SERBIAN JOURNAL OF ELECTRICAL ENGINEERING
Vol. 15, No. 2, June 2018, 201-211

UDC: 621.316.93:004.4(497.11) DOI: https://doi.org/10.2298/SJEE1802201J

LINETGIS Analysis of Lightning Flash Density in Serbia Based on Ten Years Data

Vesna Javor[1], Leonid Stoimenov[1], Nikola Džaković[1], Nikola Dinkić[1], Dario Javor[1], Hans-Dieter Betz[2]

Abstract: Lightning detection networks installed throughout the world provide data for obtaining flash density maps and information about lightning discharges characteristics. According to the IEC 62858 Standard, lightning data for at least ten years is required to ensure that short time scale variations in lightning parameters are accounted for. LINET (European Lightning Detection Network) was installed in Serbia in 2008, so its data for the last ten years period are used for the analysis in this paper. LINETGIS is a new software application based on geographical information system (GIS) technology in order to obtain regional flash density maps of Serbia. LINETGIS application may be used for up-to-date regional flash density maps of Serbia, but also for any other GIS covered area.

Keywords: Lightning flash density map, GIS technology, Lightning current, Lightning detection system.

1 Introduction

Flashovers caused by lightning activity are one of the major factors which seriously affect the safety operation of overhead transmission lines. The information about lightning characteristics has crucial importance in the design of protection systems for these structures. Cloud-to-Ground (CG) lightning parameters and spatial distribution of lightning flashes are of fundamental interest for the design of lightning protection systems for various objects and installations. Research results also have great importance for weather forecasting and climatology.

Prior to the late 1980s, CG lightning parameters were studied mainly at single locations, such as elevated towers or triggering sites, and the spatial distribution was estimated from thunderstorm days monitored by the meteorological services or lightning counters. With the introduction of various LLSs (Lightning Location Systems) [1] it was possible to determine statistically meaningful flash densities of the specified areas and lightning parameters over

[1]University of Niš, Faculty of Electronic Engineering, A. Medvedeva 14, 18000 Niš, Serbia;
E-mails: vesna.javor@elfak.ni.ac.rs; leonid.stoimenov@elfak.ni.ac.rs; ndzakovic@elfak.rs; dinkicnikola@elfak.rs; dariojavor@mts.rs
[2]University of Munich, Physics Department, 85748 Garching, Germany; E-mail: betz@lmu.de

large areas. Since the late 1980s, temporal and spatial lightning distributions and CG lightning parameters have been studied in many areas based on LLS data. Such networks require setting up of sensors at certain distances to satisfy the detection efficiency and location accuracy requirements and to obtain optimal coverage of some territory. The results for detected lightning discharges are characterized with spatial and temporal variability as for the number of occurrences and geographical distribution, so that proper data analysis is necessary. These results are not only meteorological information and weather forecast tool, but also basis for the lightning protection design.

Lightning detection networks as LINET (European Lightning Detection Network) [2], collect information about lightning strokes coordinates, peak currents, altitudes, and polarity (positive or negative) of discharges. According to the IEC 62858 Standard [3] return strokes are grouped into flashes for the calculation of flash density N_g by LLS. A subsequent stroke is grouped with the first return stroke into a flash if it occurs in less than 1s after the first stroke and the location is less than 10km from it. Successive strokes follow in time intervals less than 0.5s from the subsequent stroke. It is estimated [4] that the stroke density N_{sg} detected by some LLS is about two times greater than the flash density N_g. Flash density is usually presented using some spatial grid, but municipality regions are preferable in the case of regulations established for lightning protection of objects to be built in a specified area. The information about the flash density in some municipality region may be easily recognized by people living in the area and useful for estimation of lightning protection level.

LINET is described in detail in [2]. New application named LINETGIS, presented in this paper, is developed in order to visualize and process the accumulated data for Serbia [5], but it may be used for other countries according to their GIS information. The dimension of the spatial grid needs not to be greater than a few hundreds of square meters, as that is the LINET accuracy of determining CG discharge locations. Municipality regions are selected as defined areas preferable for this purpose.

After the Introduction, LINETGIS application is described in Section 2 with its modules and capabilities. Section 3 describes the statistical results of Serbian data gathered for the ten years period from 2008 to 2017. Section 4 concludes this paper and gives directions of the future work.

2 Data and Methods

The lightning flash density is defined as the mean number of CG flashes to the ground per square kilometer per year. LINET detects the VLF/LF part of the spectrum for both cloud-to-ground (CG) and intra-cloud (IC) flashes. Strokes with amplitudes down to ~5 kA can be effectively recorded and located with LINET system. The location accuracy of some 200-300 meters makes the spatial grid with 1km^2 elements suitable for the analysis of LINET data. In order to efficiently detect and geolocate lightning events within the Serbian territory, two sensors were installed, one at the Faculty of Electronic Engineering in Niš, and the other at Republic Hydrometeorological Service of Serbia in Belgrade, surrounded by LINET sensors in other European countries. The map of LINET sensors placement in Europe is given in Fig. 2.

GIS (Geographic Information System) based methods for optimizing performance of power utilities network using flash density data are described in [6 − 8]. GIS is used to store, process and manipulate geospatial data, but it also provides visualization and analysis of data that have geo-references. GIS is used in different areas such as environmental monitoring, traffic control, preservation of public security, safety control of the facility and management of natural disasters, lightning protection and obtaining flash density maps, etc. The core of GIS represents its database which organizes geospatial data in specific format, so it is easy to add new and query existing data. Besides that, GIS is necessary to provide proper functions for presentation and visualization, as well as analysis and planning of the stored geospatial data. Today, GIS is available to a wide range of users, not only in form of desktop applications, but also as web and mobile application.

LINETGIS is a special type of computer-based information system, used in flash density analysis, tailored to store, process, and manipulate geospatial data. It has several modules, including GIS module, layer selection module, objects search module (toolbar) and search (query) results module. GIS module implements a standard set of GIS functionalities, so it is possible to zoom in and zoom out the selected area in the displayed map (default), to scroll the map and position on the map, to select the map parts that are needed, to visualize the entire map, to zoom to the selected part of the complete map that is currently displayed. All other modules rely on this main one and add new functionalities to the application, such as querying data, generating reports, etc.

CG lightning data is provided by LINET network of sensors and used by LINETGIS application. LINET provides data in ESRI ASCII format which has to be pre-processed and parsed to proper format before it is stored in geospatial database. The ESRI ASCII raster format can be used to transfer information to or from other cell-based or raster systems. When an existing raster is the output to an ESRI ASCII format raster, the file will begin with header information that defines the properties of the raster such as cell size, number of rows and columns, and coordinates of the origin of the raster. The header information is followed by the cell value information specified in space-delimited row-major order, with each row separated by a carriage return. The basic structure of the ESRI ASCII raster has the header information at the beginning of the file followed by the cell value data, as given in Fig. 1.

```
NCOLS xxx
NROWS xxx
XLLCENTER xxx | XLLCORNER xxx
YLLCENTER xxx | YLLCORNER xxx
CELLSIZE xxx
NODATA_VALUE xxx
row 1
row 2
...
row n
```

Fig. 1 – *Example of the ESRI ASCII grid format.*

Table 1 shows detailed description of all parameters that ESRI ASCII grid format has. As previously explained, besides basic geo-data parsing and storing, our GIS offers a variety of data analysis and visualization which can be used for generating flash density maps and for lightning protection planning.

Table 1
Explanation of the ESRI ASCII grid format.

Parameter	Description
NCOLS	Number of cell columns
NROWS	Number of cell rows
XLLCENTER or XLLCORNER	X coordinate of the origin (by center or lower left corner of the cell)
YLLCENTER or YLLCORNER	Y coordinate of the origin (by center or lower left corner of the cell)
CELLSIZE	Cell size
NODATA_VALUE	The input values to be NoData in the output raster

3 LINETGIS Results

Results given in this paper present the first flash density maps of Serbia valid for the ten years period which are provided by some LLS. According to the IEC 62858 Standard [3] lightning flash density maps may be obtained based on LLS data for at least ten years to ensure that short time scale variations in lightning parameters due to a variety of meteorological oscillations are accounted for.

In this paper is presented lightning statistics for about three million CG flashes registered over the ten years period of LINET operation in Serbia

(2008–2017). Both negative and positive flashes are included in this analysis and the study area is limited to the territory of Serbia.

The average calculated number of lightning flashes for the Serbian territory is 3.43 flashes/km^2 per year for the period of ten years (**Table 2**). The highest flash density of 5.10 flashes/km^2 per year was observed in 2014. The most critical region in that year was "Vračar" with 12.00 flashes/km^2. The region with the maximum average number of flashes over the whole period of ten years was "Čoka" with 20.74 flashes/km^2 in the year 2010. **Table 2** shows regions with the maximum average annual values over the ten years period.

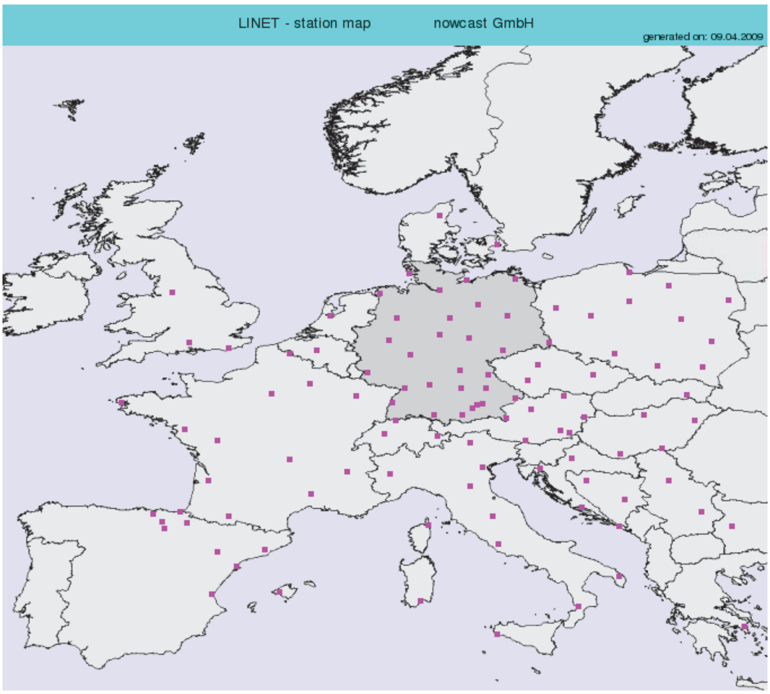

Fig. 2 – *The map of LINET sensors placement in Europe.*

The most important outcome of the LINETGIS application is presented in Fig. 3 which shows the very first regional flash density map of Serbia from the data obtained by some LLS. This map shows average annual number of flashes per square kilometer of Serbian territory in the period of ten years, from 2008 to 2017. In this period, the region with the greatest number of flashes per square kilometer was "Mali Zvornik" with 6.19 flashes/km^2 per year, whereas the region with the least number of flashes per square kilometer was "Vladičin Han" with only 2.53 flashes/km^2 per year.

Table 2
Annual average flash density for Serbia in the period 2008-2017, and the maximum regional flash density for each year.

Year	Annual average flash density in Serbia	Region with the maximum flash density	Maximum regional flash density
2008	2.72	Sečanj	7.59
2009	4.22	Vračar	10.50
2010	4.47	Čoka	20.74
2011	3.36	Vrnjačka Banja	7.44
2012	2.62	Kučevo	6.47
2013	3.07	Bač	8.46
2014	5.10	Vračar	12.00
2015	2.23	Ljubovija	5.92
2016	3.72	Kosjerić	8.57
2017	2.84	Mali Zvornik	8.99
Annual average flash density for Serbia	**3.43**		

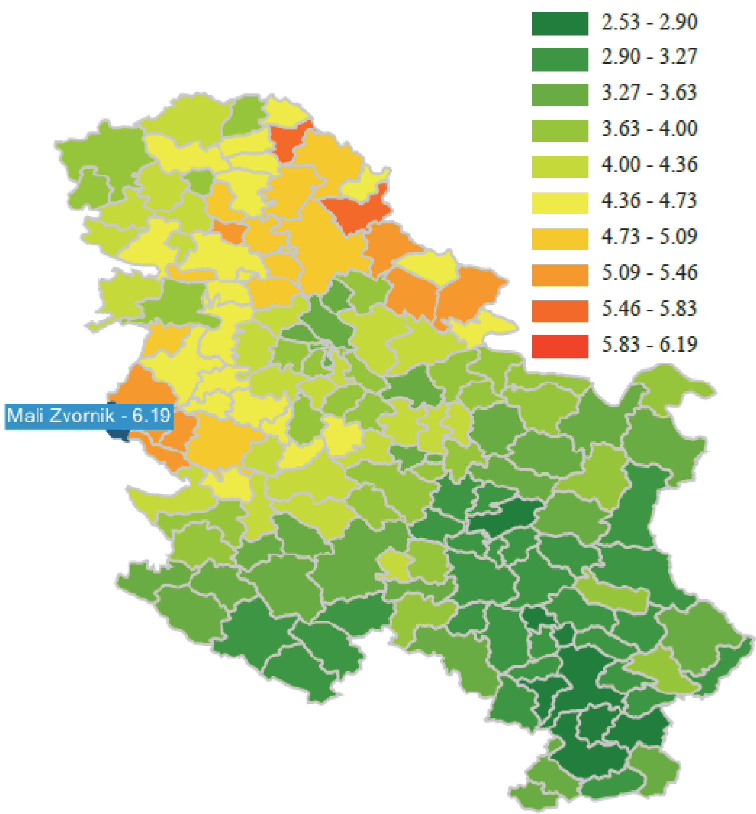

Fig. 3 – *Average number of flashes/km² for the Serbian regions for the period 2008 - 2017 and the region with the maximum value.*

The annual flash densities detected across Europe are generally of the order of 0.1–4 flashes/km^2 per year, similar to the range observed by Holle et al. [9] for the northern and western contiguous areas of USA. Peak densities in Europe of about 8 flashes/km^2 per year are less than peak values observed in Florida of 14 flashes/km^2 per year. Large sources of heat and moisture, as well as physical arrangement of the Florida Peninsula itself, make it particularly susceptible to the lightning activity. The densities are generally lower for the UK, Ireland and Scandinavia than for the rest of Europe. Some of the lowest densities are observed over the Atlantic, North Sea and Baltic Sea. The highest densities occur over mountainous regions of continental central Europe and along the northern coast-lines of the Mediterranean [10]. The higher areas such as mountain regions at the western boarders of Serbia have an increased flash density, but lower areas at the north-eastern boarders of Serbia are characterized by an increased flash density as well.

Table 3 shows cumulative statistics of the total number of lightning flashes per year that have been detected by LINET. Lightning activity varied from year to year, ranging from about 196 000 of flashes in 2015 to about 450 000 of flashes in 2014, making in total about 3 million CG flashes in ten years.

The region with the maximum total number of flashes was “Zrenjanin”, where 68546 flashes were registered (Fig. 4) in the period from 2008 to 2017, with the maximum of 12633 flashes in 2009, and nearly the same (12518 flashes) in 2010. It should be noticed that “Zrenjanin” region has a large regional area in the north-east part of Serbia, which results in a greater total number of flashes, whereas e.g. “Vračar” region is of a very small area.

Table 3
Annual flash counts for Serbia in the period 2008-2017, and the maximum regional flash counts for each year.

Year	Annual flash counts for Serbia	Region with the maximum flash count	Maximum regional flash count
2008	240 102	Subotica	5 196
2009	372 457	Zrenjanin	12 633
2010	394 232	Zrenjanin	12 518
2011	296 735	Vršac	5 456
2012	231 337	Zaječar	5 428
2013	270 486	Zrenjanin	7 763
2014	449 496	Kraljevo	10 257
2015	196 335	Valjevo	4 688
2016	327 822	Valjevo	6 712
2017	250 499	Pirot	5 829
Total number of flashes for Serbia for ten years **3 029 501**			

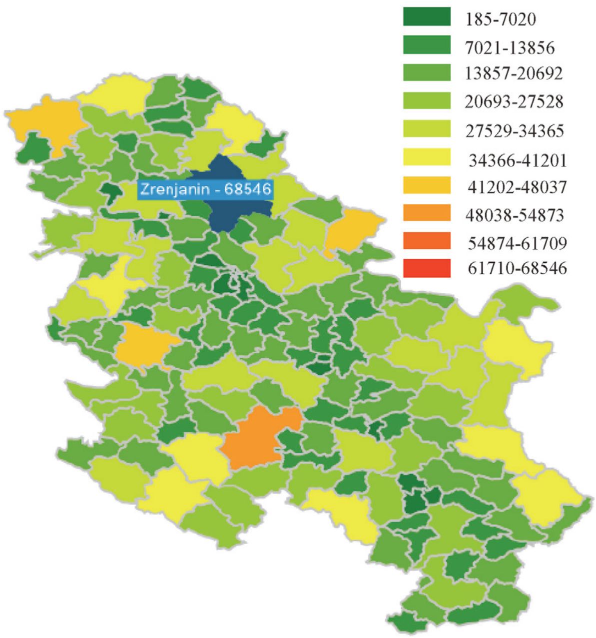

Fig. 4 – *Total number of flashes for the Serbian regions for the period 2008 - 2017 and the region with the maximum flash density.*

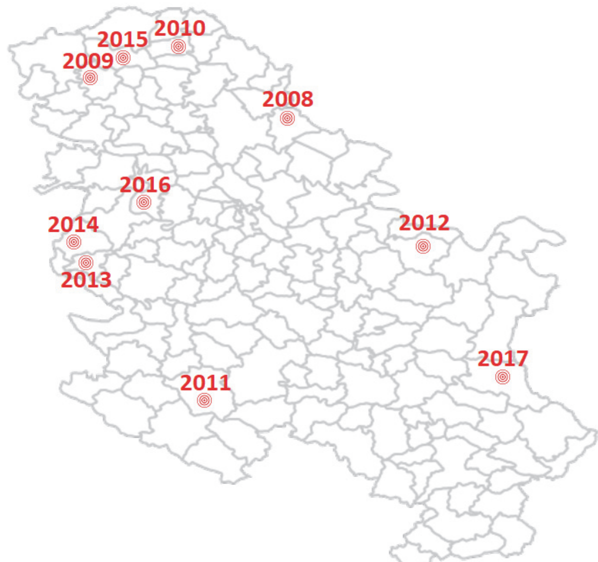

Fig. 5 – *Places (1km² element in the mesh) with the greatest number of flashes per year over the ten years period.*

There are ten points in Serbian territory marked in Fig. 5 which correspond to the positions of central points of 1km^2-grid cells that had the greatest number of flashes for the given year over the period from 2008 to 2017. Fig. 5 points out to two critical areas of Serbia as for the number of flashes, one area in the north and another one in the west of Serbia. It can be concluded from Figs. 3 and 5 that the lightning protection in such regions of Serbia should be considered with more care than in other regions.

Table 4 shows more detailed information about the most critical places and their number of flashes per year. For the considered period of ten years, the greatest number of flashes in a single year was detected in the region "Senta" and that number was 49 in the year 2010. These 49 flashes were detected within the square area of 1 km^2 with the central point of the square at the latitude 45.8971°N and the longitude 20.1012°E.

Fig. 6 shows variations of the number of flashes/km^2 per year for the four regions. The regions were chosen based on their geographical position, just two in the north of Serbia ("Žitište" and "Sečanj") and two in the west ("Mali Zvornik" and "Loznica"). Besides lines representing annual changes for these regions, this graphic contains also the fifth line (in red color and with circles) which shows how the average number of flashes/km^2 has changed from year to year for the Serbian territory.

Table 4

Annual lightning hotspots (1km^2-grid cells) in Serbia on the basis of maximum count of CG flashes to 1km^2 during the ten years period from 2008 to 2017.

Year	Latitude/longitude of the central point in 1km^2-grid cell	The region with the hotspot	Count of CG flashes to 1km^2-grid cell
2008	45.5494°N / 20.8114°E	Sečanj	24
2009	45.7812°N / 19.3827°E	Kula	33
2010	45.8971°N / 20.1012°E	Senta	49
2011	43.4485°N / 20.1136°E	Ivanjica	23
2012	44.4040°N / 21.7193°E	Kučevo	24
2013	44.4311°N / 19.3953°E	Krupanj	27
2014	44.4287°N / 19.2320°E	Loznica	29
2015	45.8748°N / 19.6635°E	Bačka Topola	26
2016	44.8057 °N / 19.8528°E	Ruma	35
2017	43.3776 °N / 22.6082°E	Knjaževac	28

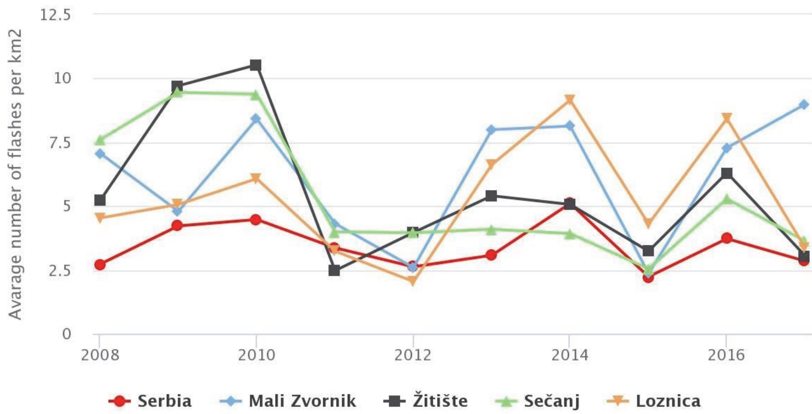

Fig. 6 – *Annual variations of flash densities for some regions and for the Serbian territory over the ten years period from 2008 to 2017.*

4 Conclusion

Lightning detection networks, like LINET, collect information about lightning discharges, strokes coordinates, currents amplitudes, altitudes, and polarity of discharges. In this paper is presented lightning statistics for about three million CG flashes registered in Serbia by LINET over the last ten years. The average flash density for the Serbian territory is 3.43 flashes/km^2 per year for the period from 2008 to 2017. The highest flash density of 5.10 flashes/km^2 per year was registered in 2014. Both negative and positive flashes are included in this analysis.

LINETGIS application presented in this paper is developed in order to visualize and process accumulated data for Serbia obtained from LINET for the period of ten years. These are the first valid flash density maps of the Serbian territory based on LLS data. Municipality regions are selected as defined areas preferable for this purpose. Regions with the highest lightning activity are determined, so as annual variations of the total number of lightning discharges. In this period, the region with the greatest number of flashes per square kilometer was “Mali Zvornik” with 6.19 flashes/km^2 per year, whereas the region with the least number of flashes per square kilometer was “Vladičin Han” with only 2.53 flashes/km^2 per year.

LINETGIS may be also used for greater areas covered by LLS and in the flash density analysis for other countries according to their LINET data and GIS information. The data from any other LLS covering the same area may be used to make the comparison of the calculated flash densities. Further research may include also distribution of other lightning parameters such as currents amplitudes and types of strokes.

5 References

[1] E. P. Krider, R. C. Noggle, A. E. Pifer, D. L. Vance: Lightning Direction Finding Systems for Forest Fire Detection, Bulletin of the American Meteorological Society, Vol. 61, No. 9, 1980, pp. 980 – 986.

[2] H.-D. Betz, K. Schmidt, W. P. Oettinger: LINET – An International VLF/LF Lightning Detection Network in Europe, in: Lightning: Principles, Instruments and Applications, Eds. H.-D. Betz, U. Schumann, P. Laroche, Ch. 5, Dordrecht (NL), Springer, 2008.

[3] IEC 62858, Ed. 1.0, Lightning density based on lightning location systems (LLS) - General principles, Geneva,, Switzerland, 2015.

[4] C. Bouquegneau, A. Kern, A. Rousseau: Flash Density Applied to Lightning Protection Standards, International Conference on Grounding, Lightning, Physics and Effects, Ground'2012 and 5th LPE, Bonito, Brazil, November 2012, pp. 91 – 95.

[5] V. Javor, H.-D. Betz, L. Stoimenov, N. Dinkić, N. Džaković: Flash Density Regional Maps of Serbia, 12th International Conference on Applied Electromagnetics PES 2015, Nis, Serbia, 31 August – 2 September 2015, P1_9

[6] G. Lakota, G. Milev, V. Đurica, B. Žitnik: Use of High Resolution Flash Density Data and GIS Analysis Methods in Power Utilities Networks, International Conference on Lightning Protection ICLP 2014, Shanghai, China, 11 – 18 October 2014, pp. 1229 – 1233.

[7] J. V. Brandon, S. J. Hodanish: A High-Resolution Lightning Map of the State of Colorado, Monthly Weather Review, Vol. 142, No. 7, 2014, pp. 2353 – 2360.

[8] M. F. Worboys, M. Duckham, GIS: A Computing Perspective, Second Ed., CRC Press, Boca Raton, Florida, 2004.

[9] R. L. Holle, K. L. Cummins: Monthly Distributions of US NLDN Cloud-to-Ground Lightning, 21st International Lightning Detection Conference and 3rd International Lightning Meteorology Conference, Orlando, Florida, USA, April 2010, pp. 1 – 13.

[10] G. Anderson, D. Klugmann: A European Lightning Density Analysis Using 5 Years of ATDnet data, Natural Hazards and Earth System Science, Vol. 14, No. 4, 2014, pp. 815 – 829.