Calculation of Damage to Buildings and Structures by Lightning According to the Thunderstorms’ Visual and Instrumental Observations

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Abstract. The materials and construction of buildings and structures used should be linked to the number of lightning strikes per year. Lightning protection of buildings and structures should be based on the parameters of thunderstorms in the territory of the project design. Thunderstorm is one of the most dangerous meteorological phenomena. Both ground objects and aircrafts are affected by thunderstorm activity: airplanes and rockets. The main objective of this work is a comparative assessment of the buildings and structures impact by lightning, depending on the methodology for determining the thunderstorms duration in hours for the territories in the North Caucasus. The analysis on the basis of data from the thunderstorm direction finding net (TDFN) of the FSI “VGI” and data from weather stations has been performed. To solve this problem, a study on the relationship between the number of days with a thunderstorm and the duration of thunderstorms in hours for the territories in the North Caucasus has been performed on the FSI “VGI” (TDFN) data basis. In order to determine the above-mentioned 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.

Introduction
Thunderstorm refers to the fast-flowing, stormy and extremely dangerous atmospheric natural phenomena. A striking factor in a thunderstorm is lightning. It is a high-energy electric discharge arising from the establishment of a potential difference (several million volts) between the surfaces of clouds and the earth or between the oppositely charged parts of the cloud. Lightnings are ground-based positive, ground-based negative and cloudy. Thunderstorms can affect both ground objects and aircraft: airplanes and missiles.

The methodological foundations laid down in the regulatory documents “Instructions for lightning protection of buildings and structures” (2003) and Instructions WD 34.21.122-87 (1987) regarding the characteristics of lightning activity and lightning parameters are outdated due to widespread adoption of new passive radio engineering tools for monitoring thunderstorm activity and measuring the lightning parameters both in Russia and abroad. The use of thunderstorm observation tools allows to optimize the lightning protection solutions.
The regulatory documents currently in use [1-3] are poorly focused on the use of rather inaccurate characteristics of thunderstorm activity and the lightning parameters averaged over large areas. The transition to the digital control systems, digital economy, planned in Russia, requires a fundamental increase in the lightning-dependent objects operation reliability but also of control systems in the modes associated with the lightning current effect and the lightning electromagnetic field.

**Materials and methods**

The number of lightning strikes of various objects per year depends on its geometric dimensions and the number of lightning strikes on the Earth’s surface per year $n, 1/(\text{km}^2 \text{ per year})$ in the territory of the facility.

The Estimated Expected Quantity $N$ lightning lesions per year are performed according to the formulas (1) and (2). For the concentrated buildings and structures (chimneys, towers, towers) it has the form:

$$N = 9\pi h^2 n 10^{-6};$$

for the buildings and structures of a rectangular shape it has the form:

$$N = [(S + 6h)(L + 6h) - 7,7h^2]n 10^{-6}$$

where $h$ is the highest height of a building or structure; $S, L$ are respectively the width and length of the building or structure; $n$ is the average annual number of lightning strikes in 1 km$^2$ of the Earth’s surface (specific gravity, lightning strikes to the ground) at the location of a building or structure.

For the buildings and structures of complex configuration as $S$ and $L$ the width and length of the smallest rectangle into which the building or structure can be inscribed are considered.

The lightning strikes’ density into the earth, expressed in terms of the number of lesions 1km$^2$ Earth’s surface for the year, is determined according to the meteorological observations at the location of the constructed object. If the density of lightning strikes on the Earth’s surface $n, 1/(\text{km}^2 \text{ per year})$ is unknown, it can be calculated by the following formula:

$$n = 6,7 \cdot \frac{T}{100},$$

where $T$ is an average annual duration of thunderstorms in hours, determined from the regional thunderstorm activity intensity maps.

In accordance with Appendix 2 of WD 34.21.122-87 of the Instructions for the buildings and structures lightning protection installation [1], the territory of Russia is zoned for the thunderstorms’ duration. The average annual duration of thunderstorms at an arbitrary point on the territory of the former USSR is determined by the map (Figure 1), or by the regional thunderstorm duration maps approved for some regions of the former USSR, or by the long-term average data (about 10 years) of the weather stations closest to the location of a building or structure. There is also a map of the average number of days with a thunderstorm. Based on the map, the average annual duration of thunderstorms in the North Caucasus varies from 60 to 80 hours.
Figure 1. Map of the thunderstorms’ average annual duration in hours for the territory of the Russian Federation.

The source of information on thunderstorms for creating maps presented in Figure 1 is a visual observation of the number of days with a thunderstorm that are made at the weather stations throughout Russia [4,5]. According to these data, other parameters of thunderstorms are estimated, for example, the duration of thunderstorms per year in hours.

Until now, the main source of information on thunderstorms in Russia is visual - auditory observation at the weather stations in accordance with the regulatory documents of the Federal Service for Hydrometeorology and Environmental Monitoring of Russia [6,7].

Zoning maps of the territory of Russia according to the thunderstorm characteristics are based on the data from the weather stations on the number of days with a thunderstorm for the long-term observation periods and the relationship between the average annual values of the number of days with a thunderstorm and the thunderstorms’ duration. The relationship of the average annual duration of thunderstorms in hours \( T \) and the number of days with a thunderstorm \( D \) can be defined by the expression:

\[
T = K \times D, \tag{4}
\]

where \( K \) is the size factor taken as 2 hours / day.

There are both visual and instrumental methods for observing the thunderstorms nowadays.

The registration system for the characteristics of thunderstorms is the thunderstorm direction finding net (TDFN) LS 8000 manufactured by Vaisala, was first deployed in Russia at the VGI in the North Caucasus in 2008 [8]. GPS allows for a short time to collect information about the climatic characteristics of thunderstorms (number of days with a thunderstorm, duration of thunderstorms) and lightning parameters (lightning currents, discharge time), etc.

**Discussions and Results**
The main objective of this work is a comparative assessment of the impact of buildings and structures by lightning, depending on the methodology for determining the duration of thunderstorms in hours
for the territories of the North Caucasus. The analysis was performed on the basis of data from the GPS of the FSI “VGI” and data from weather stations [2,3,9].

In this work, to determine the statistical characteristics of the duration 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 ranging lightning registration system.

To study the relationship between the number of days with a thunderstorm recorded by weather stations and the duration of thunderstorms in hours for these days, instrumental observations of the FSI “VGI” (TDFN) were used. The data on thunderstorms in the North Caucasus were collected over a long-term period of observations (from 2008 to 2019). Based on them, different data are grouped for analysis in different territories: the number of days with a thunderstorm per month, per year, as well as the thunderstorm duration per month and per year. Figure 2 shows the annual course of the monthly values of the number of days with a thunderstorm and their duration in the monitoring territories at the weather stations. The radius of the observed weather station territory is 15 km.

The collected long-term data of the FSI “VGI” (TDFN) was grouped (ranked) as the parameters increased - the number of days with a thunderstorm and the thunderstorms’ duration (Figures 2 and 3). An analysis of the correlation between the number of days with a thunderstorm $D$ and the thunderstorms’ duration $T$, as well as the expressions of their correlation between $D$ and $T$ characteristics.

**Figure 2.** Graph of the number of days with a thunderstorm and the thunderstorms’ duration by months.

We searched for the relationship between the thunderstorms’ duration $T$ and the number of days with a thunderstorm $D$ and an assessment of the dependence significance.
Figure 3. Dependence of the thunderstorms’ duration on the number of days with a thunderstorm.

Exploring the statistical relationship between the number of days with a thunderstorm $D$ in the range from 0 to 30.5 days and the thunderstorms’ duration in hours in the range from 0 to 300 hours, the correlation coefficient was calculated.

A high and statistically significant correlation coefficient was obtained - 0.98, therefore, it is possible to build a regression model that reflects the real laws of the relationship between $D$ and $T$. The regression model parameters are calculated by the well-known least squares method. In accordance with the theory of statistics, the simple regression equation has the form:

$$ T = 10.66 \times e^{0.1461D} $$

(5)

The instrumental observations of the FSI “VGI” (TDFN) showed that the average annual number of days with a thunderstorm is 75 days, the duration of thunderstorms is 200 hours at the observation point (weather station). For comparison, the formula (4) gives 150 hours for such a number of days with a thunderstorm, which is less by 50 hours. This difference leads to a significant discrepancy of up to 30% in the number of lightning strikes on buildings and structures $N$, obtained by the visual-auditory method and instrumental observations (Table 1).

Table 1. The number of lightning strikes per year on buildings and structures $N$, according to visual and auditory observations at the weather stations and instrumental observations.

| №  | Object Type                                      | According to the weather stations | According to LS8000 |
|----|-------------------------------------------------|----------------------------------|---------------------|
|    |                                                 | $T_i$, [hour] $n$, [1/km² in year] $N$ | $T_i$, [hour] $n$, [1/km² in year] $N$
| 1  | Focused buildings (pipes, towers, towers). $h=100m$ | 150 10.0 2.8               | 200 14.0 3.9        |
| 2  | Buildings and constructions. $h=30m$, $S=50m$, $L=200m$ | 150 10.0 0.7               | 200 14.0 1.0        |

Summary
A comparative assessment of the buildings and structures’ impact by lightning depending on the methodology for determining the duration of thunderstorms in hours for the territories of the North Caucasus has been performed. The analysis on the data basis from the FSI “VGI” (TDFN) and the data from the weather stations has been performed.

The instrumental observations of the FSI “VGI” (TDFN) showed that the average annual number of days with a thunderstorm is 75 days, the duration of thunderstorms is 200 hours at the observation point (weather station). According to the long-term instrumental data analysis results, the dependences between the duration of thunderstorms $T$ and the number of days with a thunderstorm $D$ in the exponential expression form and the dependence significance is estimated.

References
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