Featuring the thunderstorm activity using lightning data provided by the Romanian Lightning Detection and Location Network

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***Abstract*-- The paper presents some of the results issued from the statistical analysis of the events recorded by the Romanian Lightning Detection and Location Network (RDLN) during three years of activity (2003 to 2005). General features of the lightning activity over the Romanian territory were obtained using GIS software, namely the regional distributions of the keraunic level and the flash density. The assessment of lightning exposure for transmission lines was realized by detecting lightning events inside the exposure zones associated to the overhead lines' path. Several criteria to establish appropriate dimensions for the exposure zones were tried, in order to compensate the inherent uncertainty associated to the impact location. The results of the basic and advanced statistical analyze of the collected lightning data are presented and compared to the overall distributions. We conclude with some general observations on the use of lightning data by power utilities.**

***Index Terms*—Lightning, Power Systems lightning effects, Power transmission meteorological factors.**

I. Introduction

The Lightning Detection and Location Network (RLDLN) operate in Romania since 2002, collecting information on the lightning activity over the national territory, [9]. The detection network consists of 8 SAFIR 3000 Total Lightning Automatic Detection Stations located over 1000 m altitude. The station combines a VHF interferometric array and a LF sensor for the localization and characterization of total lightning activity. The SAFIR interferometric array uses differential phase measurement on electromagnetic lightning waves for long-range direction finding of lightning activity. The SAFIR LF discrimination sensor is a wide-band electric antenna capable of identifying cloud-ground lightning characteristic. The data is all GPS synchronized and reported to a central station, which computes the location by the triangulation technique The detection algorithm is based on the well known IMPACT method [1], [2] which can process information provide by any combination of sensors: direction finding (DF), TOA (time of arrival), or combined DF/TOA. RLDLN can provide both real-time and historical lightning data to different end users including electric utility industry.

The real-time data include the time-stamp of each detected event (return stroke), their location (in terms of longitude and latitude), multiplicity, polarity and an estimate of some of the current's parameters such as peak current, slope, electric charge transferred during the return stroke, the integral of action (stroke energy), the rise and decay time.

The network covers all the national territory with a detection efficiency greater than 90% and a location accuracy (specified by the estimated value of the median accuracy) smaller than 1000 m.

The RLDLN location algorithm groups individual strokes into flashes and determines the flash multiplicity and polarity. In the present paper the basic statistical analyze is extended to lightning data collected over the all country during 2003, 2004 and 2005. During 2006 the network was down due to technical problems and lightning data were not collected. Due to the possible detection of non-CG flashes when the polarity is positive, several thresholds have been used as a cutoff to isolate the most probable positive CG flashes. This threshold ranges from 5 kA to 15 kA [3], [4]. For the dataset utilized to perform the present analysis no threshold was used and all detected positive CG flashes were count.

II. Description of lightning activity

The paper is focused on the general description of the lightning activity at national and regional level because knowledge of the frequency of occurrence of lightning strokes is of utmost importance in different engineering applications related to lightning. The severity of the stormy activity over a given region can be evaluated with the aid of three indicators:

- annual number of thunderstorm days (keraunic level),
- annual number of thunderstorm hours (cronokeraunic level),
- lightning flash density.

In Romania, information concerning the frequency of thunderstorm days and thunderstorm hours has been collected since 1952. Over 50 observation points in meteorological stations have covered all the country. Each of the meteorological stations have hourly recorded the number of times the lightning flashes were saw or the number of times that thunders were heard in one day. Maps of the multiannual mean distribution of both keraunic and cronokeraunic levels are available to be used in lightning applications. These maps represent 11-year climatology of geographic distribution of

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lightning activity in Romania. Although the thunderstorm days or the thunderstorm hours are not precise attributes of the regional thunderstorm profile, they happened to be good enough indicators of lightning activity when systems for lightning detection are not available in the region.

A. Thunderstorm days frequency (keraunic level)

As already mentioned, up to now, the knowledge of the stormy activity over Romania is limited to the map of mean annual values of the keraunic level averaged over 11 years of observation. The maps obtained using the lightning data provided by the RLDLN were structured in the same way, to supply a base for comparison. The maps displaying the geographical distribution of the keraunic level are represented in Fig. 1. The information is presented as filled contours of the isolines system build with observed values of the keraunic level on a grid of 237399 cells covering all the national territory. The isolines of the keraunic level divide the territory in 4 zones with different degrees of stormy severity from A (the most severe) to D (the less severe). The extension and position of the severity zones are subject to annual variation, as it can be observed comparing the maps reproduced in Fig. 1 On the same figure one can see the average map established over the entire observation period.

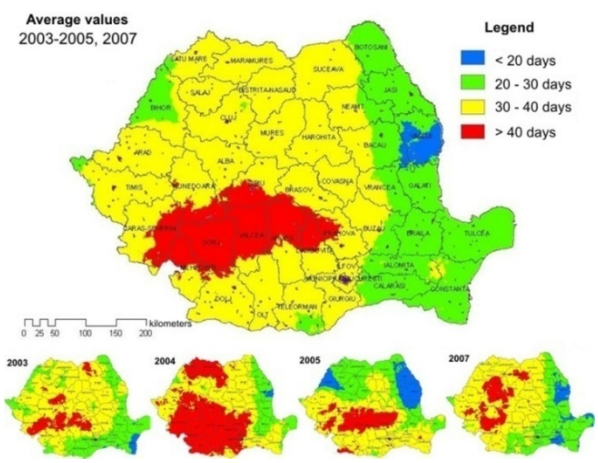


Fig. 1. Geographic distribution of the thunderstorm days' frequency.

TABLE I
EXTREME VALUES OBSERVED FOR THE KERAUNIC LEVEL

	2003	2004	2005
Lowest observed value	18	15	0
Highest observed value	65	81	55

TABLE II
AVERAGE VALUES OF THE KERAUNIC LEVEL

	Keraunic Level (days)	2003	2004	2005	Old map
Zone D	< 30	26	26	20	27
Zone C	30…39	35	35	35	36
Zone B	40…49	44	45	44	44
Zone A	> 50	55	59	52	52

Extreme and average values observed for the keraunic level inside a given area are given in tables I and II. The average values evaluated with the lightning data are compared with the average value given by the old map. The agreement can be qualified as "good".

B. Thunderstorms hours frequency (cronokeraunic level)

The annual number of thunderstorms hours is a parameter potentially more correlated to the lightning occurrence than the keraunic level, as it can distinguish between small thunderstorms producing a few lightning flashes in tens of minutes and large storms lasting for several hours and producing hundreds of flashes. A map with the geographical referenced frequency distribution of the average thunderstorm duration over Romania is given in Fig. 2 together with the same type of map established for the frequency of thunderstorm days. Both maps were superimposed over the physical map of Romania in order to underline the possible correlation with orographic attributes. Up to now, the correlation between thunderstorm days and hours is confirmed in a qualitative manner, comparing the two maps. Further research will produce quantitative information. As for the relation with particular relief features, it can be observed that the zone A of storm severity is centered over the region of the Southern Carpathians Mountains.

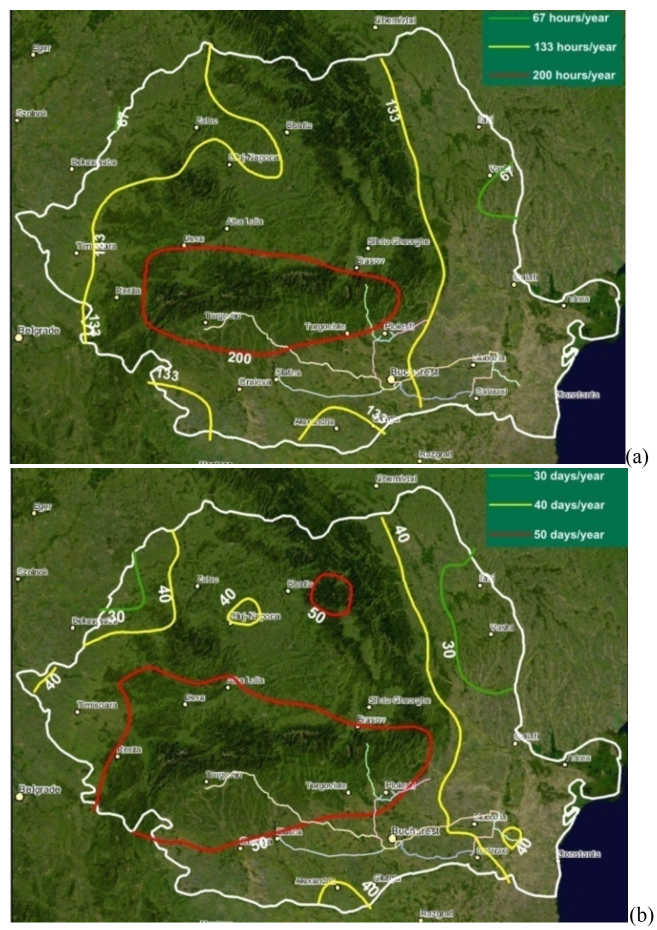


Fig. 2. Average multiannual geographical distribution of the isolines' system for the frequency of (a) -thunderstorm hours and (b) -days.

As for the keraunic level, extreme and average values of the cronokeraunic level are given in Tables III and IV. The cronokeraunic level's values manifest a greater annual variability as it can be seen.

TABLE III
EXTREME VALUES OBSERVED FOR THE CRONOKERAUNIC LEVEL

	2003	2004	2005
Lowest observed value	42	42	0
Highest observed value	270	309	266

TABLE IV
AVERAGE VALUES OF THE CRONOKERAUNIC LEVEL

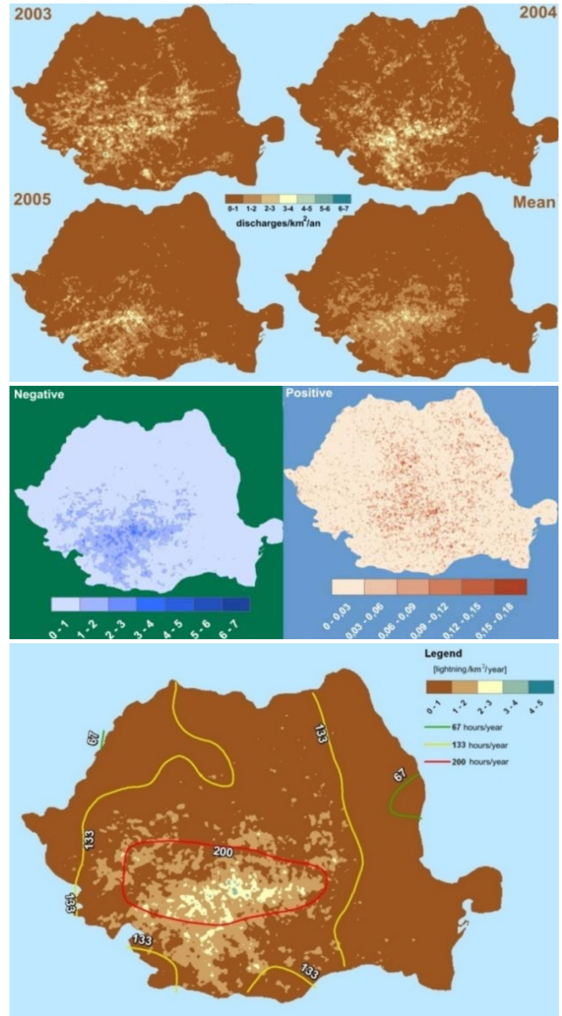
	Cronokeraunic Level (hours)	2003	2004	2005	Old map
Zone D	<160	197	202	194	167
Zone C	100…159	131	134	129	115
Zone B	70…99	87	82	84	87
Zone A	< 70	57	59	40	68

C. *Lightning flash density*

Defined as the number of flashes occurring per unit area per year, the flash density is the primary descriptor of lightning incidence. It is common practice to characterize the overall lightning threat with maps of the territorial distribution of the flash density. In the past, estimates of this parameter were derived from thunder-day and/or thunder-duration statistics or more directly from readings of lightning flash counters. Clearly, a direct measurement of the lightning strike locations provides a much better and more accurate method of quantifying the lightning exposure. Good knowledge of its territorial distribution is mandatory for use of modern lightning protection solutions.

Fig. 3 shows the density maps of the annual flash density and the average annual flash density for CG flashes over Romania derived from RLDLN data over years 2003-2005. The maps were made by counting all flashes that occurred in 1-km^2 cells and then smoothing these counts by averaging over the 24 "nearest neighbor" points. In making this the Romania was divided into more than 10000 cells, each element (about 5 x 5 km^2) containing the total smoothed counts. Each value of the flash density was rounded to the nearest integer and categorized in classes from 0 to the highest integer value detected. Each class received a distinct color. For the maps in Fig. 3.a, all flashes were counted (i.e. singular and multiple flashes of negative and positive polarity). The maps in Fig. 3.b illustrate the geographical variation of the negative and positive flash density (average multiannual values). For positive flashes the highest values observed lie between 0.15 and 0.18 flashes/km^2/year. Fig. 3.c contains a composite map in which the multiannual average geographical distributions for both the flash density (all flashes) and the isolines' system for the thunderstorm days frequency are superimposed to illustrate, in a qualitative manner for the moment, a possible stochastic correlation between physical (relief) attributes and values of the flash density.

The maps reveal the annual variability of the flash density. Lightning flash density is sometimes greater over the slopes leading to higher terrain and is minimal over large areas of rough terrain. It is obvious on all maps that, as same as for the keraunic level, the region situated over the Southerner Carpathian Mountains and the sub Carpathian adjacent zones are the location of an intense lightning activity. The highest value recorded for the flash density was a value of 7 flashes/km^2/year.



(a)

(b)

(c)

Fig. 3. Different types of flash density geographic distributions: (a) annual values for all flashes (disregarding the polarity or the multiplicity) and average multiannual value; (b) average multiannual values for negative and positive flashes; (c) geographical disposition of thunderstorm hours' average values superimposed on the average multiannual flash density map.

From the large national scale, the analysis was extended to the medium scale of territorial administrative units (counties), in order to establish the degree of dependency between relief attributes and the flash density. An overall image of the storm severity associated to each county can be observed in Fig. 4 where both the amplitude of the flash density interval of variation and the multiannual average values are represented. The counties are classified following the average value of the flash density in increasing order. In a first approach the influence of the average terrain elevation value (altitude) upon the flash density was checked; the results can be seen in Fig. 5. Data in Fig. 5 prove the existence of a correlation with terrain elevation already mentioned by other authors, [5], and [11]. The correlation is positive (the flash density has the tendency to increase when the terrain elevation increase). For the multiannual values of the flash density the correlation coefficient equals 0.42 which qualify the correlation as "significant". An important change in the annual values of the correlation coefficient can be observed – from 0.06 in 2005 to 0.70 in 2007; for now the factors responsible for this variability of the correlation coefficient are to be identified.

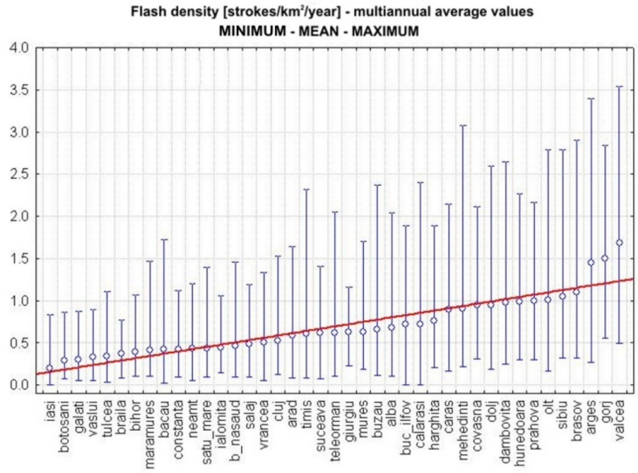


Fig. 4. Flash densities' multiannual intervals of variation for different Romanian counties.

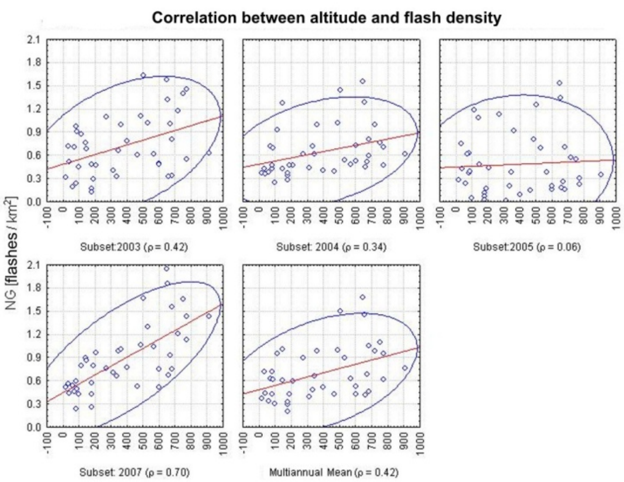
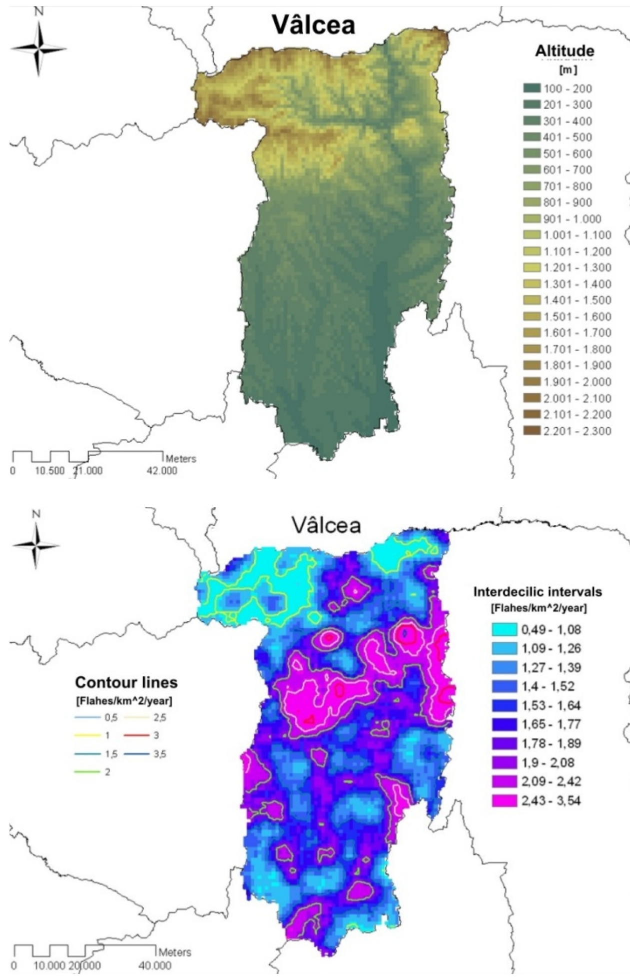


Fig. 5. Correlation between the mean value of county's altitude and the mean value of county's flash density.

To describe the flash density territorial distribution pattern, two types of graphical visualization were used, raster map and contour plots overlaid as it can be seen in Fig. 6.b. For this particular case, the data set contains multiannual average values of the flash density computed for each of the 5698 cells of the raster built for the Vâlcea-county; the raster consists of (1x1) km square cells. The 5698 values were classified in increasing order and categorized in 10 classes; each class includes 10% of the data sample. The limits of the resulting classes are the 10-quantiles (deciles) of the sample cumulative distribution function. A distinct color was allocated to each of the interdecilic intervals; in this way, areas with values belonging to a given interdecilic interval can be easy located on the map. The second graphical visualization was the family of contours plots. A contour is a curve that connects points of equal value of the flash density; the distribution of these curves shows how values change across the surface. The location of the contour plots highlights areas of lightning strokes concentration on the county's surface.

The county under study (Vâlcea) has the following typical values for the terrain elevation: minimum value 127 m, maximum value 2296 m, median value 178 m and a standard deviation of 484 m; the region is characterized by a contrasting topography, where a mountain chain boarder on the much lower region of an important and extended hydrographic basin. The results indicate that, for localized areas (following the mountain shape) within this region the flash density is correlated with the terrain slope and not with the altitude. This suggests that terrain slope has more influence than terrain elevation on lightning activity as mentioned in [5].



(a)

(b)

Fig. 6 Physical map of the county with the highest storm activity in (a) and the territorial distribution of flash density in terms of classified multiannual average values in (b).

Further study, using a Digital Terrain Model (DTM) will hopefully quantify the influence of elevation and other geographical elements and natural features, such as rivers and other break lines, on the lightning incidence.

III. Lightning current's parameters- main statistics

The RLDLN post-process primary data and produces estimations for some of the lightning current's parameters such as the peak value, the current derivative, the impulse charge and the integral of action (or energy). Lightning data were classified in 6 groups following the polarity of the flash and the multiplicity; the resulting groups are referred as negative and positive single strokes, NEG-SING and POS-SING, negative and positive first stroke in a flash, NEG-MC1 and POS-MC1, negative and positive subsequent strokes

NEG-MC2 and POS-MC2 regardless the rank of the subsequent stroke in the flash.

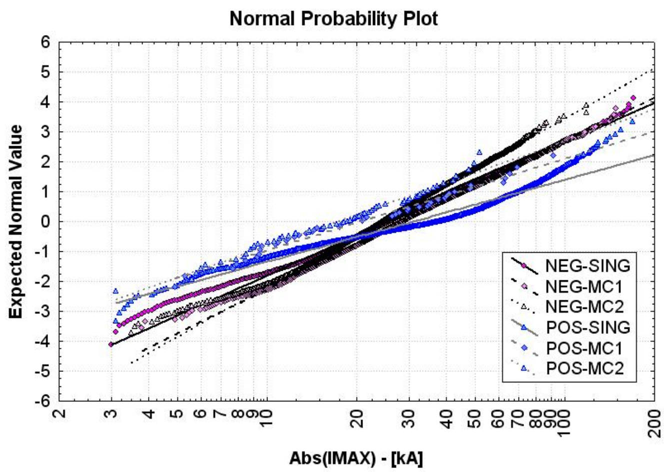


Fig. 7 Sample cumulative distribution functions and fitted log-normal distributions for the current's peak value

In a first approach, the lightning data were processed independently, by groups, in order to obtain the descriptive statistics (such as mean, median, dispersion and others). The records obtained during a month have formed the basic unit for the statistical analyze. In the first step, the 36 samples (each corresponding to a month of observation) were processed independently, by groups, in order to obtain the descriptive statistics (such as mean, median, dispersion …). The second step was to check if all the samples can be considered as coming from the same population using nonparametric methods. In more technical terms, nonparametric methods do not rely on the estimation of parameters (such as the mean or the standard deviation) describing the distribution of the variable of interest in the population. Therefore, these methods are also sometimes (and more appropriately) called parameter-free methods or distribution-free methods. The samples considered similar were put together in a single sample for which we tried to fit a theoretical distribution on the observed (sample) distribution and validate it through appropriate tests. However, the best way to assess the quality of the fit of a theoretical distribution to an observed distribution is to review the plot of the observed distribution against the theoretical fitted distribution. There are two standard types of plots used for this purpose: Quantile-Quantile (Q-Q) plots and probability-probability (P-P) plots. The result produced by such a procedure is presented in Fig. 7 as a Q-Q plot for one of the most important current's parameters -the peak value of the lightning current.

The fitted distribution was the log-normal one. For each group of data the scale parameter (the median value in this case) and the shape parameter of the lognormal distribution are listed in the Table V.

A good fit of the theoretical distribution to the observed values would be indicated by this plot if the plotted values fall onto a straight line.

TABLE V
PARAMETERS OF THE FITTED DISTRIBUTION FUNCTIONS

Type of the flash	Median (scale parameter) μ (kA)	Shape parameter σ (in $\log_{10}$ units)
NEG-SING	25.52	0.226
NEG-MC1	28.74	0.203
NEG-MC2	24.34	0.178
POS-SING	30.98	0.366
POS-MC1	20.57	0.328
POS-MC2	17.14	0.285

The first conclusion, visible when comparing the fitted distributions to the observed ones, is the deviation of some of the observed distributions from the lognormal model especially at the lower and upper distribution's tails. In fact the log-normal model can be considered adequate for the majority of groups in the interval between [-3 … +3] of the expected normal value (or 15.86 % to 84.14 % in terms of expected normal probability). The first component for the positive multiple flashes (POS-MC1) marks an exception because the observed distribution is not log-normal and no other theoretical distribution could be fitted. We must notice that for this particular group, more than 10 % of the sample consists in current's peak values smaller than 10 kA; it is than possible that non-CG events detected as positive CG flashes have contaminated the sample.

The second conclusion refers to the fact that the current's peak value follows significantly different distribution functions for single stroke events and for first stroke in multiple strokes events. In fact, the CDF's parameters listed in Table V show:

a) *different median values*: 12% for the negative polarity and 27% for the positive polarity, confirming a stochastic significant difference in the central tendencies;

b) *different scale parameter* for both polarities which means different spread tendencies around the center of data, single events exhibiting a greater spread than multiple ones.

The same behavior was reported in [10] for lightning data collected by the French LDLN (Meteorage) which uses another type of detection than the Romanian detection network. The parameters inferred for the Cumulative Distribution Functions are listed in Table VI.

TABLE VI
CURRENT' PEAK VALUE: CDF PARAMETERS, [10]

Type of the flash	Median μ (kA)	Shape parameter σ ($\log_{10}$)
NEG-SING	14.3	0.264
NEG-MC1	22.6	0.208
POS-SING	37.1	0.297
POS-MC1	50.1	0.286

As one can see, the medians differ with 58% for the negative polarity and 35% for the positive polarity. For now the authors cannot offer any explanation of this behavior. Eventually, those important differences observed between single and multiple events should be examined in relation with the peak current estimation errors introduced by the empirical linear relationship used to convert electromagnetic field measurements into current's peak values.

The third conclusion refers to the order among groups established on the basis of the median current value (which represents the median for both the theoretical distribution and the observed one):

i)- *negative polarity*

NEG-MC2 < NEG-SING < NEG-MC1

(24.34 < 25.52 < 28.74) kA

ii)- *positive polarity*

POS-MC2 < POS-MC1 < POS-SING

(17.14 < 20.57 < 30.98) kA

iii)- *single positive and negative flashes*

NEG-SING < POS-SING (25.52 < 30.98) kA

iv)- *first stroke in multiple negative and positive flashes*

POS-MC1 < NEG-MC1 (20.57 < 28.74) kA

v)- *subsequent strokes in negative and positive flashes*

POS-MC2 < NEG-MC2 (17.14 < 24.34) kA

Relations i) and ii) show that for both polarities the current's peak value tends to be smaller in subsequent strokes. Relation iii) confirms that for positive polarity the peak value is greater than for negative polarity but only for single strokes because, for the first stroke in multiple lightning events the relation iv) the order is reversed. In fact, relations iv) and v) are to be checked again as they contradict other reported data.

To conclude the discussion about the current's peak value, a comparison will be made with other known cumulative distribution functions, namely:

o the interpolating function introduced in [6]: known as CIGRE-CDF, consists of two segments originating from the following lognormal distributions:

Parameter	Validity interval	
	I_{MAX}<20 kA Shielding domain	I_{MAX}> 20kA Backflashover domain
Median (scale parameter) μ (kA)	61	31
Shape parameter σ (in $\log_{10}$ units)	0.753	1.925

o the CDF used in IEEE standards: is not strictly a distribution function, but it is easy to use:

$$\text{Prob}(I > I_{MAX}) = \frac{1}{1+(I_{MAX}/31)^{2.6}}$$

o the distribution proposed in [13] as an alternative to CIGRE-CDF: was inferred using mainly the same sample as the CIGRE one but it is a true CDF defined as a mixture of two elementary lognormal distributions with the composition law given by

$$f(I_{MAX}) = a\, f_1 + (1-a)\, f_2$$

The mix proportion is a = 0.10 and the shape and scale parameters of the elementary lognormal distributions are:

Scale parameter μ (kA)	10.50	36.45
Shape parameter σ (in $\log_{10}$ units)	0.097	0.190

All the quoted distribution functions are displayed in Fig. 8 as complement to unity functions namely:

$$\text{Prob}(I > I_{MAX}) = 1 - \text{CDF}(I \le I_{MAX})$$

where CDF stands for Cumulative Distribution Function

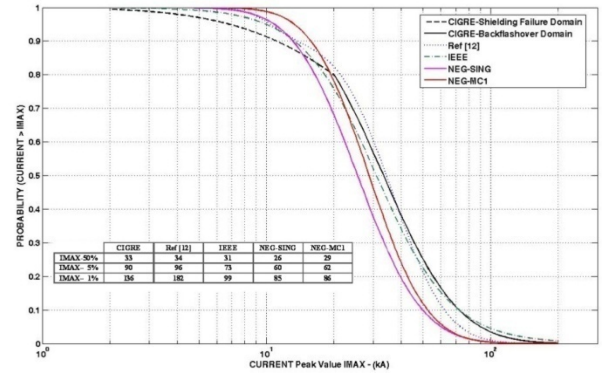


Fig. 8 Complement to unity of the theoretical CDF for lightning current's peak value, single and first return stroke in negative flashes.

In term of central tendency the CDF fitting lightning data recorded by RLDLN is shifted to the left towards smaller predicted values of the current, the differences between the median values (IMAX-50% in Fig. 8) meet 26%. The NEG-MC1 data set is closer to the CDFs in use than the NEG-SING data set. The same important differences can be noted for the 5% and 1% quantiles of the distributions (peak current's values to be exceeded with 5 respectively 1 % probability). For the lightning data set analyzed in [12] the differences are even greater. It is obvious that the current peak value obtained when post-processing the primary data recorded by any Lightning Location Systems are subject to systematic errors not easy to identify and eliminate.

IV. Lightning Exposure of Transmission Lines

The archived lightning data can be used to classify and analyze faults on transmission and distribution lines, to evaluate the performance of various methods that are used in lightning protection or to identify spots with severe lightning exposure. For all type of applications, knowledge of the time, location, and peak current value of each return stroke provides a valuable database for understanding and quantify the performance of a transmission or distribution network when exposed to lightning.

The lightning strokes that possibly interact with the transmission or distribution installations come from a collection (or exposure) zone determined by the physical process involved during the final stage of progression of the charged downward leader in its approach to earth, or toward structures such as line's conductors or towers. Various models were set out to represent this phase which generally implies quite complex analyses. The geometric volume around a structure within which this process of interception takes place, represents the "attractiveness" of the structure to lightning and may be expressed through either a "lateral distance" [7], or the "attractive radius" [8], in accordance to the model involved. Both distances depend upon the downward leader charge or the prospective current's peak value (the charge and the current being stochastically correlated). A rough approximation of the horizontal projection of the attractive volume for an overhead line, covering the interception conditions for downward leaders up to 200 kA prospective current, is a band 1000 m large, centered on the line alignment. Therefore, to identify from all the lightning events detected over a region, those events which represent possible candidates to be intercepted by the line, the selection should be made in a buffer at least 500 m large centered on the line.

At this point, attention must be paid to the inherent uncertainty associated to the impact location of the network. Location accuracy refers to the ability of the system to report the correct ground-strike point of a stroke or flash. The accuracy of an individual stroke location is affected by several parameters: standard deviations of the angle and time-to-arrival measurement, number of sensors reporting, sensor location relative to the stroke location. Basically there are two different approaches to estimate the accuracy of a lightning location network:

- Analysis based on theoretical investigations implying the existence of a theoretical model; the location accuracy is then expressed by means of error ellipses whose parameters can be computed as in [14].
- Analysis based on real (ground truth) lightning data such as comparison with impacts on power line outages or telecommunication towers.

As end users of the lightning database, the authors did not have access to those attributes allowing the computation of the error ellipses attached to each detected event, namely the times of arrivals and the directions recorded by each of the stations detecting the event. The error in the position (latitude/longitude) is being calculated by the Network Control Center of the RLDLN and the resulting value is attached to the vector of parameters as the accuracy of the location process. A circle whose radius equals the accuracy parameter, attached to each event, will cover with a given probability the real position of the impact. For the Romanian network this probability equals 50%. An example of detected impacts in the vicinity of an overhead line is presented in Fig. 9 together with the circular uncertainty zones build with using the accuracy parameter.

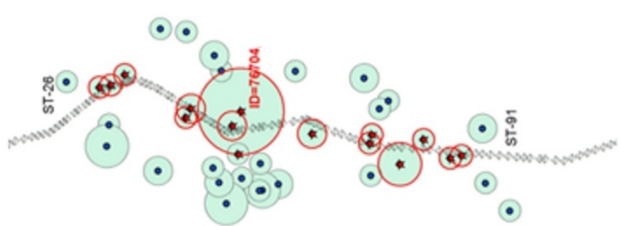


Fig. 9 Example of detected impacts near an overhead line and associated uncertainty zones.

As impacts detected in the same area at different moments had different accuracy values, the accuracy was regarded as a random variable and analyzed using appropriate methods. To obtain an estimate of the median accuracy suitable for the type of applications concerning overhead lines, the sample was formed using the impacts detected nearby the line. Fig. 10.a shows an example of "asset exposure map" displaying all impacts detected during the entire year 2004 within a distance of 2 or 5 km of a given overhead line. For the same line, the empirical Cumulative Distribution Function of the accuracy is represented in Fig. 10.b.

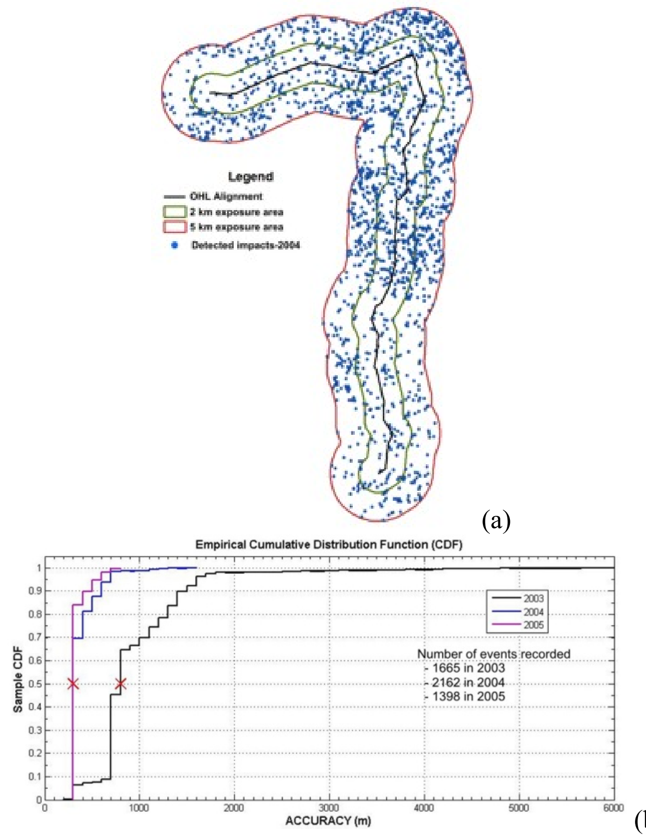


Fig. 10 Exposure to lightning map for an overhead line and related CDF for impacts' location accuracy.

As it can be seen from Fig. 10.b the accuracy realized by the network in this area has a median value of 300 m nevertheless, 5% of the impacts were localized with an uncertainty greater than 600 m (2005) and 700 m (2004). In 2003 one of the stations involved in the detection process in this area was unavailable and therefore a 800 m median value was observed and 5% of the impacts had an uncertainty zone greater than1600 m.

The number of impacts detected inside areas such as those represented in Fig. 10.a characterizes the exposure of the line to nearby and direct lightning strikes during the interval of observation.

The events occurring inside the exposure areas associated to OHL belonging to the Romanian 400 kV network were identified among the lightning data recorded by the RLDLN using GIS software. Their frequency and their features define the lightning threat for a given line.

In a first approach, the lightning exposure of an overhead line was assessed considering the nearby flash density. It is a flash density computed using a finest grid than the grid used for the regional flash density presented at point C of the paper. The impacts considered were those detected in the 5 km exposure area of the line. An example is given in Fig. 11 for the same OHL represented in Fig. 10. The "*fine* flash density" was computed for each year, in order to identify the location of eventually existent "hot spots" along the OHL alignment. It is an attempt to localize sequences of spans exposed to lightning more than the rest of the facility.

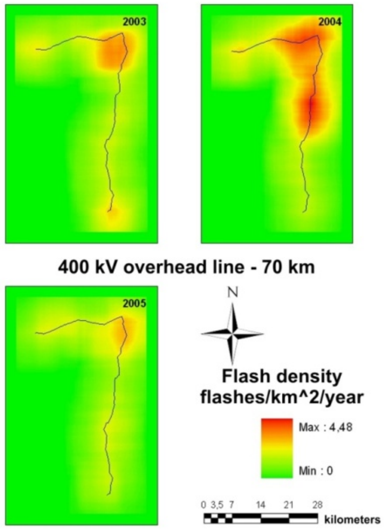


Fig. 11 Fine Flash Density computed with the impacts detected in the 5 km exposure zone of the OHL

The results plotted in Fig. 11 confirm the existence of a persistent area exposed, every year, to more than 4 impacts per square kilometer in the vicinity of the line, in a region where the flash density computed at point C was smaller than 2.4 flashes/km^2/an. Further research will be undertaken to refine this type of analysis in order to use the results in the management of maintenance operations.

V. Conclusions

The paper presents results obtained analyzing the lightning database provided by the Romanian Lightning Detection and Location Network. The general description of the lightning activity at large scale (national level) and medium scale (county level) was featured using global indicators such as the frequency of thunderstorms' days or hours as well as local indicators such as the flash density

The mapping of cloud-to-ground lightning at national level provides considerable understanding of the large-scale geographical variations of lightning characteristics over the Romanian territory. A complex pattern of lightning occurrence has been revealed, showing strong geographical, diurnal, and annual variations. The lightning ground flash density is strongly influenced by elevated terrain features and major land-water boundaries. The association of lightning ground flash density with terrain is obvious when examining the results. Further research will try to quantify this correlation.

The CDF for lighting current's peak value were inferred and compared with the CDF's recommended by CIGRE and IEEE to be used in engineering applications. Important differences were founded; these differences could be considered as systematic errors and assigned to the models used to estimate the current's peak value by post-processing electromagnetic field direct measurements.

The assessment of lightning exposure of a transmission line (knowledge of the time, location and lightning current's parameters for each return stroke) was featured by computing the *fine* flash density using impacts detected in the exposure area of the line. The information can be used:

o to improve the preventive maintenance of the facilities by including revisions of the assets in those areas exhibiting high exposures levels,

o reinforcing the lightning protection of areas identified as "hot points" in accordance with the number of recorded impacts,

o design of lightning protection systems using real data provided by lightning density-maps.

Further research will try to establish a procedure allowing the correlation between lightning events detected in the exposure area and faults recorded in the power transmission system

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VII. Biographies

Ileana Baran was born in Bucharest, Romania. She graduated from the University Politehnica of Bucharest and received the Ph. D. in High voltage Engineering at the same university. She is a professor with the Electrical Power Engineering Department. Her special fields of interest are lightning and lightning protection as well as electromagnetic compatibility.

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