and overvoltages in the power grid, interfere with control systems, damage electronic circuits, buildings and other exposed artificial structures such as power lines, and even alternative sources of renewable energy, such as for example, wind turbines and solar power plants. In addition, lightning has an adverse effect on the aviation industry, creating risks not only in flight, but also for outdoor operations such as refueling aircraft, baggage handling and towing...
operations. At cosmodromes, lightnings also pose a significant danger to fuel crews, ground-based missile preparation and launch operations. Also, discharges can cause premature operation of devices used to carry out directed explosions during the construction of canals and tunnels in open mining pits.

Danger during a thunderstorm is the performance of work related to charging static objects of various kinds, for example, oil vessels [2-6].

One of the most difficult and costly tasks is to protect against secondary manifestations of lightning discharges. Secondary manifestations of lightning discharges are understood as overvoltages applied to the isolation of secondary circuits, as well as electromagnetic interference affecting relay protection and automation equipment, automated control systems, automated systems for commercial metering of electricity and communication systems, when lightning strikes into existing lightning conductors of an object. The sources of secondary manifestations of lightning discharges are potential differences arising between the various elements of the protective devices of power plants and substations when a lightning current flows through them, as well as pulsed magnetic fields created by a lightning current. In addition to direct effects on the equipment, pulsed magnetic fields are also capable of inducing pickups in secondary circuits, especially for those using unshielded cables.

The consequences of all these events can be very costly due to energy losses, additional maintenance costs, or even to the loss of operating equipment. It is necessary to remember that a probabilistic approach is used everywhere and even with an optimally constructed system of protection against primary and secondary manifestations of lightning, it is impossible to guarantee 100% protection of equipment and its circuits during lightning discharges [6].

According to modern satellite data, the frequency of lightning strikes on Earth is on average 44 ± 5 times per second, that is, about 1.4 billion lightnings per year. Moreover, ⅔ of them belong to the cloud-cloud type and to intra-cloud and, accordingly, ⅓ lightnings are lightnings that affect the earth's surface [7]. The intensity of lightning discharges for a powerful thunderstorm in middle latitudes can be about 60 per minute over the entire territory of a thunderstorm [8].

Today, measurements of the characteristics of lightning are used to diagnose the existence and predict the temporary development and attenuation of thunderstorms in a wide range of scales. Lightning discharges in the atmosphere owe their existence to a combination of complex dynamic and microphysical processes, and are largely related to the processes of city formation, therefore, an important task is to search for interrelated and interdependent predictors of the development of dangerous atmospheric phenomena accompanied by thunderstorm activity and to develop methods for predicting trends in their development on this basis [9-11]. Their creation will significantly increase the reliability and timeliness of storm warnings, and will ensure the functioning of weather-dependent sectors of the economy (urban economy, energy, transport, etc.). To solve individual tasks of monitoring of lightning activity [1-3] and the fundamental tasks of the Global Electric Circuit [4] it is necessary to distinguish groups of lightning discharges characterized by temporal and spatial proximity. Such groups of lightning discharges are associated with a convective cell in an active thunderstorm state (thunderstorm cell) [5]. A thunderstorm cell is defined as an indivisible element of a thunder cloud. Thunderstorms consisting of a single convective cell are called a single-cell thunderstorm. If a thunderstorm consists of several cells moving as a whole, then it is called a multi-cell thunderstorm. Multi-cell thunderstorms are also called thunderstorm foci. The dimensions of a single-cell thunder cloud vary from 5 to 20 km. The life cycle of a convective thunderstorm cell at the stage of maturity takes from 20 minutes to 1 hour.

2. Materials and methods
The data on lightning parameters used in this article were obtained by a ground-based network of lightning direction finders installed in the North Caucasus. The network provides reception, processing, archiving and transmission of information about lightning from the entire territory under consideration to consumers. It consists of eight Vaisala LS 8000 lightning direction finders and a central data collection point [12]. LS 8000 sensors allow you to automatically detect and record the fact of the discharge, its coordinates, amplitude and other characteristics of this discharge. They can be used both offline and as part of a regional system of several complexes integrated by a special
communication system or via the Internet. The central point for receiving and processing information located in the city of Nalchik, in the Alpine Geophysical Institute consists of 6 computers, Vaisala software and equipment for satellite communications with LS 8000 lightning detectors.

The lightning direction finder incorporates two sensors - a low-frequency (LF), which detects cloud-to-earth (CG) and inter-cloud (CC) discharges, and a high-frequency (VHF), which detects intra-cloud (IC) discharges. The software and hardware complex also includes GPS antennas, which allow you to receive accurate time from GPS satellites, which, in turn, allows you to synchronize all time measurements made by all sensors with time at a central point. Time values are determined with an accuracy of 100 nanoseconds. During lightning discharges, each sensor determines the azimuth to discharge, the time the signal arrives at the sensor, and signal strength. The software developed by the authors was used to process the discharge data.

3. Results and discussion

The network of lightning direction finders in the North Caucasus in Russia has been operating since 2009. From 2009 to 2019 it was possible to obtain 27931192 registrations of lightning discharges of different types and polarities. Of these, 305784 CG+, 2595906 CG-, 726667 CC+, 877633 CC-, 234222 IC, or a total of 2901690 bits of CG and 1604280 CC.

The most common characteristic for the region is the statistical ratio of the form (IC + CC):CG for the studied sample, it is rounded 9:1. In fact, up to 90% of all lightning falls on intracloud discharges - when an electrical breakdown occurs between oppositely charged areas of the clouds. They can have different intensities and lengths from hundreds of meters to several kilometers. However, most of them are not available for visual observation.

Only 10% of cloud-to-earth discharges account for positive discharges, while for interclouds this parameter is approximately 1:1. The number of discharges to the ground is 1.8 times the number of intercloud discharges.

Figure 1 shows the spatial distribution of the foci of the maximum intensity of lightning discharges over the North Caucasus, and Figure 2 shows the distribution of the maximum value of the total absolute current of discharges per minute to the ground, which we obtained for the North Caucasus using data from the LS 8000 lightning recorder for 2009 ... 2019 respectively.

Figure 1. Overlays of the maximum intensity of lightning discharges with a map of the Caucasus. The location of the points of the LS 8000 ground direction finder sensors is given.
Figure 2. Distribution of the maximum value of the total absolute discharge current per minute to the ground for the territory of the North Caucasus during the measurement from 2009 to 2019.

In Figures 1-2, the maximum values of lightning intensity of positive and negative polarity recorded by the lightning recorder recorded on the ground and the maximum values of the total lightning current to the ground per minute with a map of the North Caucasus for the entire observation period are made. As can be seen from these figures, several main zones of lightning discharge activity can be distinguished, differing in territorial distribution and intensity. The most intense thunderstorm processes are observed in the Krasnodar and Stavropol Territories, in western Georgia and in the mountainous regions of Kabardino-Balkaria and North Ossetia. With the beginning of the thunderstorm season, they first appear at the beginning on the mountain-sea coast, and then with the onset of the hot summer period they are already observed in the northeast of the North Caucasus. The average intensity of lightning cloud-ground with about 8 discharges per minute, and the maximum recorded - up to 110 discharges per minute.

If you set the maximum intensity of the discharges per minute by type of discharges, then the maximum observed values will be, respectively: CG+ 23; CG- 110; CC+ 160; CC- 125; IC 2816.

Figure 3 shows the statistical distribution of the frequency of occurrence of lightning intensity per minute for various types of discharges in the North Caucasus. Their distribution is well approximated by an expression of the form:

$$N_{count/strikes per min in year} = 10^n \sum_{m=0}^{6} a_m (\log_{10} \text{strikes per min})^m$$

(1)

where $n \in 0..m$ and $m$ is the degree of the polynomial.

The values of the coefficients of equation 1 for various types of discharges are shown in table 1.

| Str. type | 0    | 1    | 2    | 3    | 4    | 5    | 6    |
|-----------|------|------|------|------|------|------|------|
| ALL       | 5.2799 | -1.5412 | 2.2519 | -2.0328 | 0.8297 | -0.1544 | 0.0085 |
| CG+       | 4.3842 | 0.44 | -14.218 | 18.406 | -7.7288 |
| CG-       | 4.7952 | -0.5914 | -0.1077 | -0.0643 | -0.2162 |
| CC+       | 4.4796 | -1.2646 | 1.0932 | -2.9868 | 2.059 | -0.4761 |
| CC-       | 4.5503 | 0.8676 | -10.792 | 19.844 | -17.807 | 7.7033 | -1.3021 |
| IC        | 4.819 | -0.2193 | -1.0477 | 1.9855 | -1.4839 | 0.4665 | -0.0543 |
The lightning current values obtained using the LS 8000 lightning recorder make it possible to identify the main factors affecting the obtained characteristics of the spatial distribution of lightning activity. These include climatic conditions, elevation above sea level, type of underlying surface and orography. Thunderstorm processes are accompanied by a significant number of lightning strikes. The limit value of the total lightning-fast activity is associated with the available energy in the environment and depends on the size and duration of the developing thunderstorm front. In thunderstorm outbreaks with smaller areas, the intensity of discharges is greater than in larger outbreaks. With increasing focal area, the discharge intensity decreases. Large thunderstorms consist of many convective cells, each of which independently creates lightning. The intensity of each individual cell may also vary. Storm outbreaks usually consist of several cells. An hour in the cell there is an average of up to 20 “cloud-to-earth” discharges and is about an order of magnitude more intracloud. The spread in the duration of thunderstorms is from one hour to one and a half days, while about 80% of all thunderstorm outbreaks exist for less than two hours. The intensity of lightning discharges in the outbreak varies from fifty discharges per hour at the initial stage to hundreds in the middle stage and decreases to several tens in the final stage. Less commonly, the maximum is observed in the last or in the first stage. In intense thunderstorms, the peak discharge intensity may exceed 60 ppm. Thus, the frequency of lightning discharges largely depends on the size of the cloud. We need strong convection, generated by strong temperature extremes and a large amount of moisture in the atmosphere. Further research will be aimed at attracting a wide range of remote sensing data in order to obtain comprehensive information about electrical processes in the atmosphere of the region.

4. Conclusion
Using the LS8000 lightning direction finding network, the spatiotemporal distribution of lightning discharge intensity during lightning processes for the period from 2009 to 2019 was studied. Lightning activity in the North Caucasus was analyzed, and spatial distribution maps were constructed. The simplest characteristics of the ratios of the number of discharges are determined, the frequency distribution of the values of the intensity of lightning discharges is analyzed. An expression is chosen.
that optimally approximates the frequency of occurrence of certain values of the intensity of discharges per minute for various types of lightning.

Minimizing the damage caused by thunderstorms is impossible without improving the methods for predicting and diagnosing dangerous weather phenomena caused by the processes of development of a thundercloud. A particularly important role in improving the methods for timely detection and effective monitoring of thunderstorm processes is played by studies of the characteristics of lightning with modern means. Operational and reliable information about thunderstorms and lightning discharge parameters will solve many problems of aviation, meteorology, energy, physics of the atmosphere, electricity of the earth and near-Earth space.

The results of similar, as well as complex, including wider use of radar, as well as satellite data, studies allow us to create a more complete picture of the electrical processes taking place in a thundercloud, which, to this day, have not been studied enough, and to improve monitoring and control methods thunderstorms in order to reduce their negative consequences.

References
[1] Hall B 2007 Precipitation associated with lightning-ignited wildfires in Arizona and New Mexico *International Journal of Wildland Fire* **16**(2) pp 242-254
[2] Cooper M A, Holle R L 2019 Contributors to Lightning Casualty Risk *Reducing Lightning Injuries Worldwide* (Springer, Cham) pp 99-103
[3] Rädler A T et al. 2019 Frequency of severe thunderstorms across Europe expected to increase in the 21st century due to rising instability *Climate and Atmospheric Science* vol 2 pp 1-5
[4] Romps D M et al. 2014 Projected increase in lightning strikes in the United States due to global warming *Science* vol **346** issue 6211 pp 851-854
[5] Petkau O etc. 2014 Protection of objects of the fuel and energy complex from threats of electromagnetic effects *Safety of objects of the fuel and energy complex* **2**(6) pp 74–76
[6] Karjakin R N 2005 Handbook of lightning protection (Moscow: Energoservice) 880 p
[7] John E O 2005 Encyclopedia of World Climatology *National Oceanic and Atmospheric Administration* ISBN 978-1-4020-3264-6
[8] Ershova T V, Dulzon A A, Gorbatenko V P, Reshetko M V 2002 Dependence of density of lightning discharges to the ground on physico-geographical factors of locality 6th Russian-Korean International Symposium on Science and Technology, KORUS pp 414-417 doi: 10.1109/KORUS.2002.1028053
[9] Kozlov V I, Mullayarov V A, Tarabukina L D, Grigorev Y M 2014 Parameters of thunderstorm activity and lightning discharges in Central Yakutia from 2009 to 2012 *Izvestiya. Atmospheric and Oceanic Physics* vol **50** issue 3 pp 323-329
[10] 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 Remote Sensing of Clouds and the Atmosphere XXII (SPIE - The International Society for Optical Engineering 22), pp 104240H.
[11] Sin’kevich A A, Mikhailovskii Y P, Dovgaluk Y A, Veremei N E, Bogdanov E V, Adzhiev A K, Abshaev A M, Malkarova A M 2016 Investigations of the development of thunderstorm with hail. Part 1. Cloud development and formation of electric discharges *Russian Meteorology and Hydrology* vol **41** issue 9 pp 610-619
[12] Adzhiev A Kh, Tapaskhanov V O, Stasenko V N 2013 Lightning direction finding system in the North Caucasus *Meteorology and hydrologists* **1** pp 5–11