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

J. Mater. Environ. Sci., 2019, Volume 10, Issue 9, Page 872-881

http://www.jmaterenvironsci.com

Geographical longitude/latitude and lightning characteristics in monsoon-season Benin thunderstorms

J. A. Adéchinan[2*], F. K. Guédjé[1], H. Kougbéagbedé[1], E. B. Houngninou[1]

[1]*Laboratoire de Physique de l'Atmosphère, Faculté des Sciences et Techniques, Université d'Abomey-Calavi, 01 BP 1946 Cotonou, Bénin.*

[2] *Laboratoire de Physique de l'Atmosphère, Faculté des Sciences et Techniques, Université Nationale des Sciences Technologies Ingénierie et Mathématiques, BP 72 Natitingou, Bénin.*

Received 02 May2019,
Revised 22 Aug 2019,
Accepted 25 Aug 2019

Keywords
- ✓ *lightning,*
- ✓ *characteristics,*
- ✓ *geographical longitude/latitude,*
- ✓ *Benin,*
- ✓ *Relationship.*

adjos85@gmail.com ;
Phone: +22995846621

Abstract

In this study, the *relationship* between the *geographical longitude/latitude* and *lightning characteristics* detected during the monsoon-season in north of *Benin* is investigated. The data used for this purpose are collected by the Lightning Detection Network and their analyses focused on the density, polarity and intensity. The main results show that intracloud and cloud-to-ground *lightning* have similar *characteristics*. The dynamics of *lightning* occurrence irrespective of their type or their polarity are contrary to their intensity. The variation of lightning density is influence by orographic effect. The *lightning* density shows a strong *relationship* with *geographical longitude* and *latitude*. Moreover, the *lightning* activity is weak in the morning but becomes intense in the afternoon with a main peak displayed around 15:00 UTC for cloud-to-ground *lightning* and 17:00 UTC for intracloud *lightning*. The variation of intracloud as a function of altitude follows the normal law with the maximum occurrence displayed around 11.5 km in August and the average intensity of these discharges decreases with altitude.

1. Introduction

Lightning is a natural, brief and very spectacular electric discharge that occurs in thunderstorms [1]. In their manifestations, lightning is able to radiate important electromagnetic fields that can disrupt telecommunication networks and induce over voltages in electric power distribution systems and sometimes even cause wildfires [2]. In this way, lightning accounts for many human casualties and tremendous property damage worldwide every year [3]. The rapid growth of new lightning detection networks during the past few decades open the door for numerous studies in different parts of the world. So, lightning distribution in time and space, peak current, type, polarity, flash multiplicity have been analysed [4]. The aim of these investigations is not only to better understand the conditions of formation and appearance of these discharges, but also, to reveal various lightning characteristics in different geographical regions, to identify their links with other atmospheric parameters and to find their involvement in the climate change that our planet earth is undergoing.

There are numerous studies reporting the spatiotemporal distributions of lightning characteristics. For example, many researchers analyzed the geographical distribution of cloud-to-ground (CG) lightning in the contiguous United States [5, 6]. Similar works have also been undertaken in Florida [7]; over the Beijing Metropolitan Region in China [8]; in Brazil [9]; in Germany [10]; on the Iberian Peninsula in Spain [11]. Statistical analyses have also been conducted on the relationship between lightning activity and topography influences. Some studies indicated that topography not only affects the incidences and locations of lightning activity but also influences the physical parameters of CG flashes [8]. The conclusions of these studies show that the spatial distribution of CG lightning density is depending to the orographic effects. But the investigations between flash characteristics and geographical longitude or latitude are less [12]. The Study conducted in Israel show a decrease of lightning density with geographic latitude [13]. In contiguous United States, it's found a strong dependence between polarity and latitude [5]. This study also suggested that the peak current amplitude also varies as a function of latitude. The results obtained in Spain have shown that there is a strong dependence between flash density and both longitude and latitude, which may be explained as effect of altitude distribution and Mediterranean Sea [12]. Recently, the study conducted in Congo basin shows a dissymmetry with respect to the equator in the zonal distribution of flashes detected by World Wide Lightning Location Network [14].

The information based on a 5-yr dataset using the Optical Transient Detector on-board the MicroLab-1 satellite enabled to make a map of global lightning climatology [15]. This map shows that the contribution of African continent to the global lightning density is the most important. Unfortunately, these areas are very little or poorly covered by electrical activity observation networks. Since Benin doesn't have a warning system that can inform people about extreme events, the material and human damage related to lightning events each year are enormous. So it's clear that the best knowledge of these electrical phenomena at our latitudes is an imperative. However, few in-situ lightning data is available to undertake such an initiative, in particular because of the high cost of acquiring and maintaining lightning detection systems. In the frame of AMMA campaign (African Monsoon-Multidisciplinary Analysis), Benin had the privilege of being retained as one of the measurement network in West Africa. The lightning data collected by the LINET (lightning detection network) during this measurement campaign have already been used for several publications [16-18].

This work is an extension of lightning data analysis collected in monsoon-season during the special observation period of AMMA campaign. It aims correlate lightning characteristics and geographical longitude/latitude. The next section describes the data source and methodology used in this study. Results are discussed in section 3, and summary is provided in the final section.

2. Study area, data and methodology

The present study is conducted in north of Benin. This area is surrounded by the Atakora mountains in the northwest parts and is located just east of Greenwich Meridian (GM) in the semi-humid Sudanian zone of central Benin. The mean annual cumulative rainfall is 1200 mm with a rainy season from March to October [19].

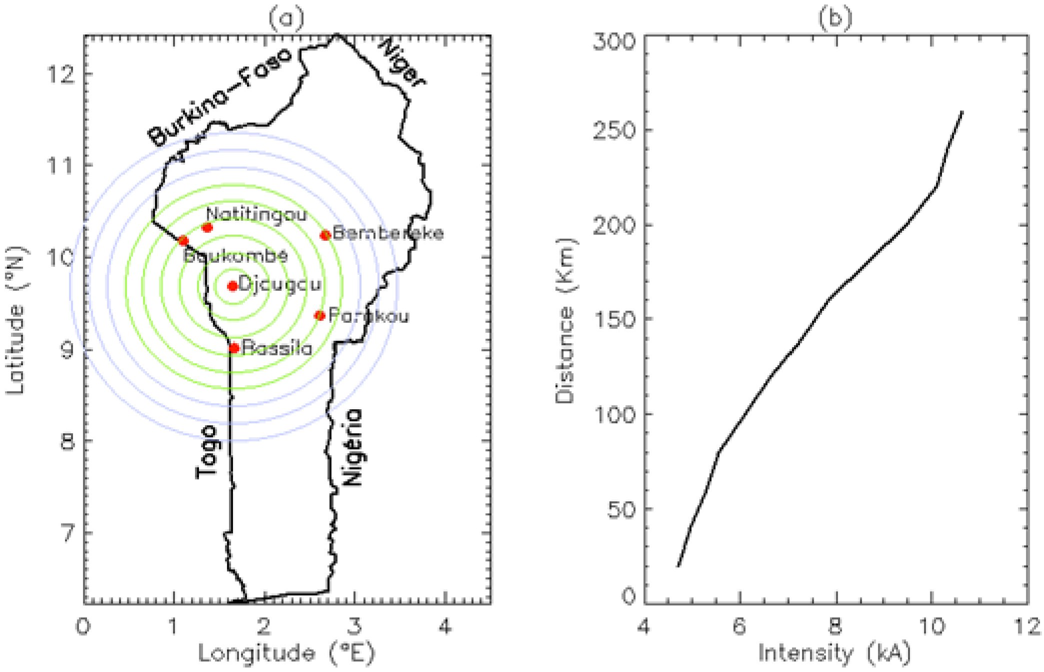

Figure 1: (a) Map of Benin with the six stations of the LINET network as well as the area of good detection efficiency (green), and (b) distance variations in the mean peak current.

Lightning data used in this study were obtained from the LINET which is a three-dimensional multi station detection system that can discriminate between CG and IC flashes. Although this network only worked for a short time period (mid-June to mid-November), it however make possible for the first time in Benin, the availability of lightning in-situ data. The LINET consists of the following six substations (Figure 1): Natitingou (1.3796°E, 10.3206°N), Djougou (1.6528°E, 09.6798°N), Parakou (2.6123°E, 09.3577°N), Bassila (1.6704°E, 09.0055°N), Boukoumbé (1.1038°E, 10.1794°N), and Bembereke (2.6733°E, 10.2359°N). Djougou is considered as a central station. The distance between two stations is about 124 km and the average level of all sensors of this network in relation to the sea level is 429 m. The LINET working at very low frequency (VLF) and low-frequency (LF) range with 3D capability. Each station in the system consists of: a crossed loop antenna for measuring the magnetic field, a GPS antenna for measuring the precise time reference and a computer for data acquisition. The locations of radiation sources are detected using the time of arrival method. The LINET data provides information on stroke date and time, stroke type, geographical location, polarity, height for IC events, peak current of the radiation sources associated with lightning, the stations involved in the data fit and data quality parameters. Both IC and CG data are computed and their peaks current are averaged over concentric rings with radius at 20 km intervals (Figure 1.b). It can be seen in fig 1.b that the mean peak current increased with distance from Djougou station that considered as the center of the LINET network. So, the location errors increase significantly with distance from the center of this station. According to the previous studies, the best detection area is inside the rectangle defined by the whole LINET stations [15].

The method used in this study to analyze the lightning data is similar to that used in Spain [12]. Indeed, classes of longitudes/latitudes with a fixed pitch of one kilometer have been established. In each of these classes, we determine not only the number of flashes counts, but also the corresponding average intensity. Since the flashes of negative currents are identifiable by negative intensity in our data, the average intensity of each class was computed by taking the absolute value of the amplitudes of all the intracloud lightning. The same approach was followed to analyze the vertical profile of IC lightning. At this level, classes of one kilometer fixed pitch altitudes have been formed. The number of intracloud flashes corresponding to each of these classes is then determined and normalized with respect to the total number of IC flashes counts during the observation period. At the same time, the average intensity of IC flashes detected in each class is calculated.

3. Results and discussion

3.1. Spatial variability

The variation of both IC and CG lightning counts as well as their intensities were analyzed according to geographical longitude and latitude. As can be seen globally in Figure 2, the number of both IC and CG lightning count and the corresponding average intensity do not follow the same dynamic. In fact, the lightning statistics have shown that the longitudinal variation in IC lightning activity exhibits a unimodal shape and therefore consists of two important contiguous areas. The first part located between the GM and the latitude 1.4 °E is characterized by an increase of the number of IC flashes whatever their polarity. The end of this part is marked by the largest peak, corresponding to 0.8% of these discharges. The correlation coefficient obtained between the number of IC lightning count and longitude is 0.97. The second part, which beginning coincides with the end of the first one, extends to longitude 3.8 °E. In this part, there is a gradual decrease in the IC proportion with longitude. The correlation coefficient between the number of IC and the longitude is - 0.90. It follows that as we move away from 1.4 °E, on the East side as on the West side of the observation window, the electrical activity related to intracloud discharges decreases. The same trends are observed for both positive and negative IC flashes although there are slight differences in location. The largest differences are recorded between 0° and 1 °E, where the proportion of positive IC is greater than that of negative IC. These is results are similar to those obtained by other authors at both global and local scales.

Like the IC lightning, the CG lightning density increase gradually from the GM to 1.2 °E, where the largest peak is finding. From the position of this peak to 2.1 °E, no clear trend is observed since the proportion of CG in this range fluctuates a lot. Then, there is a rapid decline in lightning to 3.8 °E. This trend is valid for both positive and negative CG (Figure 2b). However, it should be noted that the proportion of negative CG flashes is consistently higher than that of positive CG. This increase number of electric activity around the peak observed at 1.4° E may be explained as an orographic effect. Indeed, when we refer to the topographic map of our area study, we note the presence of the Togo mountains and the Atakora mountains in the NW parts of Benin. This influence of orography on the lightning distribution was also reported on the Iberian Peninsula in Spain [12]. These authors found a statistically significant correlation coefficient (0.93) between lightning and geographical longitude.

Figure 2.b shows the IC peak current distribution as a function of longitudinal. This has the appearance of a convex curve. In a first phase, there is a decrease in the mean intensity up to the longitude corresponding to the peak observed in Figure 2a with respect to the frequency of IC lightning distribution according to geographical longitude. There is then a gradual increase in mean intensity to 3.8 °E. The areas with the highest numbers correspond to those with the lowest average peak current. The mean intensity of IC flashes ranges from 5.42 kA to 10.69 kA. It's also easy to see in Figure 2b that the average intensity of positive IC varies between 4.5 kA and 10 kA while that of the negative IC varies between 6.5 kA and 12.5 kA. Regardless the longitude range considered, the average intensity of the negative current IC is significantly higher than that of the positive current IC.

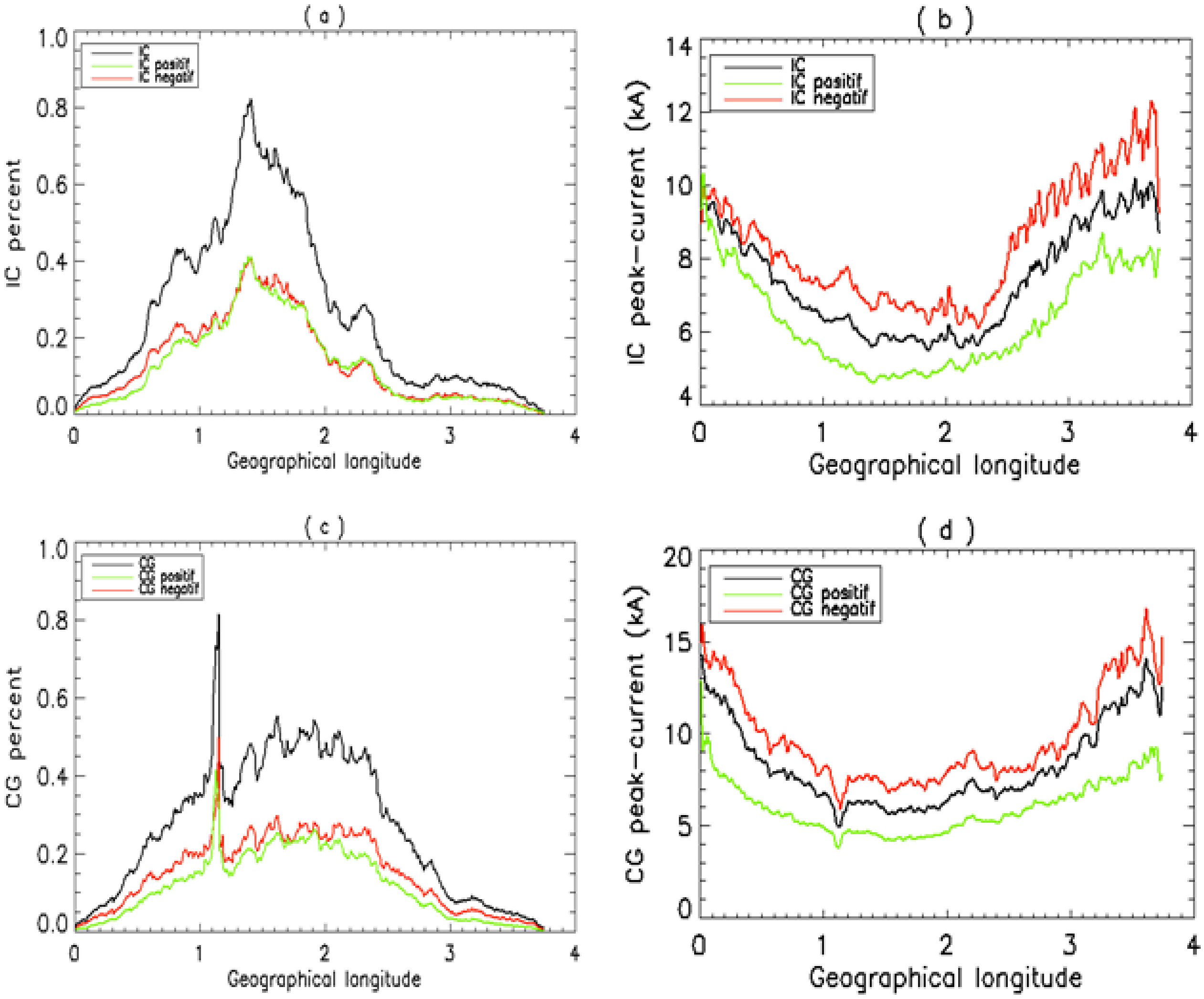

Figure 2: Frequency distribution of both IC and CG lightning count and their intensity as a function of geographical longitude. (a, b) for IC according to their polarity; (c, d) for CG according to their polarity.

The cloud-to-ground lightning variations as a function of longitudinal are similar to those obtained for intracloud lightning. Indeed, while the number of CG gradually growing from the GM to 1.2 °E, we note in parallel, a decrease in the corresponding average intensity. The modal class of the series of CG coincides with the class with the lowest average intensity (4.5 kA). Looking west from the East to the observation area, there is a slight and gradual increase in mean lightning intensity over 1.2 °E, but also a decrease in the number of lightning bolts of these lightning. From the polarity point of view, the general trend is the same. The average intensity of the CG of positive currents in each of the longitude bands considered is lower than that of CG of negative currents. The average intensity of positive CG varies between 4 kA and 10 kA while that of the negative CG varies between 6 kA and 17 kA. It follows that the longitudinal variation of the average intensity of lightning follows a dynamic opposite to the longitudinal distribution of the occurrence of these discharges.

Figure3 shows the variation of both IC and CG lightning count and average intensity as function of geographical latitude over the observation area. Unlike to the longitudinal variation, the figure 3 does not show a single clear peak. There is a gradual increase of IC proportion from 7.9° N to 9.5 °N, and then there is a rapid decrease in these flashes beyond 11 °N. Between 9.5° and 11 °N, no clear pattern emerges because there strong fluctuations. These observations are the same for both positive and negative IC intensity. The differences between the proportions of positive and negative IC are perceptible beyond 10.5 °N. The variation of the average intensity of IC as function of geographical latitude shows a similar appearance to that observed along geographic longitude. Thus, in a first phase, a decrease in the average intensity of these flashes up to the longitude 9.5 °E. There is then a gradual increase in the average intensity to the upper limit of the window observation. Classes with the highest enrolment correspond to those with the lowest average intensities. For all these flashes, the average intensity varies between 5.42 kA and 10.69 kA. Note also that the average intensity of positive IC varies between 4.5 kA and 10 kA while that of the negative IC varies between 6.5 kA and 12.5 kA. Regardless the longitude range considered, the average intensity of the positive current IC is significantly lower than that of the negative current for IC. A strong occurrence of IC according to geographical latitude does not necessarily induce a strong average intensity.

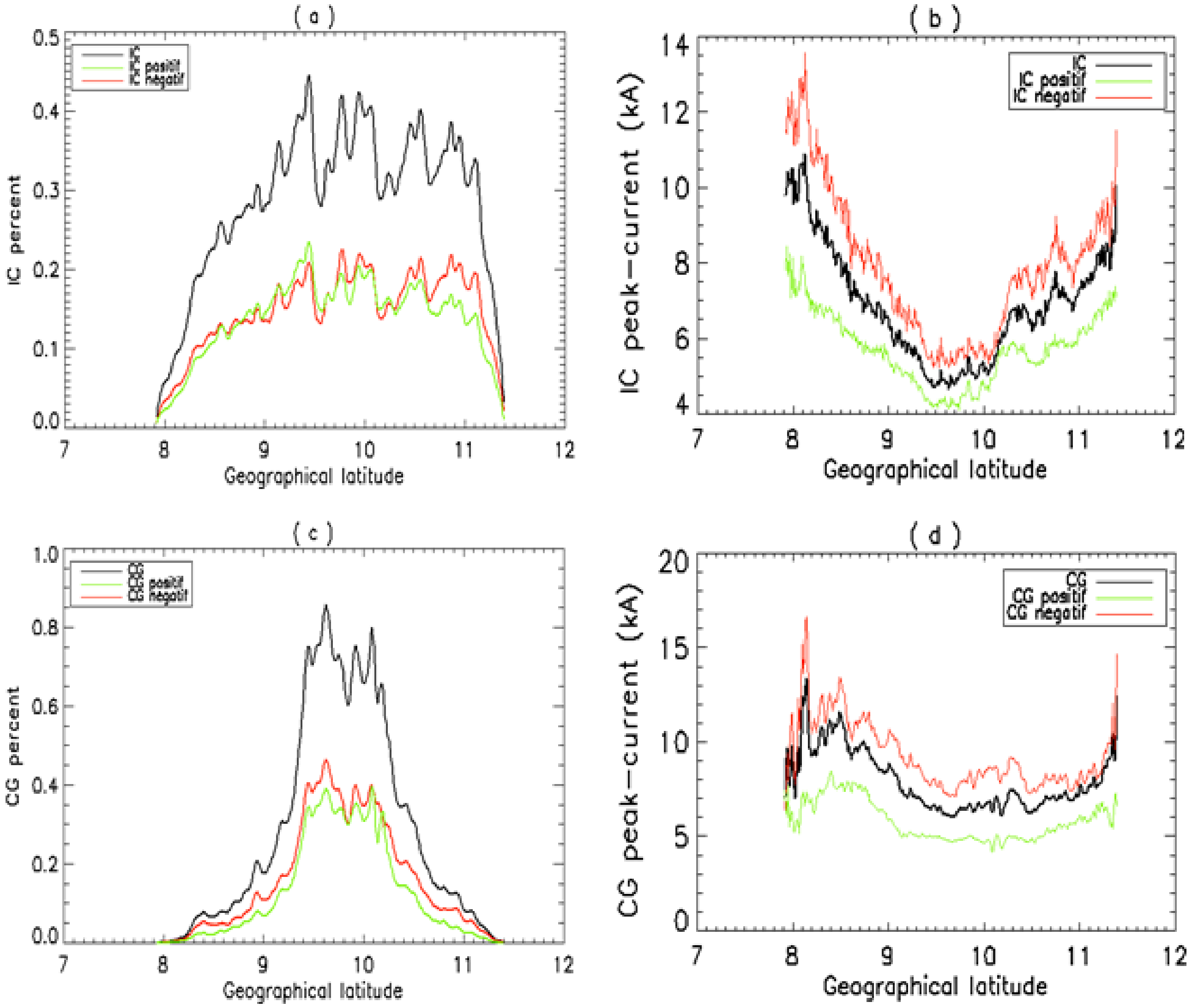

Figure 3: Frequency distribution of both IC and CG lightning count and their intensity as a function of geographical latitude, (a, b) for IC according to their polarity; (c, d) for CG according to their polarity.

When looking at the distribution according to the geographical latitude of CG lightning (Figure 3c), two large areas emerge. In this case, the first area characterized by an increase of IC lightning count irrespective of their polarity is followed by a second area marked by a decrease in the occurrence of these lightning. There is no clear trend between 9.5 and 10.1°N. As for the evolution of the average intensity of these lightning bolts according to the geographical latitude (Figure 3d), we note that the average intensity of CG varies between 6 and 15.5 kA and is always superior to that of the positive CG which varies between 4 and 9 kA. The highest values of the average intensity of the CG are noted in the first area.

3.2. Temporal variability

Figure 4 shows the monthly variation of both IC and CG flashes count during the monsoon season. It is clear appear from the analysis of this figure that the total number of flashes varies monthly with the advance of the monsoon. More than half of the flashes appear before August and the peak is observed in July. From August on, there is a gradual decrease in the total electrical activity until the final removal of the monsoon. This dynamic is observed regardless the type of lightning considered. Intracloud flashes are the most numerous (55.14 %). From June to August, the proportion of IC exceeds that of CG flashes. But, this trend is reversed from the end of August until mid-November. The contribution of CG to the total electrical activity becomes more important and noticeable from September. On the other hand it would not be prudent to decide on the tendency that one would have before the monsoon jump which happens in June. In the same way we noted that negative CG flashes are the most numerous whatever the considered month. This trend is contrary to the dynamics of IC lightning. At this level, the positive IC flashes become the most numerous.

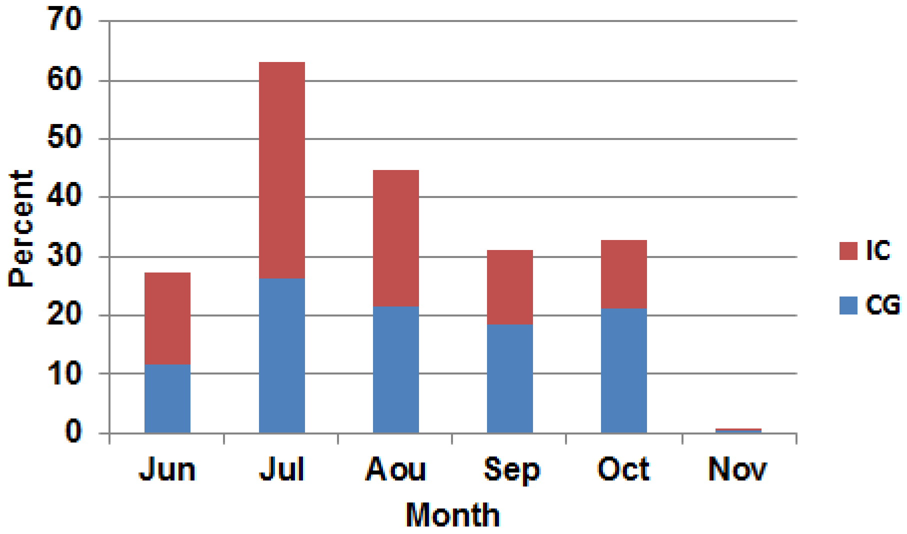

Figure 4: Monthly variations in the percentages of IC and CG lightning counts relative to their total amounts during the monsoon season.

Figure 5 shows the diurnal variation of lightning activity recorded during the monsoon season. Both CG and IC flash counts displayed a main peak in afternoon. Indeed, the lightning activity is weak during the night and in the morning. The lowest numbers are recorded between 06:00 and 10:00 UTC. After 10:00 UTC, there is a rapid increase in the number of IC flash until 17:00 UTC when the main peak is displayed. There is a rapid decrease in the number of lightning bolts until the end of the day. In the same way, the variation of the proportion of positive and negative IC flashes is practically the same regardless the time of day, except between 14:00 and 18:00 UTC, where the number of negative IC exceeds that of positive IC. The gap between the number of positive IC flashes and negative IC increases a lot in the afternoon, reaching its maximum at the time when the maximum number of IC flashes is recorded, that is to say at 17:00 UTC. This change in the IC staff as a function of the hours of the day therefore seems to be related to solar activity, particularly to sunshine. The diurnal variation of the average intensity of IC seems to follow a temporal dynamic contrary to that of IC lightning count (Figure 5b). The lowest average IC intensity values are observed at times when there is maximum sunlight in the area. The average intensity of IC is more stable in the afternoon than at night and in the morning. It records its maximum values in the morning and the big fluctuations are observed between 00:00 and 10:00 UTC. The first peak is most marked at 10:00 UTC. Just after this peak, there is a significant drop in average intensity until 13:00 UTC. In the afternoon, between 13:00 and 19:00 UTC, the fluctuations are less important. After sunset, there is a further increase in the average hourly intensity until 21:00 UTC when the second peak (less marked) is reached. When we look at the diurnal cycle of IC intensity according to their polarity, we find that the highest values for both positive and negative IC are recorded before 10:00 UTC. The peak observed at 10:00 UTC corresponds to an average intensity of 8.6 kA and 11.6 kA, respectively for positive and negative IC. At all hours of the day, the average intensity of the IC is higher than that of positive IC, as evidenced by the values recorded for the second peak observed at 21:00 UTC. The increase in average intensity that occurs after sunset begins at 18:00 UTC for negative IC flashes and one hour later for positive IC.

Like IC, the diurnal variation of CG lightning count (Figure 5c) and their average intensity (Figure 5d) was analyzed. As can be seen in figure 5, the CG activity is weak in the night and the morning. The number of CG decreases gradually from 00:00 to 07:00 UTC. Between 07:00 and 10:00 UTC, the CG activity reaches its lowest level. From 10:00 UTC, there is an increase in the number of lightning up to 15:00 UTC where the peak is reached. From 15:00, a rapid decline in the number of CG until dark, without coming below the low values recorded in the morning. Comparing with the diurnal variation of the IC lightning, it is noted that the IC flash peak is obtained two hours after the peak of CG. This distribution of the number of CG according to the hours of the day is similar to both positive and negative CG. The probability to detect a positive or negative CG is almost the same in the morning, especially between 07:00 and 10:00 UTC. Beyond 10:00, the number of CG bolts becomes constantly higher than that of the positive CG bolts. The gap between the number of positive and negative CG flashes increases rapidly in the afternoon to reach its maximum at 15:00 UTC. It is thus noted that the hours in which the minimum/maximum difference between the proportion of positive and negative CG are observed correspond exactly to the hours recorded respectively, the minimum/maximum for all CG. The soil that begins to heat up after 06:00 UTC thanks to the sunrise, becomes very hot around 12: 00 UTC when the sun is at the zenith and therefore favours a rise of hot air that can induce strong localized convection, and therefore the formation of Storm clouds providing lightning. As for the electrical activity observed in the night, it can be explained by the maintenance of a strong convective instability long after sunset. We also illustrated in Figure 3.d the diurnal variation of the average intensity of all CG lightning. It varies between 6.3 and 10.7 kA. The average intensity of CG is consistently higher than that of positive CG. The average intensity of CG flashes varies between 7.7 and 13 kA while that of the CG flashes varies between 4.6 and 8 kA. The most important fluctuations are observed in the morning, especially between 06:00 and 10:00 UTC. In contrast to the diurnal variation of CG, the maximum values of the corresponding average intensity are recorded in the morning. The lowest intensities are recorded during the hours of maximum electrical activity. It follows that the number of CG and their corresponding average intensity evolve in the opposite direction during the day. Overall, therefore, there appears to be a time lag between the beginning of the increase in the number of lightning and the sunrise.

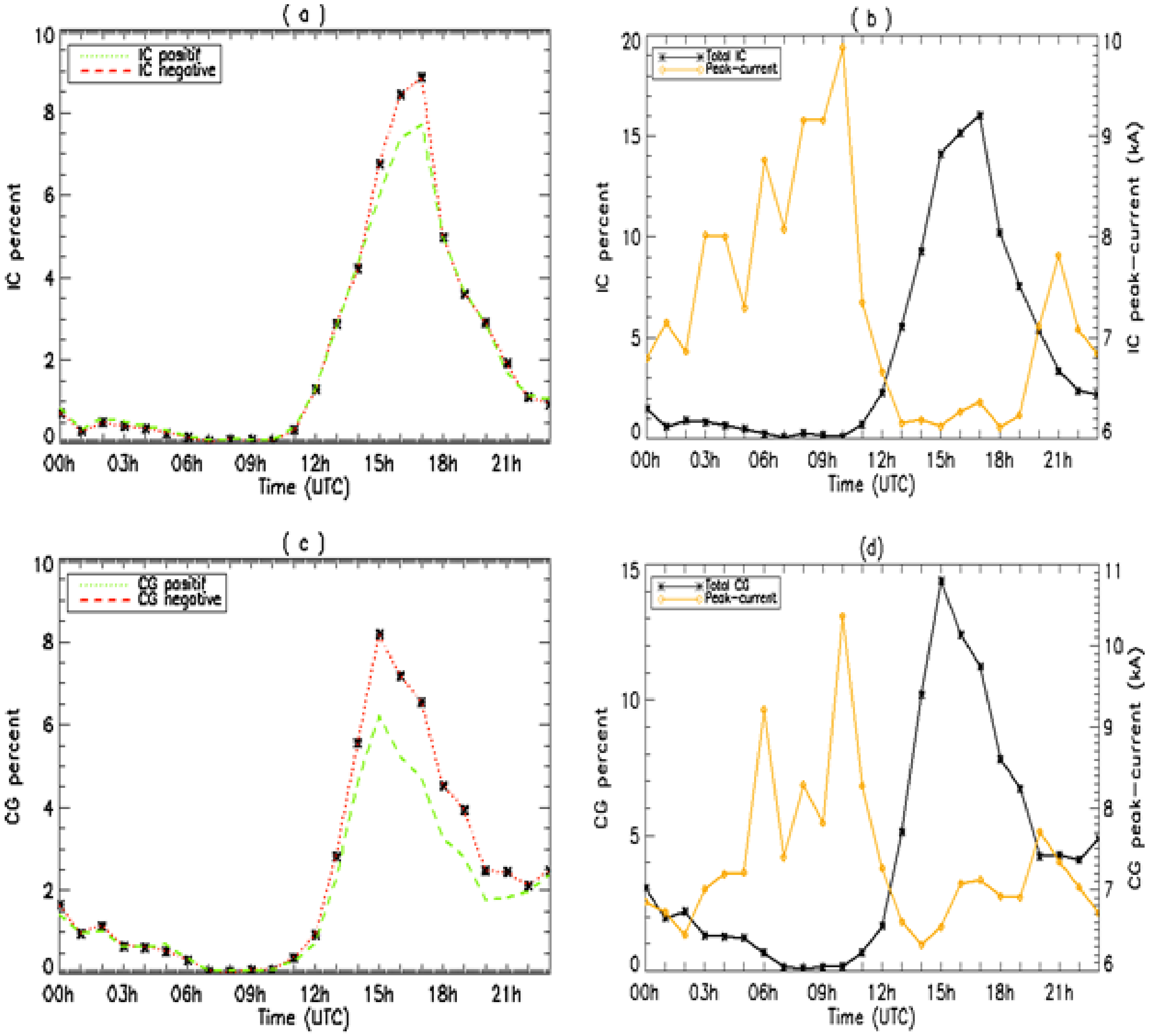

Figure 5: Diurnal variations of (a, c) IC and CG flash count, and (b, d) their intensity.

3.3 Vertical profile of intracloud lightning

Figure 6.a shows the variation of IC as a function of altitude. As can be seen in this figure, the vertical distribution of IC flashes count exhibits a unimodal shape with the peak obtained around 11.5 km. Indeed, the proportion of IC lightning increase between 1 km and 11.5 km then a rapid decrease just after this peak. We note on this curve

that the majority of IC remains concentrated between 8 km and 15 km. Although intracloud discharges are detected up to 50 km altitude, the proportion of IC flashes detected above 30 km altitude tends to zero. This tendency in the flash density to increase with altitude has been reported by many authors [9, 15]. For example, the variation of IC as a function of altitude is used in previous study to explain the structure of thunderstorms that are developing in West Africa. As can be seen in Figure 6.a, variation of IC as a function of altitude obeys to the normal law. The coefficient of determination between the values observed and those deduced from the normal distribution is 0.89 with the mean square error close to zero. From the polarity point of view, the general trend is the same but at different proportions in some places. Thus, from 6 to 12 km above sea level, the proportion of IC is consistently higher than that of IC lightning flashes, whereas the contrary is observed outside this range.

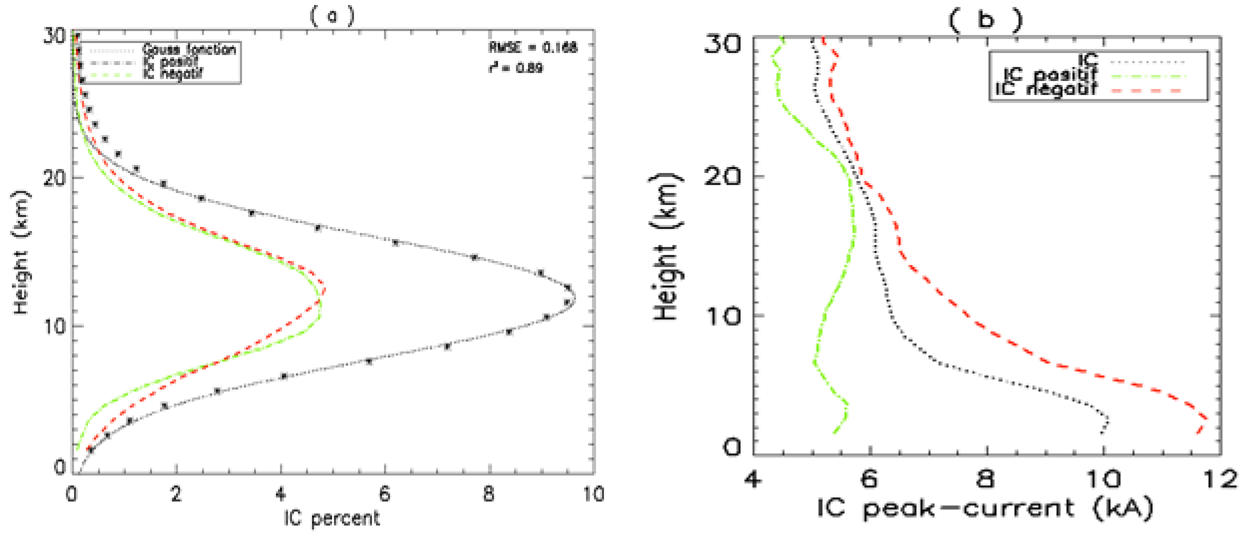

Figure 6: Variation of IC as function of altitude, (a) lightning count and (b) their peak current.

As mentioned above, we note in Figure 6.b a decrease in the average intensity of IC flash as a function of altitude. Indeed, the average intensity of IC varies according to the altitude between 5 and 10 kA. Decay is very fast and abrupt in the first ten kilometers but much slower beyond. Depending on the considered polarity, the change in average intensity as a function of altitude varies. As we go up, the difference between the average intensity of the positive and negative IC is reduced to an altitude of 20 km where we observe again an increase in this gap. The maximum average intensity (11.75 kA) of positive IC lightning is identified at 2.5 km while that (5.7 kA) of positive IC lightning is recorded around 15 km.

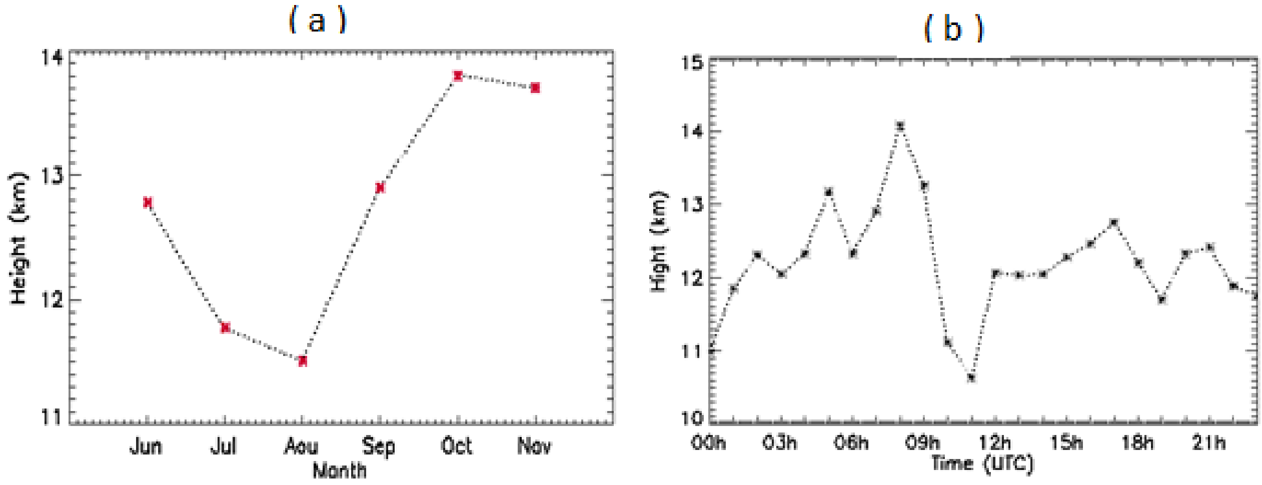

Figure 7: (a) Monthly and (b) hourly variations of IC height.

From Figure 7.a, the average monthly height of all IC lightning varies between 11.5 km and 13.8 km. From June to August, there is a decrease in the average height of interception of all IC and an increase in this average altitude until the removal of the monsoon. It’s therefore during the month of August that represents the heart of the rainy season in northern Benin that the electric shocks. At the time scale (Figure 7.b), we note that the largest peak is recorded at 08:00 UTC around 14 km altitude, while the minimum average height is 10.5 km and is recorded at 11:00 UTC. In the morning as in the evening, this average height fluctuates a lot and therefore no clear trend emerges.

Conclusion

In this study we have examined the relationship between lightning (intracloud or cloud-to-ground) characteristics and geographical longitude/ latitude in north of Benin. Our analyzes focused on the flash count, intensity and polarity. The data used to carry out the work was collected in the frame of AMMA campaign during its special observation period. The main results shown that the variation of IC and CG lightning as a function of geographical longitude/latitude irrespective of their type or their polarity is contrary to their intensity. As one moves away from these mountains, the occurrence of the set of flashes according to geographic longitude/latitude decreases. The variation of lightning density is influence by orographic effect induced by the presence of the mountain range in northwestern Benin, which extends into neighboring Togo. The lightning density shows a strong relationship with geographical longitude and latitude. The diurnal variation of lightning activity allowed us to identify the time of preference of appearance of lightning. At this level, we found that this diurnal variation is strongly modulated by the sun. The high proportions of lightning are obtained in the afternoon while the electrical activity reaches its minimum values in the morning, and more precisely just after sunrise. A temporal shift was therefore identified between the beginning of the increase in the number of lightning and the sunrise. The maintenance of electrical activity early in the morning before sunrise is possible attributed to the transfer of the earth to the atmosphere, the latent heat stored the previous day. The variation of IC flashes as a function of altitude follows the normal law with the maximum occurrence displayed around 11.5 km during the month of August, which represents the heart of the rainy season. The average intensity of IC flashes decreases with altitude.

Acknowledgments

The authors are grateful to the coordinators of the international AMMA project for providing lightning data. The authors are also grateful to the two anonymous reviewers for their comments and suggestion that helped to improve the manuscript.

References

1. F. Wu, X. Cui, Da-L. Zhang, D. LIU, SAFIR-3000 Lightning Statistics over the Beijing Metropolitan Region during 2005–07, *J. of Applied Meteorology and Climatology*, 55 (2016) 2613-2633. https://doi.10.1175/JAMC-D-16-0030.1
2. A. Tapia, J. A. Smith, M. Dixon, Estimation of convective rainfall from lightning observations, *J. Appl. Meteorol*, 37 (1998) 1497-1509. https://doi.org/10.1175/1520-0450(1998)037%3C1497:EOCRFL%3E2.0.CO;2
3. S. K. Kar, H. A. Kyung-JA, Characteristic Differences of Rainfall and Cloud-to-Ground Lightning Activity over South Korea during the Summer Monsoon Season, *Monthly Weather Review*, 131 (2003) 2312-2323.
4. Y. YanRong, S. Die, W. ShengYan, Li. Ping, Yi Xu, Characteristics of cloud-to-ground lightning and its relationship with climate change in Muli, Sichuan province, China, *Nat Hazards*, 91 (2018) 1097–1112. https://doi.org/10.1007/s11069-018-3169-3
5. R. E. Orville, A. C. Silver, Lighting ground flash density in the contiguous United States: 1992-95, *Mon. Wea. Rev*, 125 (1997) 631-638.
6. R. E. Orville, A. C. Silver, Cloud-to-ground lightning in the United States: NLDN results in the first decade, 1989–98, *Mon.Wea. Rev*, 129 (2001) 1179-1193.
7. S. Hodanish, D. Sharp, W. Collins, C. Paxton, R. E. Orville, A 10-yr monthly lightning climatology of Florida: 1986-95, *Weather For*, 12 (1997) 439-448.
8. F. Wu, X. Cui, Da-L. Zhang, L. Qiao, The relationship of lightning activity and short-duration rainfall events during warm seasons over the Beijing metropolitan region, *Atmospheric Research*, 195 (2017) 31-43. http://dx.doi.org/10.1016/j.atmosres.2017.04.032
9. O. Jr. Pinto, I. R. C. A. Pinto, M. A. A. S. Gomes, I. Vitollero, A. L. Padilha, J. H. Diniz, A. M. Carvalho, A. C. Filho, Cloud-to-ground lightning in southeastern Brasil in 1993: geographical distribution, *J. Geophys. Res*, 104 (1999) 369-379.
10. U. Finke, T. Hauf, the characteristics of lightning occurrence in Southern Germany, *Beitr. Phys. Atmosph*, 69 (1996) 361-374.

11. L. R. Soriano, E. D. Pablo, E. G. Diez, Relationship between convective precipitation and cloud-to-ground lightning in the Iberian Peninsula, *Mon. Wea. Rev*., 129 (2001) 2998-3003.
12. L. R. Soriano, E. De Pablo, E. G. Diez, Relationship between geographical latitude and longitude and cloud-to-ground lightning flash characteristics in the Iberian Peninsula, *Atmosfera*., 15 (2002) 139-146.
13. Y. Yair, Z. Levin, O. Altaratz, lightning phenomenology in the Tel-Aviv area from 1989 to 1996, *J. Geophs Res*, 103 (1998) 9015-9025.
14. S. Soula, J. K. Kasereka, J. F. Georgis, C. Barthe, Lightning climatology in the Congo Basin, *Monthly Weather Ressource*, 178 (2016) 304-319. http://dx.doi.org/10.1016/j.atmosres.2016.04.006
15. H. J. Christian, R. J. Blakeslee, D. J. Boccippio, W. L. Boeck, D. E. Buechler, K. T. Driscoll, M. F. Stewart, Global frequency and distribution of lightning as observed from space by the optical transient detector, *J. Geophys. Res*, 108 (2003) 4005-4015.
16. H. Höller, H. D. Betz, K. Schmidt, R. V. Calheiros, P. May, E. Houngninou, G. Scialom, Lightning characteristics observed by a VLF/LF lightning detection network (LINET) in Brazil, Australia, Africa and Germany, *Atmospheric Chemistry and Physics*, 9 (2009) 7795-7824.
17. E. B. Houngninou, A. J. Adéchinan, M. Sounmaïla, K. F. Guédjé, H. Kougbéagbédé, C. S. U. Y. Allé, T. E. Houngninou, Relation Entre Éclairs Nuage-Sol et Précipitations Pendant la Mousson de 2006 au Bénin, *European Journal of ScientificResearch*, 115 (2013) 12-132.
18. A. J. Adéchinan, E. B. Houngninou, H. Kougbéagbédé, Relationships between lightning and rainfall intensities during rainy events in Benin, *International Journal of Innovation and Scientific Research*, 9 (2014) 765-776.
19. A. E. Lawin, A. Afouda, M. Gosset, Th. Lebel, Caractéristiques évènementielles des pluies en zone soudanéenne: apport des données à haute résolution AMMA-CATCH à l'analyse de la variabilité de la mousson Ouest africaine en climat soudanien, *Annales des Sciences Agronomiques du Bénin*, 13 (2010) 1-22.

(2019) ; http://www.jmaterenvironsci.com