Journal of Materials and Environmental Science
ISSN : 2028-2508
CODEN : JMESCN

J. Mater. Environ. Sci., 2020, Volume 11, Issue 12, Page 1987-2006

http://www.jmaterenvironsci.com

Climatology of the lightning in the northern of Benin Republic

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Received 31 Aug 2020,
Revised 25 Dec 2020,
Accepted 26 dec 2020

Keywords
- ✓ *WWLLN,*
- ✓ LIS,
- ✓ Lightning density,
- ✓ Detection efficiency,
- ✓ Benin.

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Abstract

Lightning climatology based on World Wide Lightning Location Network (WWLLN) data is examined in detail for the first time in Benin. 1160196 flashes are reconstructed from the return arcs located by WWLLN for the entire study period, 2005 to 2017. The detection efficiency of the WWLLN network is determined from Lightning Imaging Sensor (LIS) data covering the period from 2005 to 2015. It is generally low but increases from 0.11% in 2005 to 8.09% in 2015. The proportion of single arc flashes reaches about 88% in the early years compared to about 76% in 2017, while the average multiplicity of the period is about 1.13. The results show an annual cycle with high electrical activity between April and October and low activity between November and March. The maximum monthly proportion of the period is 19.1% obtained in September. The diurnal cycle shows maximum activity around 18:00 UTC and minimum activity between 10:00 and 11:00 UTC. The maximum annual density is 13.93 $fl.km^{-2}yr^{-2}$ and the maximum number of days when thunder rumbled at least once is 299 obtained in 2013. The electrical activity is closely related to the relief of the region. However, an anomaly is to be noted in the WWLLN data for the years 2009 and 2010 that this study was unable to elucidate.

1. Introduction

Thunderstorms are complex and dangerous meteorological phenomena involving dynamic, thermodynamic, microphysical and electrical processes. One of these components that is both useful and dangerous is lightning. It is an aerial electrical discharge that allows electrically charged clouds to transfer part of their charge to the ground and thus compensate for the fair-weather current that is permanently distributed between the electrosphere and the Earth. It is this same discharge that is destructive or deadly. The thunderstorm is more dangerous when the discharge hits a person [1].

The accelerated development of electrical and electronic techniques, such as equipment that is extremely sensitive to the effects of lightning, has led to renewed interest in research into thunderstorm phenomena and ways of protecting oneself from their harmful effects. Electrical and electronic equipment is invading all areas of human activity. As a result, more and more people are being called upon to take an interest in the consequences of thunderstorm phenomena.

Man has always located lightning by the sound it produces or the light it emits. The emergence of several networks has led to the establishment of lightning climatology. The efficiency of lightning location and identification is closely linked to the type of network used. A distinction can be made between global satellite networks such as the Optical Transient Detector (OTD) / Lightning Imaging

Sensor (LIS) and terrestrial networks such as the World-Wide Lightning Location Network (WWLLN), regional, national or local networks. Each type of network has its advantages and disadvantages. Global networks have greater coverage. They therefore reach areas that are inaccessible to other networks [2]. These networks sometimes suffer from lack of precision in locating and identifying lightning strikes [3]. Local, national or regional networks, especially terrestrial ones, have a high accuracy in locating and identifying lightning [3]. They are used to analyse the detection efficiency of global networks. The disadvantage of these networks is that they produce a large amount of data that is not easily manipulated at the regional or national level [3].

There are several local, national or regional networks summarized through the following works: the ONERA (Office National d'Etudes et de Recherches Aérospatiales), Interferometric Mapper [4], Lightning-Mapping Arrays [5-8], the U.S. National Lightning Detection Network [9], the Los Alamos Sferic Array (LASA) [10], the Europe ZEUS system [11], the Brazilian Integrated Network (BIN) [12], the Chinese Cloud-to-Ground Lightning Location System (CGLLS) [13-15] and the French Météorage network (MTRG) [16]. These networks are sometimes specific to the area or study. This is the case of the network called LIFT (Localization of Impacts for Flashes in Tahiti), developed by [17] which is intended for an austere environment such as Tahiti or the German network, Lightning Detection Network (LINET), deployed on several continents over a short period of time [18] but which is a European network operating in low frequencies (200 to 400 kHz) [19]. Some networks are long-range. This is the example of the one developed by [20]. They have developed, calibrated and analysed the performance of the Pacific Lightning Detection Network (PacNet), which is a complement to the long-range lightning detection network (LLDN) for the northern Pacific Ocean. The performance of the network is analysed using data from the American National Lightning Detection Network (NLDN). Thus they were able to examine detection efficiency (DE) and location accuracy and find 17%-23% during the day and 40%-61% in the evening. Calibration of the network is done using Lightning Imaging Sensor (LIS) data from the National Aeronautic and Space Administration (NASA). Using these data, they have conducted several other studies such as [21]. There are other long-distance networks such as ATDnet (Arrival Time Differencing Network) [22].

Several studies have used OTD or LIS data either to analyse network performance [23-25]; to study lightning climatology [26-33] or to evaluate data collected by other networks [12,34-38]. Similarly, several studies have used data from the WWLLN network either to evaluate the performance of the network [39-49] or to analyse storm climatology, NO_x production from lightning and jet studies[2,38,50–75].

Several studies have presented the global climatology that takes into account our study area [27,29,31,32,51,61,76,77]. Most of these studies have identified the Congo Basin as the most active area in tropical Africa. The specificities of our study area were not highlighted. Moreover, the data cover different time scales. Several studies have addressed the characterization of lightning in West Africa and its links with other atmospheric parameters. A study [52] to analyse the impact of convective systems on NOx and O_3 characterized lightning in West Africa. [78] through a comparative analysis of detection systems on three continents, addressed the study of thunderstorms in West Africa. [79] and [80] characterized lightning in northern Benin using LINET data. They were able to establish the link between lightning and rainfall on the one hand, and between lightning and insolation on the other. All these studies used LINET data covering a period of up to six months. Characterization of the same lightning flashes from data covering a longer period would increase the robustness of the results. The WWLLN data are very appropriate because they are available according to [81] from 2003 to the present and, moreover, the detection efficiency of the network increases over the years according to [56].

The main objective of this work is to propose for the first time the lightning climatology of northern Benin. The variability associated with the electrical activity of lightning will thus be highlighted. The electrical activity of lightning in Africa can be an important precursor to the formation of hurricanes or cyclones in the Atlantic Ocean [76]. From this point of view, this study will update the information for specialists in these phenomena. This work is organized as follows: the next section presents the study area, the data used and the adapted methodology, then the third section presents the results.

2. Material and Methods

2.1. Topography and Climatology of the Study Area

The study area is located in northern Benin between latitudes [9°N, 12°N] and longitudes [0°E, 5°E]. Figure 1 shows the topography of the region. It consists of two topographic units: the crystalline peneplain and the sandstone plateau. The peneplain is dotted to the south with a multitude of isolated hills. It is connected to the Atacora massif to the west and to the Kandi plateau to the north and northeast. These hills, although not very high, are the major topographical feature of the sub-basins of the Mekrou, Alibori and Sota rivers at Gbassè [82]. Despite their modest altitude, they influence atmospheric flows and also constitute the crest lines where most of the rivers (Mekrou, Alibori and Sota) that drain the region originate. These reliefs increase daytime heating, disrupt currents, aggravate turbulence and promote the rise of air masses. Their presence explains the increased importance of thunderstorms in this region [82]. The region is subject to a sudanian-type climate characterized by a single dry season and a single wet season. The rainy season in this area is from March to October [79,83,84]. Thunderstorms occur mainly from late spring and late summer, but they are particularly numerous and violent near even modest relief [82]. Two reasons justify the choice of this area. It records high electrical activity of thunderstorms and has been the subject of several studies using different data sources.

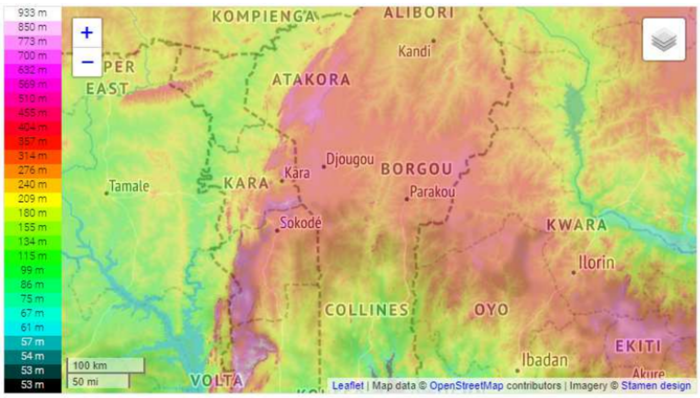


Figure 1: *Topography of the study area.*

The lightning data used in this study are from two independent lightning detection systems: the World Wide Lightning Location Network (WWLLN) and the Lightning Imaging Sensor (LIS).

2.2. WWLLN Data

The WWLLN is a global real-time flash detection network. With global coverage, lightning climatology and different temporal and spatial scales can be studied. The WWLLN started with 11 sensors in 2003, [36,81] and has gradually increased to more than 70 sensors from January 2013 to the present day [85]. The stations consist of a 1.5 m antenna, a Global Positioning System (GPS) receiver, a receiver for very low frequency (VLF) electromagnetic radiation called sferics emitted by lightning arcs and a computer with internet connection. The Time of Group Arrival (TOGA) technique for locating lightning strikes is used, [39,43,56,86-88]. Global coverage requires relatively few sensors because VLF radio waves pass through the waveguide of the Earth's ionosphere with minimal attenuation, [39,89,90]. Figure 2 shows the distribution of sensors. Note the installation of new sensors relatively close to the study area after 2010. The lightning localization algorithm has also evolved, [44]. WWLLN sensors detect very low frequency (VLF) radiation (3 to 30 kHz) during a lightning strike and use the Time of Arrival of the Group (TOGA) to locate the position of the lightning. This technique has replaced the principle of detection by the Time of Arrival (TOA), [91]. Residual minimization methods are used in TOGA data from processing stations to create high quality data on lightning sites. WWLLN data processing ensures that the residual time is less than 30ms and that the data provided by the network correspond to lightning strikes detected by at least five stations, [64]. The precision of lightning location on the network is 5 km, [45]. Thirteen parameters are measured: date, time in UTC, latitude and longitude in fractions of a degree, residual error in microseconds (always < 30), the number of stations involved in locating the lightning (always ≥ 5), the energy radiated at very low frequency by the lightning in joules, the uncertainty on the energy radiated in joules, the sub-group of stations being between 1000 and 8000 km from the strike used to estimate the energy. Each line in the database represents one recorded flash. Several atmospheric electricity studies have used data collected by the WWLLN. The data in this study cover the period from January 2005 to December 2017.

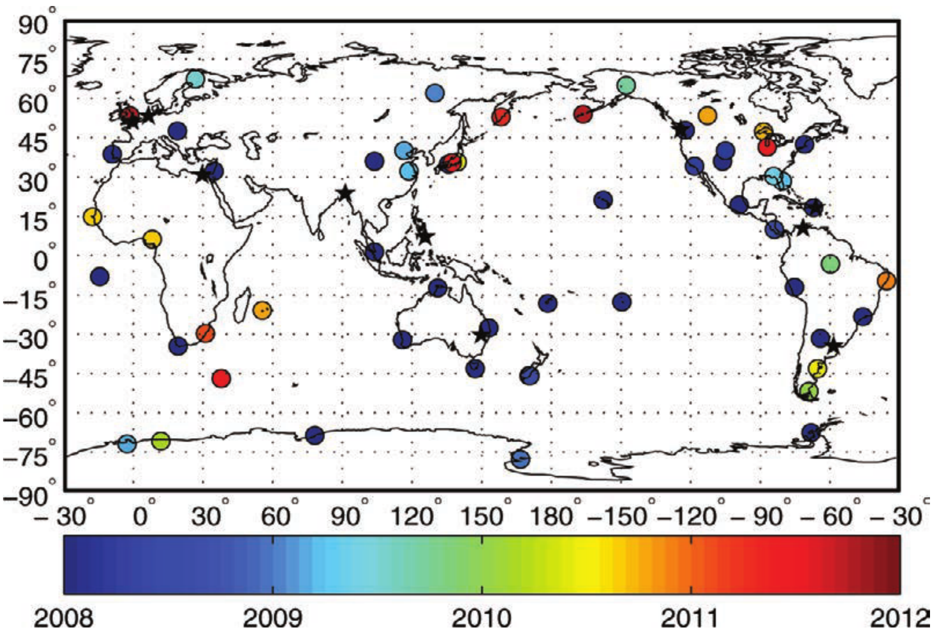


Figure 2: *Location of coloured WWLLN sensors according to the date of installation. The black stars indicate the sensors added from 2012 to the present. From* [61].

2.3 LIS Data

The TRMM LIS was launched into low Earth orbit (350 km) in November 1997 [36], providing coverage between 38°N and 38°S, [25,36]. Its orbit was then increased to 402 km in August 2001 to increase the mission lifetime, without changing the detection efficiency, [32,36,64]. The LIS is an optical sensor that measures transient changes in cloud brightness caused by lightning, [27,36]. LIS detects both GC and IC [2,4,5,64,92] with a detection efficiency of about 90% [2]. The area seen by the sensor covers an area of 600 × 600 km2 with a spatial resolution of 3 to 6 km. As for temporal resolution, LIS sees a given point for a period of nearly 90 s. It should be noted that LIS only detects flash rates greater than 1 fl.min-1 [2]. Between 5689 and 5704 orbits are scanned by the LIS per year [64]. The LIS data used in this study are available on the NASA website: https://lightning.nsstc.nasa.gov/lisib/lissearch.pl?. The information provided is: date, position, radiated energy, events and groups. These data cover the period from 2005 to 2015.

Note that the LIS (optical) and WWLLN (sferics) detect different aspects of lightning. This study compares WWLLN shots to LIS flashes. WWLLN locates a strike at a given time and place while LIS flashes have durations (tens to hundreds of milliseconds) and extents (tens to hundreds of square kilometres). In addition, WWLLN continuously detects mainly CG lightning, while the LIS provides snapshots of about 90 s of all types of lightning within its field of view. Despite these differences, the LIS is used as a reference because it provides constant lightning observations with high detection efficiency since its launch in 1997, [36].

2.4. Reconstruction of lightning strikes

The WWLLN network detects lightning arcs, locates them and records the time of their point of impact. Several methods exist to convert arcs into flashes, including the method adopted for the analysis of NLDN data by [9]**.** Arcs are grouped together in a single flash when they are separated by less than 10 km and less than 0.5 s, and with a maximum duration of 1 s. Studies such as [56] or [64] have reconstructed the WWLLN data. The latter authors used a variant of the one adopted by [9]**.** It is this method that is adopted in the present study. The multi-year analysis of the sensitivity test on time and distance thresholds justified this choice. Figure 3 shows the ratio between flashes and WWLLN hits for the whole period, considering time differences of 0.5 s and 1s and for several radii. This ratio decreases progressively with distance. The difference between the curves, on the other hand, increases with distance. Depending on the years, this gap increases for lower ratios. It should be noted that the time threshold dt represents the maximum duration between two arcs related to the same flash and the distance threshold represents the maximum distance between the first arc of the flash and the subsequent arcs.

2.5. Detection efficiency

The methodology adopted by [64] is used to determine the effectiveness of lightning detection by WWLLN per year. The LIS observes a given point for 90 s and covers latitudes between 38°S and 38°N. In this band the elementary surface is given by:

$$dS = (R_T \cos\lambda d\lambda)\,(R_T\, d\varphi) \quad (1)$$

where λ is the latitude, ϕ the longitude and R_T the radius of the earth.

The area scanned by LIS is:

$$S_A = \int_{38°}^{38°} R_T \cos\lambda d\lambda \int_{-\pi}^{\pi} R_T\, d\varphi = 4\pi R_T^2 \times 0.6157 \quad (2)$$

The duration in a leap year is:

$$366 \times 24 \times 3\,600 = 31\,622\,400 \quad (3)$$

TRMM travels 5704 orbits per year. Thus, the average duration per orbit is:

$$31,622,400 \div 5704 = 5\,543.89 \quad (4)$$

The area covered by an orbit is given by:

$$S0 = 2\pi R_T \times 600 \quad (5)$$

Then the area coefficient is defined by:

$$\alpha_s = \frac{S_0}{S_A} = \frac{600}{2R_T \times 0.6157} = 0.07639 \quad (6)$$

For one orbit, the area covered is therefore 7.64 % of the surface S_A. Furthermore, the TRMM covers each point of this surface during only 90 s over the 5543.89 s (according an equality 4) of the orbit. A time coefficient αt has to be considered to estimate the proportion of the lightning activity that can be detected by LIS. It is given by:

$$\alpha_s = \frac{90}{5544} = 0.0162 \quad (7)$$

The time proportion during each point is observed by LIS for the whole coverage of the band S_A is given by:

$$\alpha = \alpha_s \times \alpha_t = 0.00124 = 0.124\% \quad (8)$$

This coefficient is applied for any point of S_A and therefore for any point of the study area. Statistically, the sampling made by LIS is representative of the whole lightning activity for any region of the study area, according to the number of orbits described during one year.

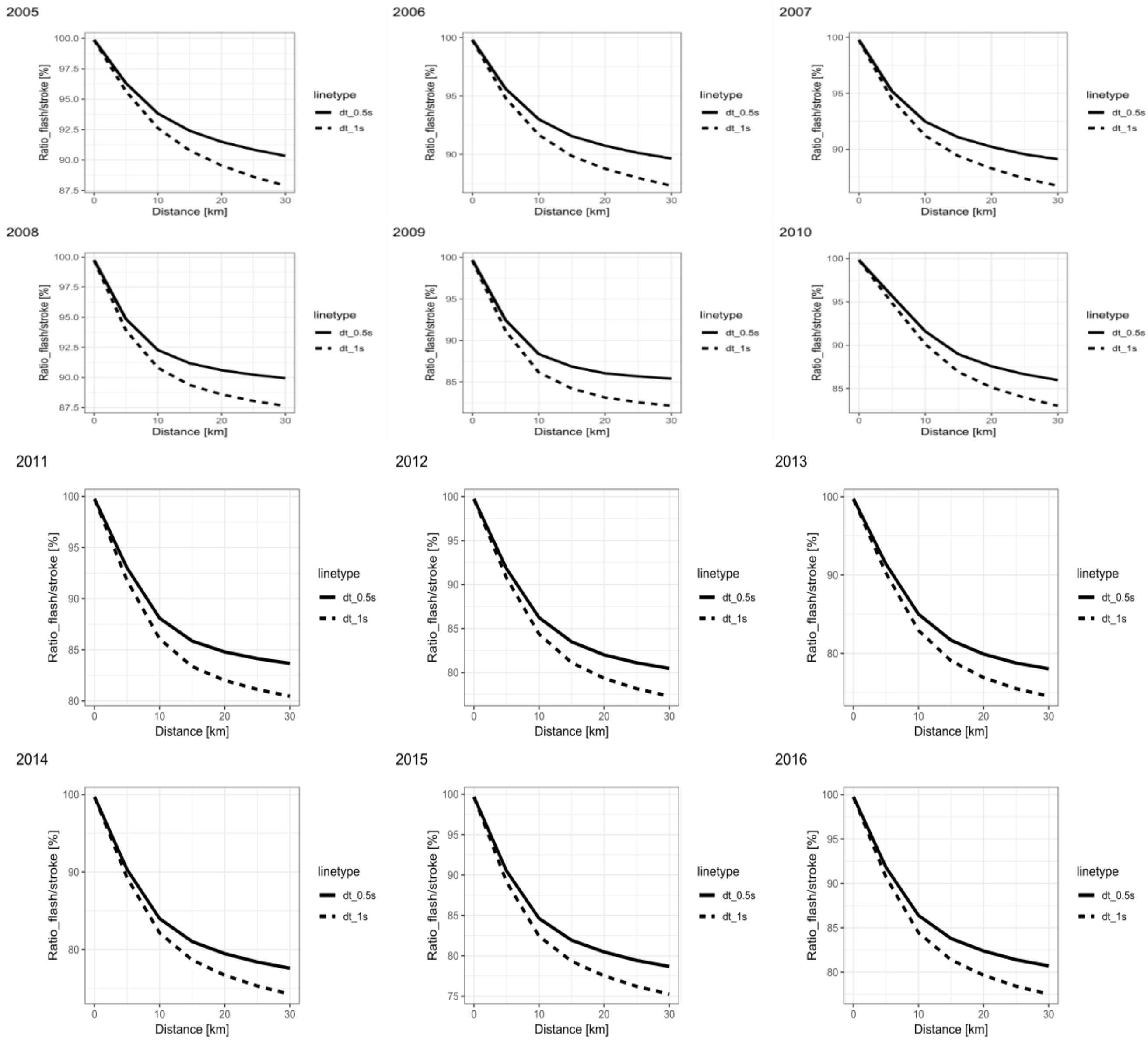


Figure 3: Ratio between the number of WWLLN flashes and that of strokes as a function of the distance criterion for two distinct time criteria.

Then this coefficient is use to recover the total number of flashes mark N_0 produced within the area from the number of flashes detected by LIS mark N_L:

$$N_L = \alpha N_0 \quad (9)$$

Thus

$$N_0 = \frac{N_L}{\alpha} \quad (10)$$

The detection efficiency (DE) of WWLLN relative to LIS is:

$$DE = \frac{N_W}{N_0} = \frac{N_W}{N_L} \times \alpha \quad (11)$$

The DE (detection efficiency) is calculated for each year from 2005 to 2015 as shown in table1 and compared respectively to that determined by [2] and [64]. Figure 4 shows the DE without the 2015 one. The number of LIS flashes is particularly low in 2015, so the detection efficiency is particularly high (8.09 %). The efficiency of DE detection increases significantly year after year from 2010 onwards. This result is consistent with that of [49,64]. It should be noted, however, that the DE are very low compared to the studies of [2,64].

Three reasons can be advanced to explain this low rate of detection efficiency. The first can be attributed to the low coverage of the area by WWLLN sensors. Due to the very good WWLLN coverage in North America, the detection efficiency in this region is above 80% [2]. The second reason may be due to the surface characteristics of the area. The earth's surface is composed of several types of soils and vegetation, each with different conductivities. Thus, sferics are more attenuated on the continent (low conductivity of the order of 10-2-10-4 Sm-1) than in the ocean (4 Sm-1) [2,93,94]. The last reason is that the electrical activity of thunderstorms is naturally lower than that of the study areas of these authors.

Table 1: Number of annual flashes detected by WWLLN (N_W) and LIS (N_L), extrapolation of the total number of flashes detected by LIS per year and over the whole study area (N_0), DE from WWLLN to LIS for the study area, for the South West Indian Ocean (SWIO) zone (DE_B) of [2] and from the Congo study (DE_S) of [64], maximum number of thunderstorm days (SD_{max}), mean multiplicity (M_m) and proportion of flashes linked only to one hit (M = 1).

Année	N_W	N_L	N_0	DE (%)	DE_B (%)	DE_S (%)	SD_{max} (jour)	M_m	M
2005	68551	73956	59641935	0.11	2.00	1.74	260	1.07	87.78
2006	49539	63059	50854032	0.10	3.40	1.65	271	1.08	86.20
2007	68336	86060	69403226	0.10	5.00	2.44	258	1.08	85.00
2008	46658	102147	82376613	0.06	4.70	1.66	241	1.08	84.49
2009	51338	94590	76282258	0.07	6.60	2.18	178	1.13	76.38
2010	13705	65768	53038710	0.03	8.30	2.39	48	1.09	83.08
2011	89544	107217	86465323	0.10	8.50	3.03	242	1.14	75.71
2012	112510	105848	85361290	0.13	-	4.44	279	1.16	71.89
2013	142973	90599	73063710	0.20	-	5.90	299	1.18	69.12
2014	148814	60175	48528226	0.31	-	-	270	1.19	66.80
2015	110713	1698	1369355	8.09	-	-	233	1.18	68.17
2016	133397	-	-	-	-	-	240	1.16	72.12
2017	124118	-	-	-	-	-	239	1.14	75.80

3. Results and discussion

3.1. Temporal distribution

Table 1 shows several parameters related to the electrical activity of thunderstorms for the entire study period. The second and third columns show the number of flashes detected by WWLLN (N_W) and LIS (N_L) respectively. These two numbers are also shown in Figure 4 in order to compare their evolution during the study period. The temporal evolution shows a non-uniform variation in the number of N_w flashes for the first five years. After 2010 when both networks detected low flash rates, N_w grows steadily to reach in 2014, about 10.86 times the minimum of the series obtained in 2010. N_w in 2010 is atypical despite our previous remark. The maximum obtained in 2014 is about 2.2 times the number of flashes detected in 2005 and 3.2 times that of 2008. N_L increases from 2006, falls in 2010 and then increases and decreases from 2013. In agreement with [64], it can be estimated that the electrical activity did not vary significantly. The increase in the number of flashes counted by the WWLLN is due to the improvement of the detection efficiency during the same period. Several reasons can be given to explain this improvement in network efficiency: the number of stations has increased over the years and the processing algorithm has also evolved [39,56,64,95,96]. The proportion of single arc flashes (M=1) hovers around 85% during the first four years compared to about 70% for the last four years, while the average multiplicity hovers around 1.08 at the beginning of the period and close to 1.15 at the end. The evolution of all these parameters indicates an improvement in the detection efficiency of the WWLLN network. Indeed, according to Figure 2, nearly five new stations relatively close to the study area were installed between 2008 and 2009 compared to three between 2010 and 2011. Figures 6 and 7 show the comparative evolution of these parameters.

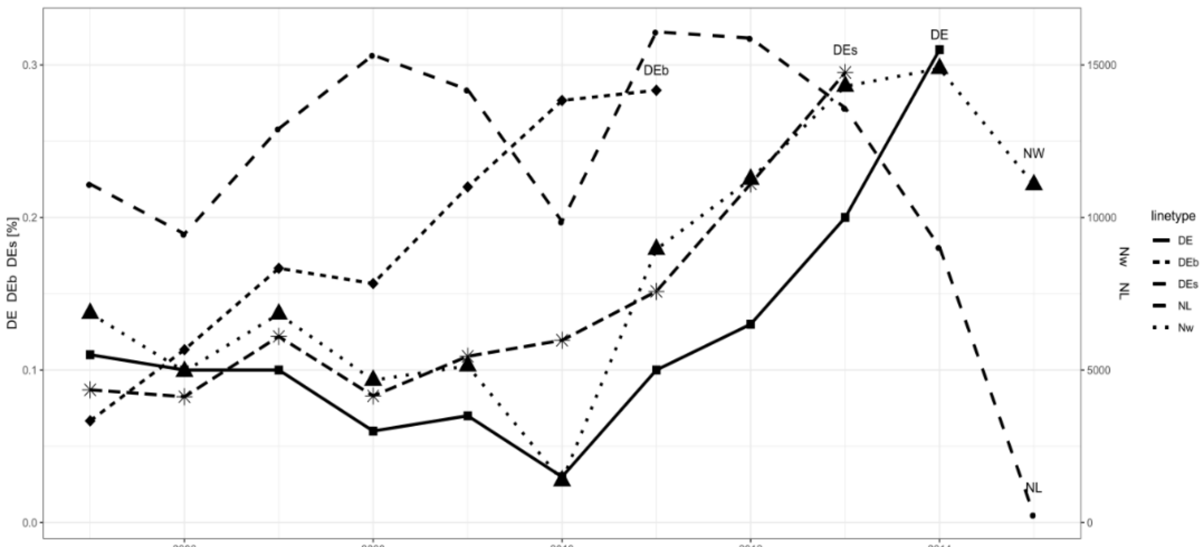


Figure 4: Annual number of flashes detected by WWLLN (Nw) and that by LIS (NL), and the estimated detection efficiency of WWLLN relative to the LIS (DE) and those found by [2] (DE_b) and by [64] (DE_s).

Figure 4 shows the interannual evolution of the WWLLN and LIS flash numbers and detection efficiencies. It reveals a large variability between 2005 and 2009 in the number of WWLLN flashes. As for the number of LIS flashes, the fluctuation is maintained over the entire period. Several reasons can explain these irregularities, such as the hypotheses formulated by [64]. They suppose that this irregularity may be due to natural variability of storm activity or failures at WWLLN stations. Either of these hypotheses do not allow us to explain the irregularities observed in 2009 and 2010 because the network recorded very low values. On the other hand, the steady increase in the number of WWLLN flashes can be attributed to the installation of new sensors and the improvement of the localization algorithm.
Figure 5 shows the annual evolution of the monthly proportion of flashes detected by WWLLN over the entire study area. The histogram shows the proportions of average monthly activity over the 13 years of the study period. The lowest flash activities are identified during the months of November, December, January, February and March. The highest activities, on the other hand, are observed during the months of May to October. The last six months of high electrical activity correspond to the period from May to October. These results are consistent with those of [79.97]. This is also consistent with the maximum number of SDmax thunderstorm days indicated in Table 1. 2013 has the highest number of days (299) with at least one thunder rumble. Figure 6 shows the flash distributions as a function of multiplicity for the years 2005 to 2016.

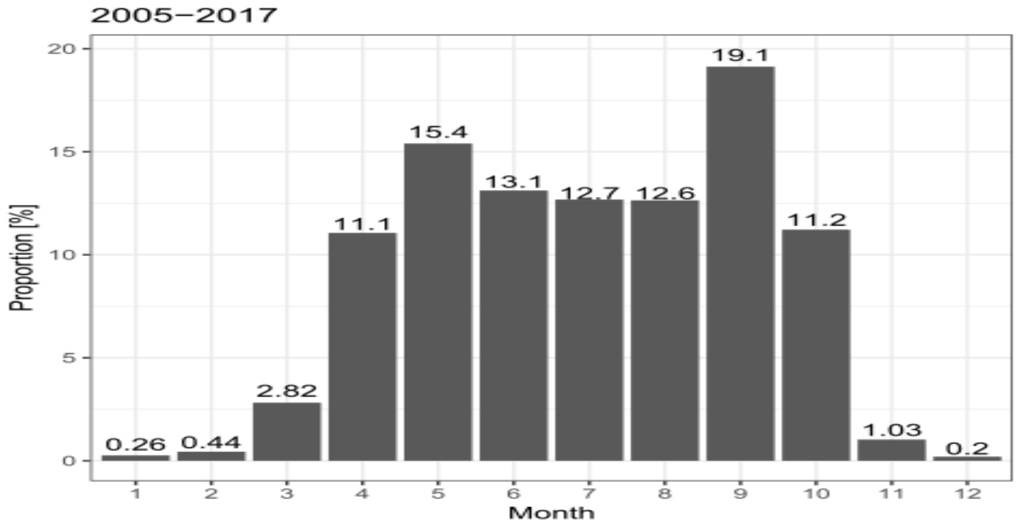
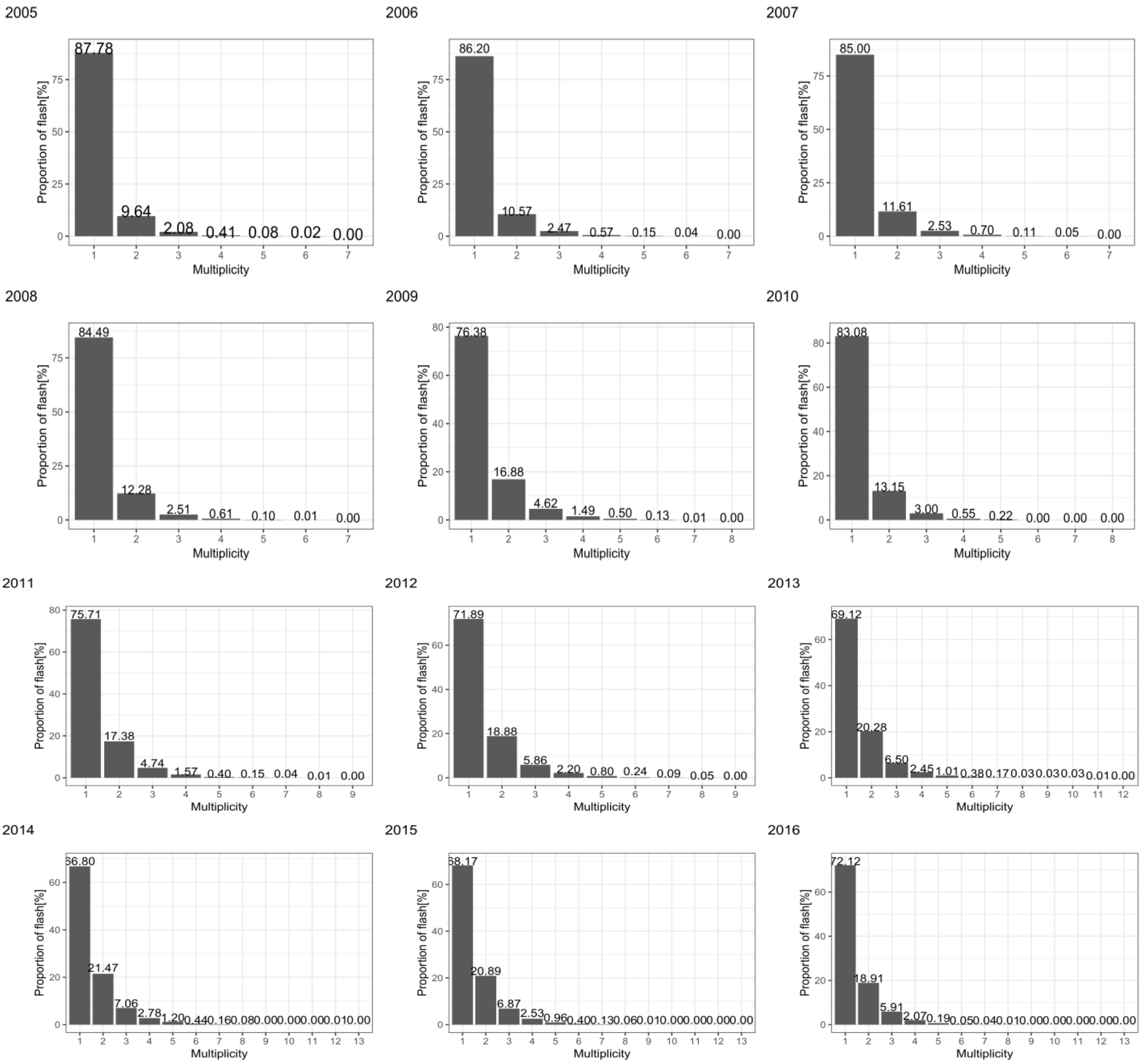


Figure 5: Annual evolution of the monthly proportions of WWLLN flashes for the study period.



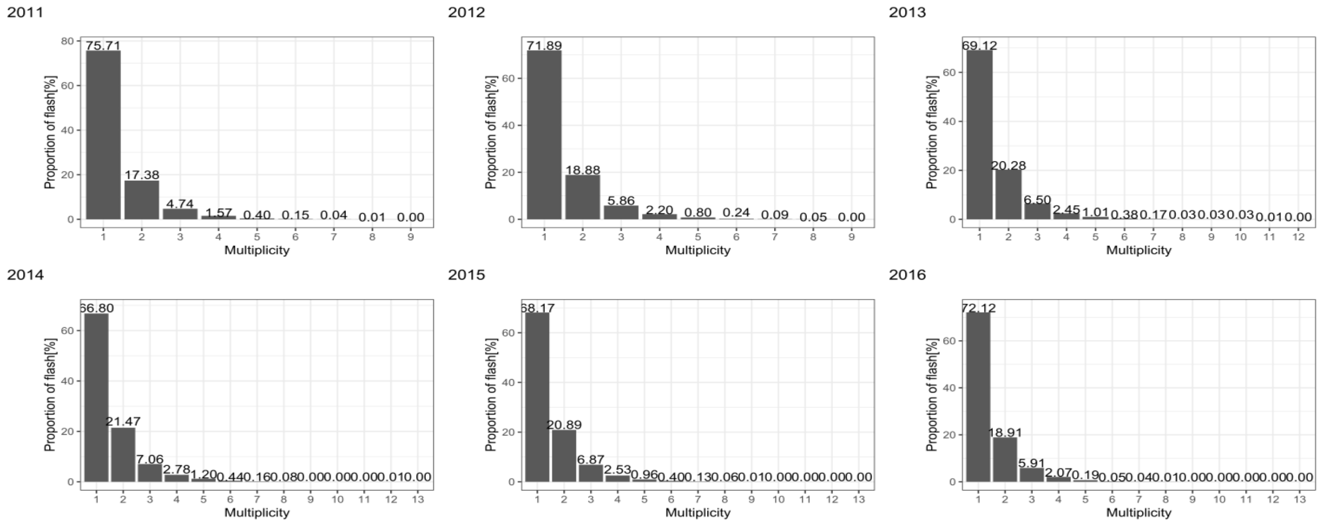


Figure 6: WWLLN flash distributions as a function of multiplicity.

Figure 7 shows the evolution of the mean multiplicity and the proportion of flashes corresponding exactly to one hit. Initially the multiplicities are low, but they increase significantly over the period showing the increase in network performance. His results are in agreement with those obtained by [64]. On the other hand, the mean multiplicity increases with the number of flashes, i.e. with the detection efficiency (DE) as long as the proportion of flashes having a single hit as a correspondent decreases. His observations are close to those of [64]. They found that in general the mean multiplicity increases with increasing detection efficiency. The proportion of flashes with M = 1 is perfectly anti-correlated with Mm. Thus the increase in DE leads to detect not only more flashes but also more secondary arcs. If DE increases the average multiplicity increases. Moreover, secondary arcs usually have lower current peaks and are therefore more difficult to detect.

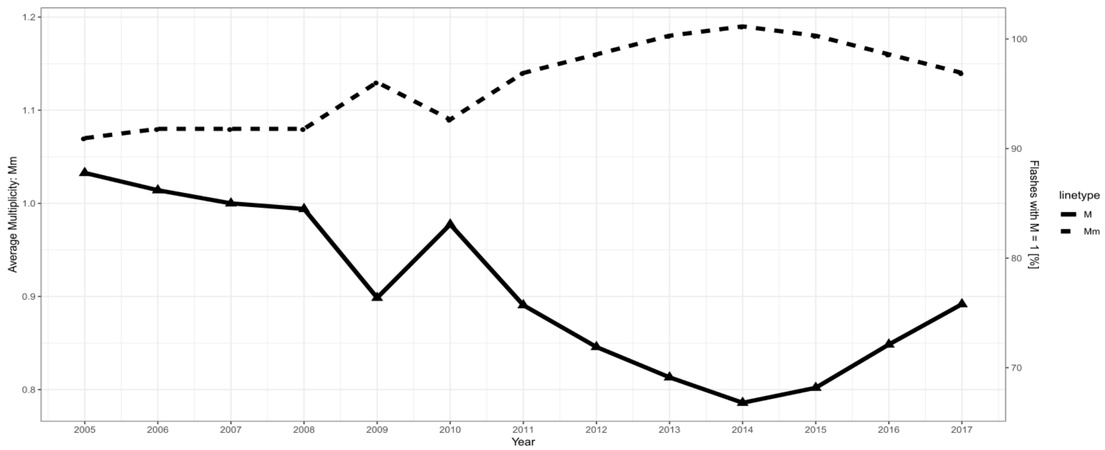


Figure 7: Average multiplicities Mm and proportion of WWLLN flashes having a multiplicity equal to 1.

Figure 8 shows the diurnal variation in electrical activity over the entire study area in terms of the hourly proportion. The proportions shown correspond to the production of flashes one hour after each event. The evolution obtained is characteristic of the diurnal variation of the area as shown in the study of [98] covering South Africa; [99] for tropical lands around the world with LIS data; [79] for their study of the same area but with LINET data; [100] for mid-latitude lands with ZEUS data; [64] for their study in Congo. Thus, the minimum proportions are between 10 and 11 hours UTC (11 and 12, local time) and the maximum proportion is obtained at 18 hours UTC (19 hours, local time). The ratio between the maximum and minimum is 7.87%, comparable to that of [64]. According to Figure 8, the variability of the proportions is very wide between 4:00 and 14:00 UTC and short between 15:00 and 23:00 UTC. The maximum is observed in the evening as shown in [79,97] and this is close to the results of [64].

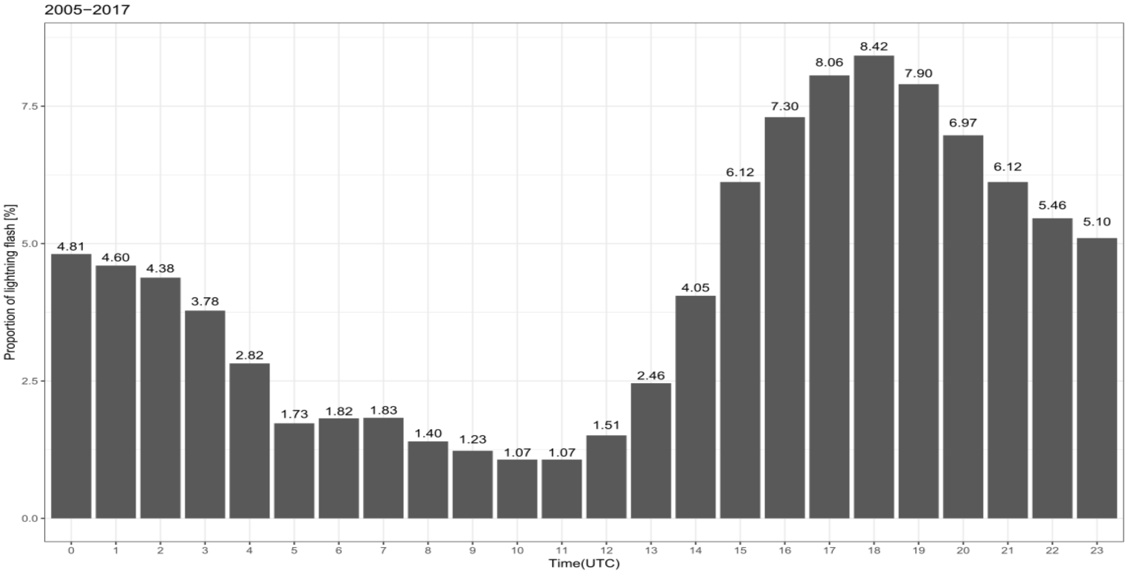


Figure 8: Diurnal variation in the proportion of WWLLN flashes.

3.2. Spatial distribution

A mesh with a resolution of 0.1° × 0.1° is made. The flash density is calculated per year and is expressed in number of flashes per square kilometre per year (fl.km^{-2}.yr^{-2}). Figure 9 shows the density distribution per year and over the entire study area for the two networks. The detection efficiency (DE) varies as a function of time. The scale is adapted to each year but the same trend is observed. We note a non-uniform distribution and maxima are very often observed in two or three areas. Both indicate comparable distributions. The density reduced to unity is shown in Figure 10. Table 2 shows the maximum values of the flash density FDmax from 2005 to 2017. They oscillate but the values increase significantly from 2012 onwards.

Table 2: Maximum annual density value according to WWLLN (FDmax) and theoretically estimated (FD'$_{max}$).

Year	FD_{max} $(fl.km^{-2}.yr^{-1})$	FD'$_{max}$ $(fl.km^{-2}.yr^{-1})$
2005	1.25	1136.36
2006	0.82	820
2007	1.43	1430
2008	0.74	1233.33
2009	1.03	1471.43
2010	0.52	1733.33
2011	1.39	1390
2012	1.88	1446.15
2013	3.25	1625
2014	2.57	829.03
2015	1.7	21.01
2016	2.26	-
2017	1.86	-

The highest value is observed in 2013 with 3.25 fl. km-2.yr-1. The evolution of the FDmax is similar to those of the detection efficiency and the number of WWLLN flashes. The maximum density of all flashes can be estimated by:

$$F\,D'_{max} = \frac{F\,D_{max}}{DE} \times 100 \qquad (12)$$

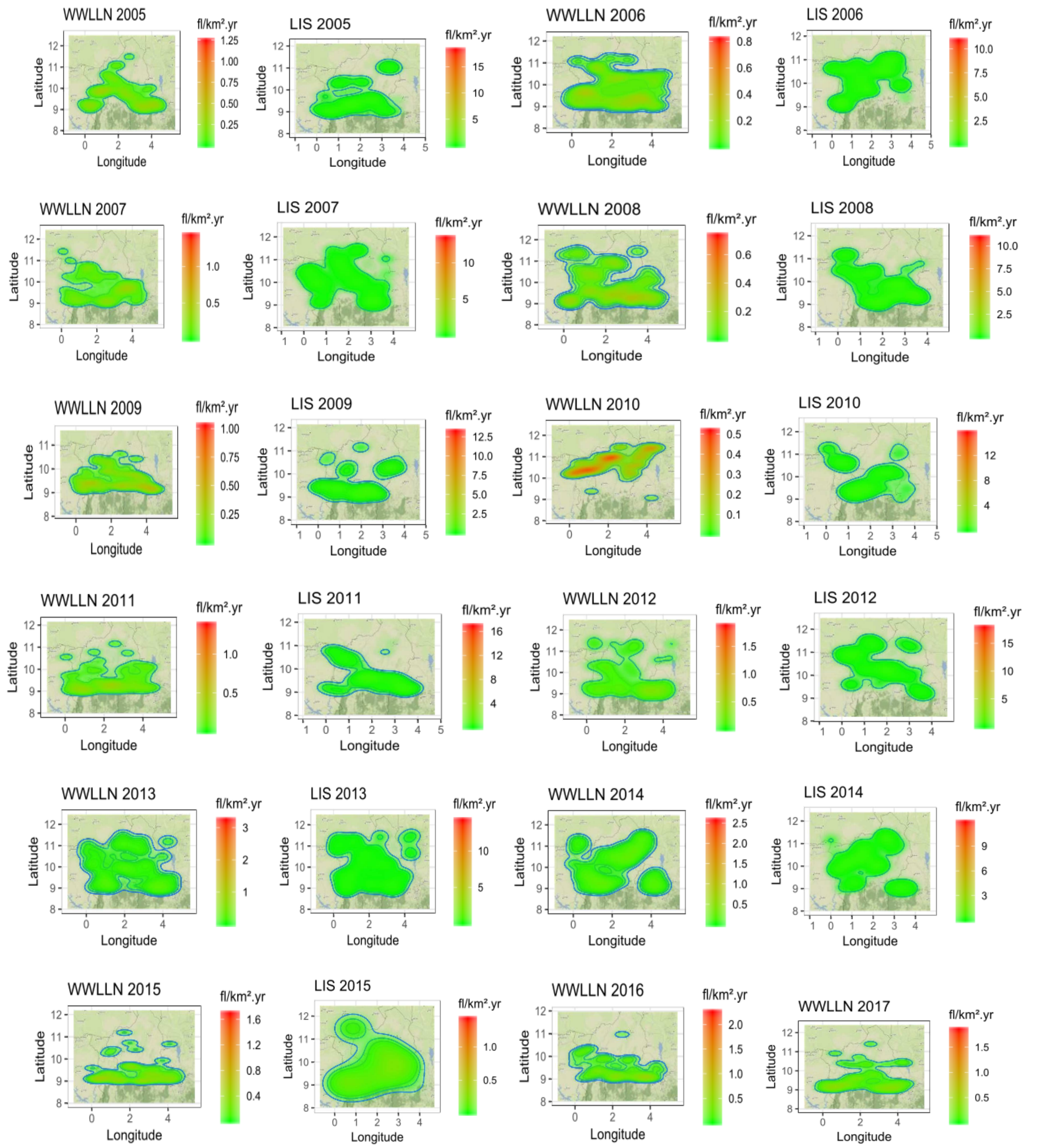


Figure 9: Flash density with a resolution of 0.1°×0.1° of the two networks.

Table 2 also gives the estimated FD'_{max} values for each year and it should be noted that they are close to the total indicated by the LIS as shown [64]. Figure 11 compares the lightning density over the entire period and the entire study area with its relief. Lightning is more concentrated along the mountains. The centres are located on the reliefs more than 510 m above sea level. These observations are in agreement with those of [79].

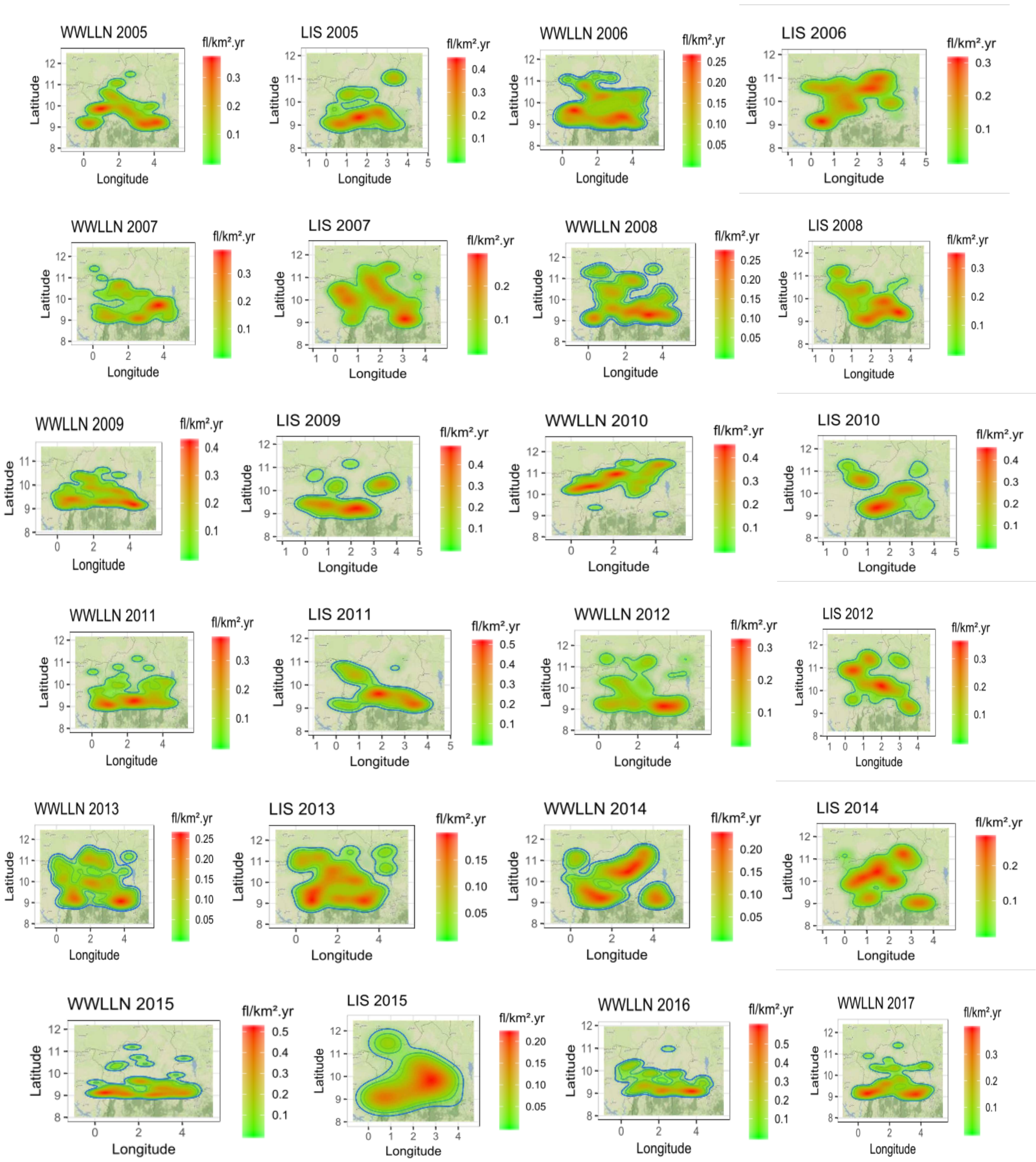


Figure 10: Proportion of flashes with a resolution of 0.1°×0.1° of the two networks.

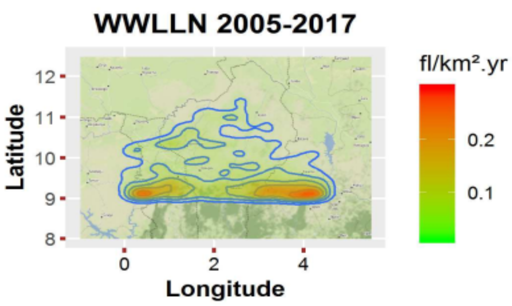


Figure 11: WWLLN flash density of the period data with a resolution of 0.1°×0.1°.

Conclusion

Lightning activity is analysed in the area between latitudes [9°N, 11.5°N] and longitudes [0°E, 4.5°E] using WWLLN and LIS data. Previous studies have shown that the detection efficiency of WWLLN decreases from the ocean to the continent. The time criterion of 0.5 s is chosen between two flashes and contrary to [64] the maximum distance between flashes is 10 km according to [9]. The detection efficiency found in this corresponds to global observations. The maximum value found by [64] is 5.90% obtained in 2013, [2] is 8.50% obtained in 2011 while for the present study the maximum is 8.09% obtained in 2015. This value is exceptional because the number of LIS flashes is comparatively very low. The maximum likely value for this study is that obtained in 2014, which is equal to 0.31%. The detection efficiency increases significantly from 2010 onwards. This increase can be attributed to the increase in the number of sensors and the improvement of the localisation algorithm. Lightning activity covers most of the year. However, seven months are still considered to have high electrical activity. WWLLN identifies September as the month of high electrical activity, while LIS identifies June as the month of high electrical activity. The year 2013 appears to be the year of high electrical activity in terms of number of flash days and density. The year 2010 is identified as an atypical year. The diurnal cycle shows that activity is more intense in the evening. Lightning activity is mainly of orographic origin. The concordance between the results obtained from the LIS and WWLLN data confirms that the WWLLN data are valid for characterizing lightning activity in the region.

Acknowledgments-The authors wish to thank Professor Pascal ORTEGA and the World Wide Lightning Location Network (http://wwlln.net), for providing the lightning location data used in this paper. We also wish to grateful to the NASA Global Hydrology Resource Centre DAAC for LIS data. The authors are at last grateful to the two anonymous reviewers for their comments and suggestion that helped to improve the manuscript.

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