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Investigation of Lightning Discharges in the North-Caucasus Region of Russian Federation

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Abstract: The parameters of the lightning currents have been determined for the Southern regions of Russian Federation for the first time. The database of the characteristics of the on-land discharges has been composed on the basis of data from the thunder-detector LS 8000. The analysis of obtained results has been performed and the analytical dependencies for the distribution of the lightning currents established applying the mathematical methods.

Key words: Lightning, thunder-detector, seasonality of discharges, ratio of in-cloud and on-land discharges, polarity of lightning

INTRODUCTION

Instrumental studies of lightning parameters and of thunderstorm activity by means of radio-devices accompanied with the analytical approaches to data retrieving are among the most actual and promising fields of thunderstorm electricity physics. Similar investigations are closely linked to the growth of performance specification to the effectiveness of protection of common objects from the influence of lightning phenomena: discharges, increased electric fields, electromagnetic emission and so on (Adjiev *et al*., 2011; Ostgaard *et al*., 2013; Barnes *et al*., 2014). That is why, the studies oriented on the establishing of the regularities of thunder electricity, determining the basic physic-statistical parameters of lightning, spatial-temporary variations of the thunderstorm activity above various territories have been paid much attention recently.

Here, the results of the observations over the North-Caucasus Federal District of Russian Federation obtained with the thunder-detecting system of the High-mountain Geophysical Institute (Nalchik, Russia) within the 2010-2013 years have been presented as well as the analytical expressions for the basic parameters of lightning have been found. The mentioned system detected about 1000 thunder days within the focused years including 250 days in 2010 and 215 days in 2011. The analyzed years are the ones with average thunder activity in the target region. The number of days with thunderstorm occurred to be 25 in 2010 and 31 in 2011 according to the data of the meteorological stations located in cities Rostov-na-Donu, Taganrog, Shakhty, Belaia Kalitva and others.

OBSERVATIONS

Basing on the observations starting from January 2010 to December 2013 held with the thunder-detector LS 8000, the Database for the North-Caucasus Federal District of Russian Federation (NCFD) has been composed. One should notice that the NCFD possesses the specific relief and can be characterized by the unique natural-climatic conditions.

One set of the retreived data is presented in the Table 1. In particular, there is shown the information on the number of days with a thunderstorm, discharges of a various kind, values of lightning currents, duration of rise and decay of the waves of the on-land discharges.

ANALYSIS

The analysis of the composed database reveals for the target region that the greatest number of days with a thunderstorm takes place at the first decade of the June ending by the beginning of August. For both 2010 and 2011 year, there came the thunder-free period (lasted for >30 days) after the maximum of days with thunderstorms. After that the thunders would have been registered almost everyday in September and finish by the first decade of October (Fig. 1a and b).

Monthly changes of quantities of the on-land discharges are depicted in Fig. 2 for years 2010 and 2011. One can see from the Fig. 2 that two afore mentioned maximums exist again: the first one in July while the second of lower amplitude in September. The amplitude of the thunder activity by number of the on-land discharges is about 30% lower in September compared to that of July.

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Table 1: A segment of the database on the parameters of the on-land discharges

Number of days with a thunder per month	Date of the thunderstorm	Number of discharges	Average current (kA)	Maximum current (kA)	Minimum current (kA)
Year 2010					
9	09 Jan.	11	-21.55	-12	-32
	12 Jan.	111	-5.42	185	-149
	14 Jan.	27	-16.15	219	-128
	17 Jan.	4	-15.25	-12	-18
	19 Jan.	1	14.00	14	14
23	29 Oct.	188	-10.34	61	-50
	30 Oct.	45	-16.53	33	-79
3	16 Nov.	2	-9.00	-9	-9
	26 Nov.	364	-34.70	193	-296
	27 Nov.	8	-26.88	-8	-43
6	10 Dec.	1	-5.00	-5	-5
	14 Dec.	4	15.50	64	-86
	19 Dec.	5	26.80	97	-35
	20 Dec.	1	-6.00	-6	-6
	30 Dec.	1	-11.00	-11	-11
	31 Dec.	265	-8.51	94	-185
Total		386779	-16.62	345	-356

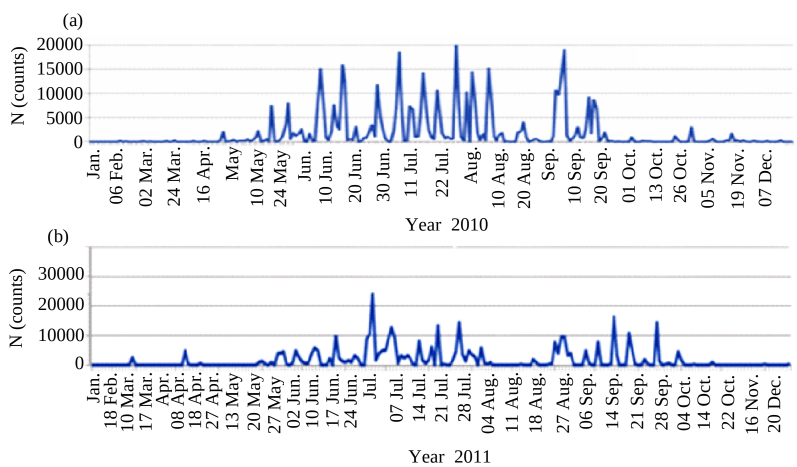

Fig. 1: Dynamics of the number of on-land discharges, N, per dates with a thunderstorm on the territory of the South of the European Russia for years; a) 2010 and b) 2011

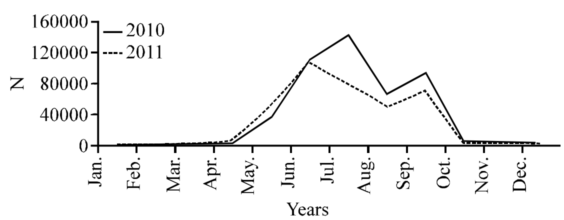

Fig. 2: Alterations of the monthly values of the number of on-land discharges for years 2010 (solid blue line) and 2011 (dashed pink line)

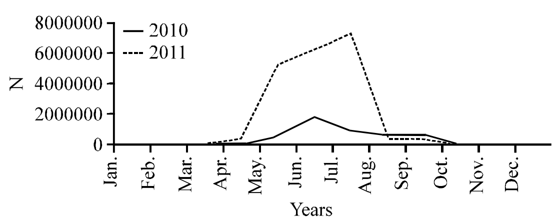

Fig. 3: Alterations of the monthly values of the number of in-cloud discharges for years 2010 (solid blue line) and 2011 (dashed pink line)

The dynamics of the changes of the total value of the number of in-cloud discharges (Fig. 3) repeats approximately the temporal behavior of the on-land discharges. However, the second maximum in the seasonal changes of the number of in-cloud discharges is absent in September. Some features of the mentioned distinctions uncover the ratio of the temporal behavior of the total number of on-land and in-cloud discharges.

The important parameter of the thunder-discharge activity in clouds is the ratio between the numbers of on-land and in-cloud lightning discharges per certain period of time for example per each thunder cycle of a

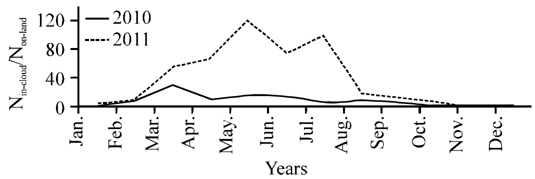

Fig. 4: Dynamics of the monthly ratio between the in-cloud and on-land discharges for years 2010 (solid blue line) and 2011 (dashed pink line)

cloud or per each thunder day. Figure 4 represents the ratio between the number of in-cloud and on-land discharges per stormy day for 2010 to 2011 years. One can see from Fig. 4 that the ratio between monthly in-cloud and on-land discharges varies in broad limits: from 0.2-104.7 at annual value 9.2 in 2010 and 30.3 in 2011. This interrelation tells that there occur dozens of in-cloud discharged per each on-land one.

The composed database can been used to determine the characteristic parameters of lightning of the Russian North Caucasus which could be accounted for at performing of works on protecting of diverse objects from lightning.

The brief list of parameters of the lightning discharge, applicable when calculating the protection of the high-voltage line and sub-stations from the thunderstorm overloading. Comprises:

- The amplitude and steep of the current
- The duration of pulse and front
- The polarity of the discharge
- The average density of impacts of lightning onto the surface of the Earth
- Others

Due to the fact that the probability distributions of lightning parameters can differ significantly for every territory possessing intrinsic physic-geographical characteristics, one has to obtain specific data for the given place. Misaccount of this circumstance usually brings the researcher to the lowered or unjustified increased levels of confidence of protection from a thunderstorm and consequently to the economic losses.

Figure 5 represents the distributions of the amplitude of current of the first components of the on-land negative lightning discharges registered at different instances of a year (curves 1 and 2 for summer and spring-autumn storms, respectively). One can see from Fig. 5 that the currents of lower amplitude are detected more often at autumn-spring seasons compared to those of summer.

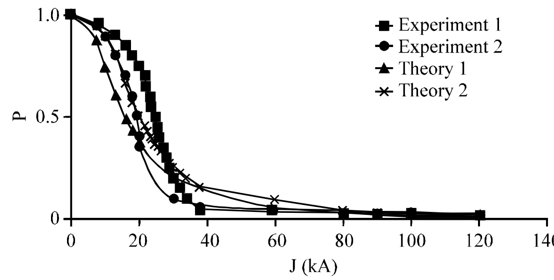

Fig. 5: Distribution of currents of negative lightning per seasons of a year

Applying the methods of the mathematical statistics we have found the following analytical expressions for the curves 1 and 2 of the Fig. 5:

$$y = e^{0.46-0.079x+3.805\times10^{-4}x^2} \quad (1)$$

$$y = e^{0.786-0.08x+2.953\times10^{-4}x^2} \quad (2)$$

Where:
y = Probability
P = The x-value of a current J (kA)

Equation 1 and 2 could be rearranged in shape of :

$$\lg y = a+bx+cx^2$$

With a, b, c being numerical coefficients. The distribution of lightning currents obtained by us (availing the equipment of LS 8000) satisfies quite well with the distributions accepted in recommendation (Adjiev, 2004), international organization on protection from lightning (Adjiev, 2004) and data obtained at High-Mountain Geophysical Institute by means of active-passive radio-mechanic resources. The found values of lightning currents allowed us to reveal the basic factors affecting the obtained characteristics of distributions of J_M. Here, must be mentioned the orographic and climatic conditions, the level over the sea: the type of the substrate surface, the type of the object (condensed or extended).

It comes from Fig. 5 that the climatic conditions the season of the developing of a thunderstorm are reflected on the distributions of the lightning currents. The ratio between the negative and positive lightning varies in ranges from 1.5:1::2.3:1. In other words, the negative lightning comprise about 60-70% of all the on-land discharges. The volume of explored selection is near 60000 cases for positive lightning.

Figure 6 represents the statistical distribution of the frequencies of originating of the positive discharges of

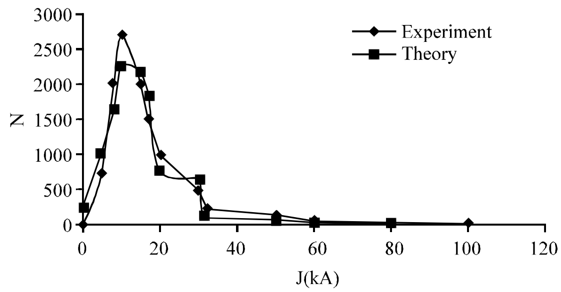

Fig. 6: Distribution of currents of lightning of the positive polarity

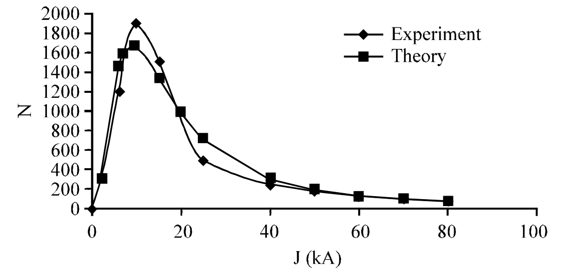

Fig. 7: Distribution of currents of lightning of the negative polarity

the lightning: $F(J_+)$ the trend line (solid) for the territories of the Northern Caucasus Russia. The volume of the explore selection is near 30000 lightning discharges. The distribution of the current of a lightning of the positive polarity can be approximated with a high accuracy by the relation:

$$F(J_+) = e^{e^{-0.1+1.596-0.297\ln^2 x}} \quad (3)$$

where, a = -0.1, b = 1.596, c = -0.297 are the numerical coefficients. The determination coefficient R^2 for the Eq. 3 is 0.9987. The weakest and ordinary (2688 cases) pulse of the measured current is 10 kA while the strongest is 13 kA. The modus is 10 kA, the median, located in the middle of the ordered variation sequence and dividing it into two equal parts is 17 kA with average current being 23 kA. The dispersion of the studied signals the degree of the scatter about the average value is 304.05 $(kA)^2$ while the root mean square deviation is 17.458 kA. The sum of all positive signals of the selection is 72290 kA. The selection swing or the difference between the maximal and minimal detected signals is 301 kA.

Figure 7 represents the statistical distribution of the frequencies of originating of the negative lightning discharges: $F(J_-)$ the trend line (solid) for the territories of the Northern Caucasus Russia. The distribution meets well with the equation:

$$F(J_-) = e^{e^{1.45+5.505-0.115\ln^2 x}} \quad (4)$$

Or in a general form of :

$$\ln F(J_-) = e^{a+\ln x + b\ln^2 x}$$

with a = 1.45, b = 0.505, c = -0.115 being numerical coefficients. The determination coefficient R^2 for the Eq. 3 is 0.9191. The weakest pulse of the measured current is 4 kA while the strongest is 210 kA. The modus is 9 kA, the median, located in the middle of our ordered variation sequence and dividing it into two equal parts is 14 kA with average current being 16.8016 kA. The dispersion of the studied signals the degree of the scatter about the average value is 140.648 $(kA)^2$ while the root mean square deviation is 11.595 kA. The sum of all negative signals of the selection is -530287 kA. The selection swing or the difference between the maximal and minimal detected signals is 206 kA.

The curves depicted in Fig. 6 and 7 characterize the currents of lightning of opposite polarity. Particularly, it is evident from Fig. 6 and 7 that possessing the probability not <10% the currents of positive lightning overcome 100 kA while those of negative polarity -70 kA. There at present arises a question about the distinction between the values of currents of opposite polarity. The lightning of a current about 200 kA are so rare that the probability of their emergence is <2%.

Another important parameter required for the correct planning and arrangement of the lightning-protecting affairs is the duration of rise of a current wave (τ_φ) at discharges from cloud to land. On the Fig. 8, we have plotted the statistical distributions of this parameter for negative and positive lightning (curves 1 and 2, respectively) taken from the measurements availing the thunder-detector LS 8000. The dependencies could be described well by the equations:

$$N = e^{e^{1.998+0.033-0.00136x^2}} \quad (5)$$

$$N = e^{e^{1.981+0.015-0.00045x^2}} \quad (6)$$

One can see from the Fig. 8 that the values of τ_φ change from 1-50 μsec. The average value for the negative and positive lightning is 8 and 13 μsec correspondingly.

Obtained data agree quite well with the Berger measurements held with the help of oscillographic methods and confirm that in respect to the sign of the lightning charge the value of τ_φ changes every 5 μsec in average.

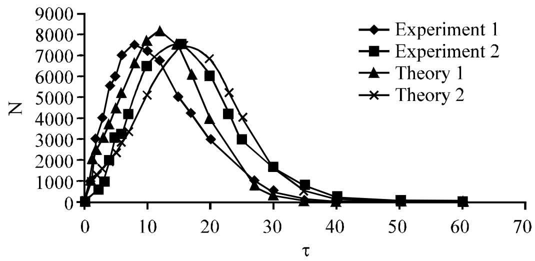

Fig. 8: Duration, τ in microseconds of a rise of the signal, N

CONCLUSION

So, there the database for the parameters of lightning registered by the thunder-detector LS 8000 on the territory of the North Caucasus of Russian Federation has been created for the first time. The analysis of the thunderstorm activity has been carried out and two seasonal maximums have been exposed. The qualitative relations between the various characteristics of the thunderstorm activity (number of discharges in-cloud, number of discharges on-land, number of days with a thunder and so on) have been established. The distributions of currents of opposite polarity and the characteristics of the distributions have been found and also the comparative analysis of the collected data has been performed in respect to results obtained by other methods.

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