Daily dynamics of thunderstorms in the North Caucasus

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Abstract. Based on instrumental observations for the period from 2008 to 2019, regional features of the regime of daily thunderstorm activity in the North Caucasus are analyzed. Thunderstorm activity is calculated at different periods of the day. The temporal and spatial changes of thunderstorm activity are analyzed by time of day and by month. Temporary trends in thunderstorm activity are shown. The characteristic of the dominant tendency and diurnal features in long-term changes in the main characteristics of thunderstorm activity is given; the role of various factors determining these changes is estimated.

1. Introduction
Thunderstorm is an atmospheric phenomenon during which electric discharges occur between the cloud and the earth or inside the clouds themselves, lightning, accompanied by thunder, glow and electromagnetic radiation. It is usually formed in cumulonimbus clouds and is accompanied by a squalling increase of wind, hail and rain showers. Thunderstorm is almost the most dangerous natural phenomenon for humans. By the number of recorded fatalities, a thunderstorm is second only to flooding. On the territory of the North Caucasus, thunderstorms are the most often observed in warm season and much less frequently in spring and autumn months. Thunderstorms are sometimes observed in winter, but they do not receive such intensity and are not as dangerous as in summer. Winter thunderstorms most often occur in the western Ciscaucasia, in the foothills and mountains, as well as on the Black Sea coast of the Caucasus [1].

The formation of thunderstorms is associated with the passage of cold fronts, with convection processes and powerful updrafts in the atmosphere. Thermal air-mass thunderstorms are formed rarely. In the occurrence of thunderstorms the orography of the area plays a significant role. It contributes to the emergence of powerful ascending air movements, exacerbation of cold fronts. The climate of the territories of the North Caucasus is formed under the influence of a set of physical and geographical conditions, the most important of which are solar radiation, atmospheric circulation and underlying surface. The North Caucasus is located in the southern part of the European territory of Russia, in the temperate latitudes of the northern hemisphere; it is characterized by a moderately continental climate. Due to its southern position, the territory receives a lot of heat. The duration of sunshine here is 2000-2200 hours per year. The amount of total solar radiation entering this territory ranges from 106 kcal / cm² in the north of the region to 118 kcal / cm² in the south. The repeatability of the number of days with a thunderstorm in mountains is greater than on plains. It is because of the affect of directions,
slope height and orographic protection. In the study area, 5 types of synoptic positions of thunderstorm formation with a corresponding distribution of thunderstorms across the territory were identified.

In the North Caucasus, thunderstorms most often occur in a diffuse gradientless baric field, and in some cases when passing through a meridionally oriented region of low pressure in a system of cold fronts, and also when passing through the fronts of cyclones moving over Ukraine. Out of a total of thunderstorms, intra-mass accounts for about 35%. In most cases (90%), these thunderstorms occur in low-gradient areas of low atmospheric pressure in the rear of filling cyclones. Thunderstorms in the zone of the atmospheric front (65% of all thunderstorms) differ in that they are observed in the form of chains of thunderstorm foci moving parallel to each other over a large territory. The zone of frontal thunderstorms can have a width of tens of kilometers with a front length of hundreds of kilometers. The predominant number of frontal thunderstorms is associated with the main cold fronts (66% of the total number of frontal thunderstorms) [1, 2]. Due to global and regional climate changes, the increase in the frequency of extreme weather events, such as thunderstorms, hail, heavy rainfall, strong winds is becoming especially relevant for the territory of the North Caucasus. A significant growth in extreme climate characteristics in the North Caucasus in recent decades increases the likelihood of existing risks of negative thunderstorms' effects on various aspects of human activity. Therefore, it is of interest to study the dynamics and trend of the patterns of distribution of thunderstorms, which are also often accompanied by intense rainfall and hail.

In solving the problems of monitoring thunderstorm activity, it currently seems possible to use effective instrumental methods and means of observing thunderstorms and measuring lightning parameters. Until now, the main source of information about thunderstorms in Russia is visual-auditory observations at weather stations in accordance with the regulatory documents of Roshydromet [3, 4].

In addition to the main meteorological parameters measured at weather stations in Russia, there is also a list of atmospheric phenomena that are also observed at all stations - fog, thunder, hail, halo and others. Each of these phenomena is evaluated qualitatively, i.e. according to the principle "there is a phenomenon" or "there is no phenomenon." Also, some types of phenomena are classified according to the intensity scale (weak, moderate or strong phenomenon), for example, "severe blizzard", "moderate thunderstorm" [5]. When registering thunderstorms, the range of the visual-auditory method is from 10 km to 20 km, depending on the orography of the area. A more effective method for determining the climatic and physico-statistical characteristics of thunderstorms is passive-active radio equipment. The main objective of this work is to study the daily dynamics of thunderstorm activity for territories in the North Caucasus based on data from the lightning direction finding network (GPS) of the FSBI “High Mountain Geophysical Institute” [6].

2. Materials and methods
To determine the above statistical characteristics of thunderstorms and their variations in the North Caucasus, for the first time in Russia, the LS 8000 lightning recorder manufactured by Vaisala Finland was used. LS 8000 is an LPATS differential rangefinder system.

The lightning registration system installed in the North Caucasus in 2008 consisted of four lightning direction finders, and since 2020, of six lightning direction finders and a central point for receiving, processing information and archiving.

Each lightning finder has two sensors - a low-frequency (LF) and high-frequency (VHF).

According to the data obtained from the LF and VHF sensors, the central processor (SR), after processing this data, provides information about the lightning discharge, the number of days with a thunderstorm and the duration of thunderstorms. The GPS LS 8000 is described in [5].

Figure 1 shows the layout of lightning direction finders of the LS 8000 system in the North Caucasus. Their location is an irregular quadrangle with sides of 158 km, 90 km, 118.5 km and 90 km. The system boundaries calculated by the system manufacturer with a 100% probability of lightning registration represent a circle with a radius of about 310 km. Thus, the territory of the collection of lightning discharge information is close to 100% reliability and amounts to about $3 \times 10^5$ km$^2$. Outside the specified territory, the system registers the coordinates of lightning discharges with errors from 10
The lightning recorder provides reception of information on lightning from all over the North Caucasus, their archiving and transmission of information to consumers. In Russia, analogues of such a system have been deployed in the Moscow Region by FSBI Scientific Research Center “Planeta” and in the Rostov Region by JSC “Streamer” (figure 1).

![Figure 1. Location and territory of registration of lightning discharge information using LS8000.](image)

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Table 1 shows the geographical coordinates and altitude (above sea level) of the lightning recorder points' locations.

| Name of the point | Latitude  | Longitude  | Height, [m] |
|-------------------|-----------|------------|-------------|
| Cherkessk         | 44,2874°  | 42,2404°   | 901         |
| Zelenokumsk       | 44,4337°  | 43,9036°   | 172         |
| Stavropol         | 45,1136°  | 42,1012°   | 483         |
| Kyzburun          | 43,6787°  | 43,4048°   | 747         |
| Central Point (HMGI) | 43,4694°  | 43,5861°   | 120         |

To study the daily thunderstorm activity, instrumental observations of the GPS of the FSBI “High Mountain Geophysical Institute” were used. Data were collected on thunderstorms in the North Caucasus over a long-term period of observations from 2008 to 2019. An example of registration of ground lightning of positive and negative polarity obtained by GPS is shown in Table 2.
Table 2. The number of ground lightning of positive (Lf+) and negative (Lf-) polarities recorded across the KBR territory in 2010.

| Months | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  | 9  | 10 | 11 | 12 |
|--------|----|----|----|----|----|----|----|----|----|----|----|----|
| Clock  | Lf+| Lf-| Lf+| Lf-| Lf+| Lf-| Lf+| Lf-| Lf+| Lf-| Lf+| Lf-|
| 1      | 0  | 0  | 0  | 0  | 0  | 0  | 2  | 0  | 2  | 0  | 8  | 4  |
| 2      | 0  | 0  | 0  | 0  | 0  | 0  | 1  | 1  | 10 | 2  | 8  | 0  |
| 3      | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 4      | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 5      | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 6      | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 7      | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 8      | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 9      | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 10     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 11     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 12     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 13     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 14     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 15     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 16     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 17     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 18     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 19     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 20     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 21     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 22     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 23     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
| 24     | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  | 0  |
Based on them, for analysis, for different territories are grouped: the number of days with a thunderstorm per month, per year, and the duration of a thunderstorm per month and per year. Further in the work the results of their analysis are considered.

To analyze the climatic characteristics of thunderstorms, the results of instrumental studies of thunderstorm activity and measurements of lightning discharge parameters in the south of the European part of the Russian Federation were used. Peculiarities of spatio-temporal changes in thunderstorm activity and lightning parameters in the territory with a radius of 650,000 km around the center of the lightning-and-direction finding network of the FSBI “High Mountain Geophysical Institute”, Nalchik, covering the North Caucasus and the Black Sea coast are revealed. The total number of thunderstorm days per year in the territory under consideration is about 239. Most often, thunderstorms at observation points (a point with a radius of up to 20 km) last 1-2 hours, but in some cases they last 4-5 hours or more. In the North Caucasus as a whole, the duration of a thunderstorm is about 4 hours per thunderstorm day.

Table 2 shows the number of ground lightning of positive and negative polarities recorded across the territory of Kabardino-Balkarian Republic at different periods of the day and months of the year. For example, we have chosen 2010.

The repeatability of thunderstorms according to instrumental registrations of GPS LS8000 lasting less than an hour is 25%, 3.5-4.5 hours - 62%, 4.5 - 7 hours 11% and more than 7 hours - only 2%. The average duration of thunderstorms per year in the North Caucasus reaches 956 hours, with a maximum value in the foothills in the southwest. Only in rare cases in the North Caucasus were thunderstorms lasting more than 15-20 hours. The maximum duration of thunderstorms is observed during the passage of well-developed frontal processes associated with the removal of warm air masses. Intra-mass thunderstorms, with few exceptions, are the most short-lived and less intense than frontal ones.

Figure 2 shows the time course of daily thunderstorm activity in August 2010, constructed according to instrumental data. As can be seen from figure 2, the greatest thunderstorm activity on the territory of Kabardino-Balkarian Republic occurs in the midday period. Such features in the dynamics of the daily variation of thunderstorm activity in the North Caucasus are observed in all months of the year.

![Figure 2. The course of daily thunderstorm activity in the CBD in August 2010.](image)
3. Discussions and Results

On the territory of the North Caucasus from January to April and from October to December, thunderstorms usually arise from 12 hours to 19 hours. In other periods of the year in the territory under consideration, thunderstorms occur during the day. Moreover, in the North Caucasus, the greatest frequency of thunderstorms occurs in the afternoon (12-18 hours), when it is 60% and slightly less - 26-30%, in the evening hours (18-24 hours). Table 3 presents the daily distribution of the frequency of thunderstorms during the day, summarized by long-term data from 2009 to 2019. As can be seen from table 3, more than 60% of thunderstorms in the North Caucasus form from 13 to 20 hours, i.e., in the second quarter of the day.

| Time, [hour] | 1 - 4 | 5 - 8 | 9 - 12 | 13 - 16 | 17 - 20 | 21 - 24 |
|-------------|-------|-------|--------|---------|---------|---------|
| Thunderstorm, % | 6     | 4     | 17     | 38      | 25      | 10      |

References

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Findings

Based on instrumental observations for the period from 2008 to 2019, the regional features of the regime of daily thunderstorm activity over the North Caucasus are analyzed. Thunderstorm activity was calculated at different periods of the day.

The greatest thunderstorm activity, over 60%, in the North Caucasus takes place in the midday period.