Variation Of Lightning Activity Over Parts Of The Western Coast Of Africa

Abstract

This study examines the variation of lightning activity along the western coast of Africa using experimental VLF-WWLLN data collected over a five-month period in 2011. A total of 3,885 lightning strokes were analyzed across five geographical regions, spanning from southeastern Ghana to northeastern parts of the Democratic Republic of Congo. The results reveal substantial variability in lightning activity, with southeastern Ghana and southern Togo (Location A) showing consistently high activity levels, except for a marked decline in September. The region covering southern Nigeria and Cameroon (Location C) exhibited the highest peak in lightning activity in September, accounting for over 41% of total strokes that month. Conversely, the region encompassing parts of the Central African Republic and South Sudan (Location E) recorded the lowest activity throughout the study period. Seasonal trends indicate heightened lightning occurrences during the rainy season, with significant spikes in August and September across several regions. The findings offer critical insights into regional lightning dynamics, emphasizing areas prone to intense activity and temporal variations that align with seasonal weather patterns. These results are vital for enhancing lightning risk management, informing infrastructure design to mitigate damage, and contributing to the development of climate models for understanding atmospheric processes in coastal West Africa.

Keywords: Lightning activity, Thunderstorms, VLF-WWLLN data, Western Coast of Africa

Introduction

Lightning is a natural atmospheric discharge phenomenon characterized by high electric currents and luminous flashes that occur during thunderstorms. It is an atmospheric phenomenon generated by the build-up of large electric fields within anvil-shaped cumulonimbus clouds during thunderstorms, typically occurring at altitudes ranging from 15,000 to 25,000 feet above sea level. The resulting discharge is accompanied by the emission of visible light, perceived as flashes in the sky. Thunderstorms, characterized by the presence of lightning and the subsequent acoustic phenomenon known as thunder, are prevalent weather occurrences (Williams, 1992).

It poses significant risks to human life, infrastructure, and ecosystems due to its potential to cause fires, damage electrical systems, and even result in fatalities (Rakov and Uman, 2003). Understanding the spatial and temporal patterns of lightning activity is crucial for mitigating its impacts and improving safety measures, particularly in regions prone to frequent lightning strikes.

The western coast of Africa, extending from Ghana in the west to parts of the Democratic Republic of Congo in the east, experiences varying degrees of lightning activity influenced by geographical and meteorological factors unique to the region (Williams, 2001). This area is characterized by diverse landscapes ranging from coastal plains to tropical forests, each potentially influencing local weather patterns and lightning occurrence (Gora*et al.*, 2023).

Recent advancements in lightning detection technologies, such as the Very Low Frequency (VLF) World Wide Lightning Location Network (WWLLN), have provided researchers with comprehensive datasets to analyze lightning activity with high spatial and temporal resolution (Rodger *et al.*, 2009). The World Wide Lightning Location Network (WWLLN) represents a pivotal advancement in lightning detection technology, providing global data crucial for scientific, commercial and other applications (Holzworth*et al.*, 2019). Unlike other networks, WWLLN offers continuous monitoring of lightning strokes worldwide, detecting all types of strokes with peak currents exceeding approximately 40kA and maintaining consistent detection efficiency (Abreu*et al*., 2010).

Seasonal variations in lightning activity, particularly along the Gulf of Guinea, have been extensively analyzed. Orville and Spencer (1979) observed that lightning in this region peaks during the summer months, with a substantial portion occurring between October and April, and significant concentrations in December and January. Lightning activity is particularly pronounced at warmer latitudes, with up to 99.8% occurrence recorded in Bioko and 98.5% in Sao Tome during these months (Albrecht *et al*., 2016).

Jacobson *et al*. (2006) made a systematic evaluation of the performance of WWLLN, using a higher-frequency (0–500 kHz) detection array [the Los Alamos Sferic Array (LASA)] as a ground truth during an entire thunderstorm season in a geographically confined case study in Florida. It was found that: (a) WWLLN stroke-detection efficiency rises sharply to several percent as the estimated lightning current amplitude surpasses ∼30 kA; (b) WWLLN spatial accuracy is around 15 km, good enough to resolve convective-storm cells within a larger storm complex; (c) WWLLN is able to detect intra-cloud and cloud-to-ground discharges with comparable efficiency, as long as the current is comparable; (d) WWLLN detects lightning-producing storms with high efficiency in every 3-h epoch; thus, WWLLN can be useful for locating deep convection for weather forecasting on 3-h update cycles; and (e) WWLLN detects a stroke count in each storm that is weakly proportional to the stroke count detected by LASA.

Adebayo and Olaniyan (2022) investigated the patterns of lightning activity across West Africa by analyzing data obtained from both satellite observations and ground-based measurements. Their study, published in the *Journal of Atmospheric and Solar-Terrestrial Physics*, highlighted significant variations in lightning distribution over time and space within the region. The results revealed a higher frequency of lightning activity during the rainy season, with the coastal and forested areas experiencing more intense lightning events compared to the Sahel region. Spatial analysis indicated that regions with greater convective instability had heightened lightning activity. The authors concluded that these patterns are closely linked to seasonal weather systems, such as the West African Monsoon, and provided valuable insights for improving lightning prediction models and mitigating associated risks in the region.

Keenan and Bickford (2021) explored changes in lightning activity patterns across West Africa using high-resolution observational data. Their study, published in *Meteorological Applications*, revealed notable trends in lightning occurrences across the region. The results showed a marked increase in lightning activity over the past decade, particularly in urban and densely populated areas, likely influenced by urban heat island effects and localized convection. Temporal analysis indicated peak lightning occurrences during the late afternoon and early evening, correlating with peak convective activity. Spatially, the coastal zones experienced the highest lightning densities, while the Sahel region showed relatively lower activity. The authors concluded that these findings could improve understanding of the impacts of climate variability on lightning patterns and aid in developing region-specific lightning risk management strategies.

Asaeda and Kuroda (2021) examined the trends and patterns of lightning occurrences across Africa using long-term satellite data. Their research, published in the *International Journal of Climatology*, revealed significant spatial and temporal variations in lightning activity across the continent. The results showed a pronounced increase in lightning occurrences in tropical regions, particularly in Central Africa, which exhibited the highest lightning densities. Conversely, arid regions such as the Sahara showed minimal lightning activity. Seasonal analysis indicated that lightning activity peaks during the rainy season, closely aligning with convective weather systems. The study concluded that these patterns are influenced by climate variability and changes in atmospheric dynamics, providing critical information for understanding lightning's role in Africa's climatology and its implications for infrastructure and safety planning.

Harrison and McCormick (2020) explored how lightning influences regional weather patterns, focusing on the West African coast. Their study, published in *Climate Dynamics*, investigates the impact of lightning on local climatic conditions and weather systems in this specific region, highlighting its role in shaping regional meteorological phenomena.

Ndiaye and Diouf (2022) examined the spatial and temporal patterns of lightning activity in Senegal by analyzing data from both ground-based stations and satellites. Their study, published in the *African Journal of Atmospheric Science*, revealed distinct regional and seasonal variations in lightning activity across the country. The results showed that southern Senegal experiences the highest lightning frequencies, particularly during the peak of the rainy season, while northern regions have comparatively lower activity. Temporally, most lightning events occurred during late afternoons and evenings, coinciding with increased convective instability. The authors concluded that these patterns are strongly influenced by the West African Monsoon and localized weather systems, offering critical insights for improving lightning prediction and risk mitigation strategies in Senegal.

The global distribution of lightning activity, as detailed by Williams (1992) and supported by Glossary of Meteorology (1959), shows a prevalence in tropical regions, with approximately two-thirds of global lightning flashes occurring within the latitude interval ±23. Lay *et al*. (2007) further explored temporal variations in high peak current lightning over land versus ocean using WWLLN data, highlighting the network’s capability to elucidate differences in lightning occurrence across diverse geographic settings.

WWLLN’s utility extends beyond local studies; Erin *et al*. (2004) demonstrated its effectiveness in Brazil, accurately locating a significant percentage of lightning events with implications for severe storm research. Similarly, Okike and Collier (2011) utilized WWLLN data alongside cosmic ray observations to explore global lightning patterns, while Roldugin and Beloglazov (2008) investigated the potential links between cosmic rays and lightning using global datasets.In summary, the integration of WWLLN data has revolutionized the study of lightning activity, offering insights into regional variability, seasonal trends, and global distributions that are essential for advancing both scientific understanding and practical applications in atmospheric sciences.

Despite the importance of understanding lightning patterns in Africa, there remains a scarcity of detailed studies focusing specifically on the western coast. Existing research often covers broader continental scales or concentrates on specific countries or regions within Africa (Ajadi and Balogun, 2022). Therefore, a focused investigation into the variation of lightning activity along the western coast is warranted to fill this gap in knowledge.

This study aims to analyze and characterize the spatial and temporal variation of lightning activity over parts of the western coast of Africa using VLF-WWLLN data. By identifying hotspots of lightning activity, seasonal trends and geographical influences, this research seeks to contribute to improve lightning risk management strategies tailored to the specific conditions of coastal West Africa.

Materials and Method

Materials

The lightning data were sourced from the World Wide Lightning Location Network (http://wwlln.net). This network records the coordinates of each lightning strike it detects, and the data are organized into files sorted by date.

Method of Data Collection

To collect data, lightning activity from the World Wide Lightning Location Network (WWLLN) was analyzed for the study period of May through September 2011. Data were extracted specifically for the geographic range of 0-15°N latitude and 0-15°E longitude, excluding any WWLLN events outside these coordinates. The lightning data were then categorized into five regions:

i. A (0-15°N, 0-3°E)
ii. B (0-15°N, 3-6°E)
iii. C (0-15°N, 6-9°E)
iv. D (0-15°N, 9-12°E)
v. E (0-15°N, 12-15°E)

Each latitude range was further divided into five equal intervals:0-3°N, 3-6°N, 6-9°N, 9-12°N and 12-15°N. The percentage of lightning strikes within each designated location was calculated and presented in Tables 1 through 5. Variations in these percentages across the five months were illustrated using multiple bar charts (Figure 1).

Results and Discussion

Table 1: Latitude/Longitude and Number of Lightning Strokes in Each Location (May, 2011)

Location	Latitude (^{0}N)	Longitude (^{0}E)	Number of lightning strokes	Percentage of lightning strokes
A	0 – 15	0 – 3	217	30.91
B	0 – 15	3 – 6	168	23.93
C	0 – 15	6 – 9	157	22.36
D	0 – 15	9 – 12	89	12.68
E	0 – 15	12 – 15	71	10.11
		Total	**702**	

Table 2: Latitude/Longitude and Number of Lightning Strokes in Each Location (June, 2011)

Location	Latitude (^{0}N)	Longitude (^{0}E)	Number of lightning strokes	Percentage of lightning strokes
A	0 – 15	0 – 3	162	22.66
B	0 – 15	3 – 6	134	18.74
C	0 – 15	6 – 9	226	31.61
D	0 – 15	9 – 12	147	20.56
E	0 – 15	12 – 15	46	6.43
		Total	**715**	

Table 3: Latitude/Longitude and Number of Lightning Strokes in Each Location (July, 2011)

Location	Latitude (^{0}N)	Longitude (^{0}E)	Number of lightning strokes	Percentage of lightning strokes
A	0 – 15	0 – 3	164	20.97
B	0 – 15	3 – 6	166	21.23
C	0 – 15	6 – 9	248	31.71
D	0 – 15	9 – 12	153	19.57
E	0 – 15	12 – 15	51	6.52
		Total	**782**	

Table 4: Latitude/Longitude and Number of Lightning Strokes in Each Location (August, 2011)

Location	Latitude (^{0}N)	Longitude (^{0}E)	Number of lightning strokes	Percentage of lightning strokes
A	0 – 15	0 – 3	207	25.78
B	0 – 15	3 – 6	198	24.66
C	0 – 15	6 – 9	153	19.05
D	0 – 15	9 – 12	170	21.17
E	0 – 15	12 – 15	75	9.34

Table 5: Latitude/Longitude and Number of Lightning Strokes in Each Location (September, 2011)

Location	**Latitude (^{0}N)**	**Longitude (^{0}E)**	**Number of lightning strokes**	**Percentage of lightning strokes**
A	0 – 15	0 – 3	50	5.66
B	0 – 15	3 – 6	193	21.86
C	0 – 15	6 – 9	364	41.22
D	0 – 15	9 – 12	211	23.90
E	0 – 15	12 – 15	65	7.36
		Total	**883**	

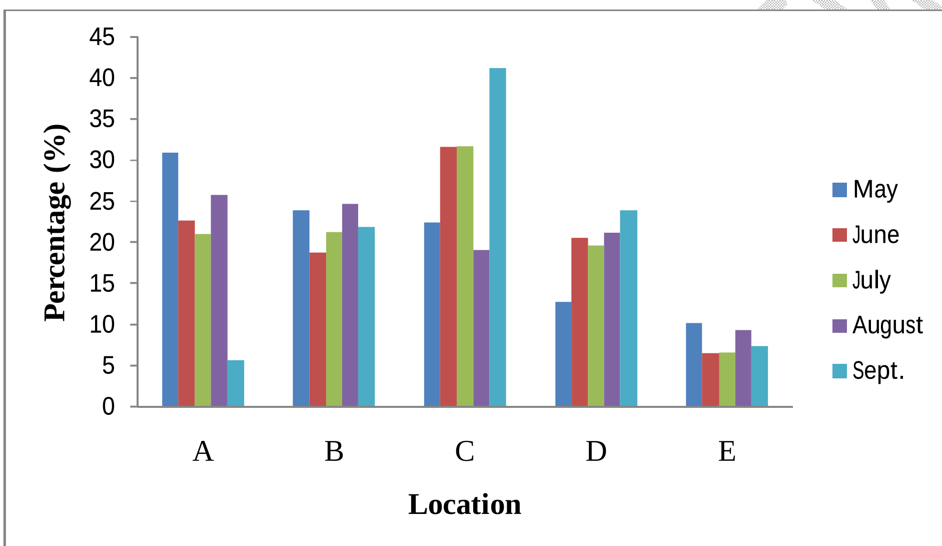

Figure 1: Multiple bar chart showing the variation of the total lightning strokes at different locations.

Table 6: Summary table showing the different locations and their respective lightning strokes over the months

LOCATION	**PERCENTAGE OF LIGHTNING STROKES**				
	MAY	JUNE	JULY	AUGUST	SEPTEMBER
A	30.91	22.66	20.97	25.78	5.66
B	23.93	18.74	21.23	24.66	21.86
C	22.36	31.61	31.71	19.05	41.22
D	12.68	20.56	19.57	21.17	23.9
E	10.11	6.43	6.52	9.34	7.36

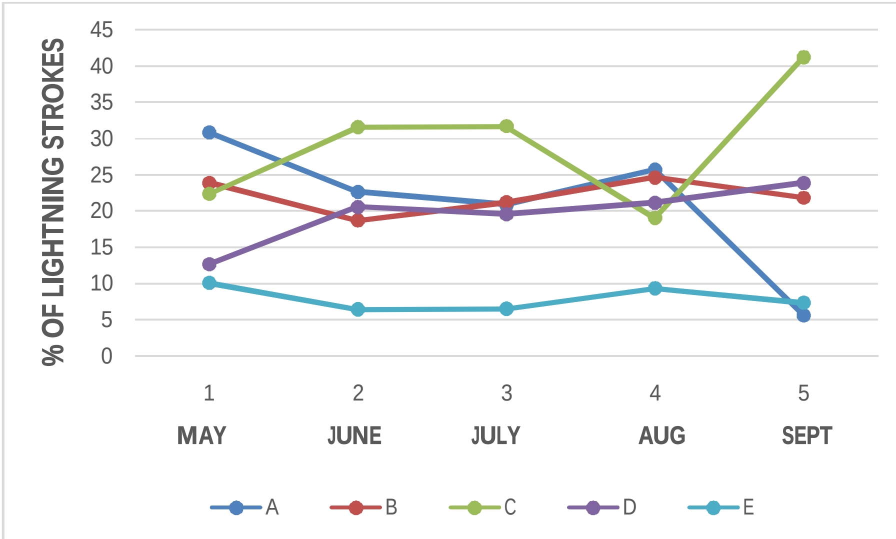

Figure 2: Line graph showing the trends of the lightning strokes variation over time at different locations within the Western Coast of Africa.

In the variation of lightning activity over parts of the western coast of Africa using experimental VLF-WWLLN data for the five months, the WWLLN data reported a total of 702 in the month of May, total of 715 in June, total of 782 in July, total of 803 in August and total of 883 strokes in September 2011 (Tables1,2, 3, 4 and 5).

Looking closely at the observations made (Figures 1 and 2), location A: latitude 0-15^{0}N and longitude 0^{0}E-3^{0}E (southeastern part of Ghana including the capital city Accra and southern parts of Togo including the city of Lomé) experienced a relatively high lightning activity except in the month of September which is significantly low.

Location B: latitude 0-15^{0}N and longitude 3^{0}E-6^{0}E (parts of southern Ghana, northern parts of Togo, southern parts of Benin, Lagos in the southern part of Nigeria) experienced almost the same level of lightning strokes with little fluctuations throughout the period of observations.

At location C: latitude 0-15^{0}N and longitude 6^{0}E-9^{0}E (cutting across Port Harcourt in southern Nigeria and City of Douala in southern Cameroon), a peak occurrence (a maximum of 41.22% of the total lightning strokes) was recorded in September within latitude 0-15^{0}N and longitude 6^{0}E-9^{0}E. Approximately the same level of lightning activity in the months of June and July were observed.

Throughout the period of our observations, the activity at location D:latitude 0-15^{0}N and longitude 9^{0}E-12^{0}E (city of Calabar in southern Nigeria, town of Kribi in southern Cameroon, northern parts of the Central African Republic and town of Nola) keeps increasing, except for the month of July where there is a little shift.

Location E:latitude 0-15^{0}N and longitude 12^{0}E-15^{0}E (the central and northern parts of the Central African Republic, southernmost parts of South Sudan, small portion of northeastern Uganda, northeastern part of Democratic Republic of Congo and parts of Ituri province) has significantly low lightning strokes throughout the stipulated period of observations.

Conclusion

The analysis of lightning activity along the western coast of Africa revealed varied patterns across different locations and months. Location A, encompassing southeastern Ghana and parts of Togo, exhibited high lightning activity consistently throughout most months, except for a notable decrease in September. Location B, covering southern Ghana, northern Togo, southern Benin, and Lagos, experienced relatively stable lightning stroke levels with minor fluctuations. Location C, spanning southern Nigeria and Cameroon, showed a peak in September, accounting for a significant portion of total strokes in that area. Location D, including southern Nigeria, southern Cameroon, and parts of Central African Republic, witnessed increasing lightning activity overall, except for a slight dip in July. Location E, covering parts of Central African Republic, South Sudan, Uganda, and Democratic Republic of Congo, recorded consistently low lightning strikes throughout the observation period. These findings highlight the regional variability and seasonal trends in lightning occurrences along the studied coastal areas of Africa.

Future research could focus on investigating meteorological factors influencing regional lightning variability, developing localized prediction models, monitoring long-term patterns to assess climate change impacts, and designing tailored lightning protection systems for high-activity regions.

Data Availability

The data underlying the findings of this research can be obtained from the corresponding author (J. N. Aniezi) upon a reasonable request.

Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript. The authors declare no conflict of interest related to this study.

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