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Relationships between lightning and insolation during monsoon season in Benin

Houngninou B. Etienne[1], Adéchinan A. Joseph[2*], Guédjé K. François[1], Onah M. Waïdi[1] and Kougbeagbede Hilaire[1]
[1]Département de physique, Faculté des Sciences et Techniques / Université d'Abomey-Calavi, Bénin
[2]Dépt. de physique, Faculté des Sciences et Techniques / Université Nationale des Sciences, Technologies, Ingénierie et Mathématiques, Bénin
adechinanjoseph@yahoo.fr

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Abstract

This work documents for the first time in Benin, the relationship between electrical activity of storms and insolation. The data used were collected for five months by the LINET network and by a Campbell-stokes type heliograph, installed at the synoptic station of Natitingou (North-West Benin). A linear regression model was used on a sample made from days with strong electrical activity. The main results obtained present a fairly good correlation between insolation and lightning intensity. The highest value (0.65) of the correlation coefficient is obtained with the cloud-to-ground lightning for 5% risk threshold within 15 km radius around the synoptic station of Natitingou.

Keywords: Lightning, Insolation, LINET, Heliograph, Relationships.

Introduction

The storm is a complex and dangerous meteorological phenomenon that involves several processes (dynamics, thermodynamics, microphysics, electrical, etc.). In view of the damages (material, human, environmental, etc.) caused by these discharges, their study has become over the years a major concern for the whole scientific community. Thus, numerous studies[1-6] have been carried out throughout the world to characterize the electrical activity of storms and to understand their manifestation. Much of this research focuses on the relationships between lightning and other parameters of storm, namely precipitations. Investigations on thunderstorm's electrical activity in relation to the triggering parameters of these natural phenomena are weak.

Initial work on a long series of data on the variability of stormy days in relation to solar activity have not been conclusive[7]. In Austria[8], used a large annual database to study the relationship between thunderstorm activity and solar activity. He showed that there is anti-phase correlated with the maximum in the thunder day data occurring just after the solar minimum and its minimum coinciding with the solar maximum. Working on two different sites[9], noted that the correlation coefficients obtained in Germany between lightning and solar activity are different from those obtained in Austria. They also concluded in 2001 that the correlation coefficient between solar activity and lightning frequency varies with the location of the observing station on Earth. More recently in Brazil[10], used a monthly thunder day data from seven cities to investigate the existence of a relationship between thunderstorm activity and solar activity. They concluded that solar activity has a strong influence on storms in Brazil.

Despite the contribution of the African continent to the global density of lightning is which the most important[11], the literature is still weak on the issues related to these discharges in West Africa. One of the main reasons for this is the inability of some African countries to meet the costs of the requisite equipment and even maintaining atmospheric observation systems. In Benin, the first in-situ lightning data were collected during the intensive period of AMMA (African Monsoon Multidisciplinary Analysis)campaign. Benin had the privilege of hosting one of measurement sites. The availability of this database combined with the existent insolation data provided by the ASECNA's (Agence pour la Sécurité de la Navigation Aérienne) synoptic station installed inNatitingou, offers the possibility to approach this study from an angle other than that presented in previous studies having available in-situ lightning data in Benin[5,6,12]. The present study is therefore an extension of the analysis of the in-situ electrical data collected during the AMMA campaign. Its main objective is to seek the possible relationship between insolation and lightning for the first time in this part of the globe.

Materials and methods

Materials: The study is carried out in Natitingou (1.37° E, 10.30° N) in the North-West of Benin (Figure 1, on left). The summer rainfall in this region is dominated by convective storms[6]. This area is essentially characterized by a dry season that goes from mid-March to October with a maximum of rain in August[6]. Two types of data were collected over a period from mid-June to mid-November 2006. The lightning data used stem from the LINET network. It combines a set of six stations, each of which has a GPS (Global Positioning System), a data acquisition system and an antenna operating in very low frequency range (Figure-1, on right).

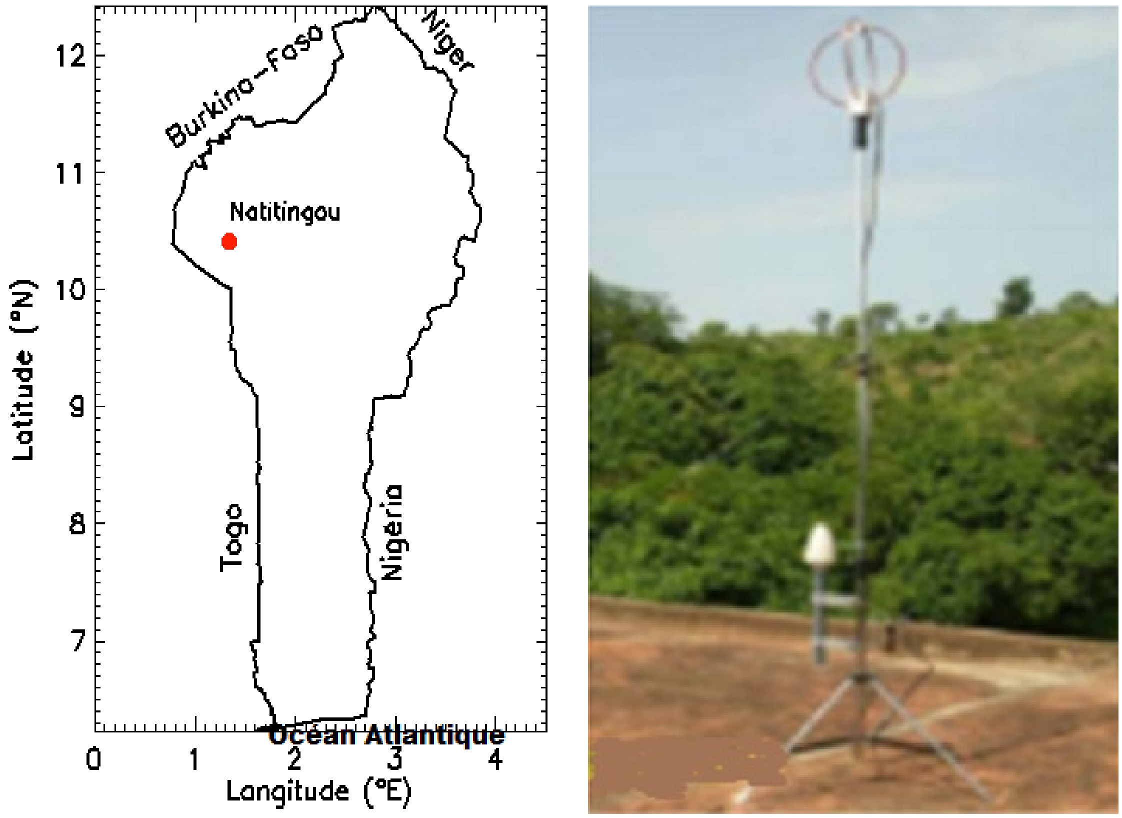

Figure-1: Location of the measurement site inside Benin and lightning sensor antenna installed on-site (Taken from Adéchinan A. J.'s doctorate thesis[13]).

The lightning detection system is based on the time difference of the arrival signal which requires at least three sensors. The mode of operation of this network is given in detail by Höller, H. and alt.[5]. The information provided to the nearest millisecond by the LINET network relates to the geographical position (longitude and latitude), the date and time of occurrence, the amplitude of the discharge current, the type of lightning (intra-cloud or cloud-to-ground lightning) without forgetting the height for discharges that do not reach the ground.

The daily insolation data are supplied by a Campbell-stokes heliograph installed at the synoptic station of Natitingou. This equipment is made of a glass sphere which concentrates the sun's rays on a standardized cardboard strip and placed on a support at its back (Figure-2). The discoloration or burning of the cardboard is measured after sunset. So, at the end of the day, the examination of the recordings is done by measuring the length of the trace burned by the sun. This length is expressed in time, since the diagram is graduated in hours.

The cardboard strip is immediately replaced by a new one for the next day measurement. The total duration of insolation of any day is thus obtained by adding together graphically on the edge of a diagram of the same type, the corresponding useful lengths of the partial traces taken in isolation and previously delimited by fine lines of pencil. The principle of operation of this apparatus is well detailed in many works[14,15].

Figure-2: Heliograph of Campbell-stokes use to collected insolation data.

Methodology: The parameters of the lightning concerned by the present study are the intensity of the discharge current and their occurrence. Since both series of data used do not possess the same temporal scale, our analysis take into account the daily and monthly variability. Thus, with flash data collected at the nearest millisecond, daily and average daily amplitudes of these landfills were determined. The average amplitude of negative currents was determined using the absolute value of corresponding data in our core files. In order to evaluate the impact of the spatial resolution on the desired correlation, three concentric circles of radius 5, 10 and 15 km were defined around the synoptic station of Natitingou.

The linear regression model was used to find out the link between selected parameters. Thus, the correlation coefficients at the daily scale over the entire period were calculated in each radius according to the types of flash and according to their polarity. These coefficients proved to be insignificant at the 5% risk level and in view of the large disparity in the scatter plot obtained, we have sampled the two initial data sets. This new sample is obtained from days with high electrical activity as proposed byH.Höller[16], following their study on the comparison of in-situ information collected by the LINET network in the same area and those provided by the LIS (Lightning Imaging Sensor) sensor onboard the TRMM (Tropical Rainfall Measurement Mission) satellite. Finally, on a day of strong electrical activity j, we attributed the insolation data of the day j-2 or j-1 and sometimes of the day j. Once the sample has been reconstituted and the correlation coefficients have been recalculated and JarqueBera's statistical tests in this case are done to verify the acceptability of obtained results.

Results and discussions

Variability of insolation and lightning during the monsoon: The variation of both the insolation and the number of lightning is shown on the same graph (Figure-3). As it can be seen on this figure, irrespective of the radius and the type of lightning considered, we note an increase in the occurrence of these electrical discharges during the first three months with a well-marked peak in the month of August. From this month onwards, there is a gradual decrease in the number of lightning until the monsoon is removed. The number of intra-cloud is always higher than that of the cloud-to-ground lightning.

Insolation, however, presents a monthly dynamic opposite to that of the number of flashes. There is a decrease in insolation from June to August. From this month we are observe a rapid increase in sunshine until November. The maximum electrical activity corresponds to the minimum of insolation. This observation could be explained by the simple fact that the month of August has been identified by many works[17,18] as the heart of the rainy season in our study area. This implies greater cloud coverage compared to other months of the year. Moreover, since electric discharges derive their source from the storm cloud, a greater electrical activity is recorded during this month. This result is perfectly in agreement with the observations made in this region by Adéchinan and alt.[6]. The trend observed with the number of lightning is similar to the monthly evolution of the mean amplitude of these electric discharges.

On a daily scale, it is generally noted that the number of daily lightning and the corresponding average amplitude vary very strongly. This observation is valid whatever the radius, type and polarity of the lightning considered. There is a general trend which suggests that the peaks of insolation precede the number of lightning and the corresponding average amplitudes, whatever the type and the polarity of the discharge in question.

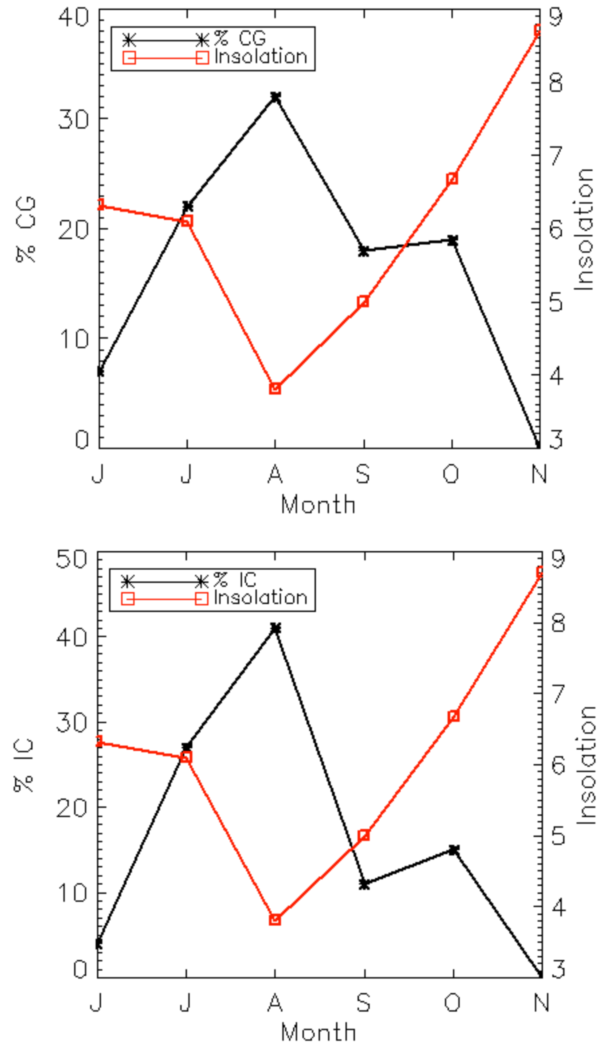

Figure-3: Monthly variability of insolation and the number of intra-cloud (IC)andcloud-to-ground (CG) lightning during the observation period.

Correlation between insolation and lightning: The series of daily lightning or corresponding average intensities of each type of lightning detected in the different rays considered as well as the insolation throughout the observation period were correlated. These correlations are made by a simple linear regression. Table-1 presents the results obtained considering recorded daily average intensities. The analysis shows that the correlation coefficients are roughly small and not significant. They vary between 0.12 and 0.45, with the highest value obtained within a radius of 15km around the synoptic station of Natitingou. These different values appear to be even lower with regard to the occurrence of these flashes. At this level, they vary between 0.03 and 0.40.

Table-1: Summary of the correlation coefficients obtained between the average intensity of lightning and the insolation on the whole of the primary data. The values in parentheses represent the p-value obtained in each case.

Lightning type	Polarity	5 km	10 km	15 km
Cloud-to-ground	Positif	0.18	0.22	0.14
	négatif	0.17	0.41	0.31
	all	0.26	0.19	0.26
Intra-cloud	positif	0.16	0.12	0.29
	négatif	-0.05	0.21	0.17
	all	0.17	0.40	0.45

In order to improve these coefficients, the days of high electrical activity were removed from the primary data to elaborate a new sample. The new values are summarized in Table-2. The analysis of this table shows a clear improvement of the values previously computed using primary data. In most cases, the correlation coefficient is statistically significant and vary between 0.12 and 0.65. The highest value of this coefficient is obtained with the cloud - ground lightning within a radius of 15 km.

Table-2: Summary of the correlation coefficients obtained between the average intensity of the lightning and the insolation after sampling of the primary data. The values in parentheses represent the p-value obtained in each case.

Lightning type	polarity	5 km	10 km	15 km
Cloud-to-ground	Positif	0.52 (9.97 10^{-2})	0.61 (1.08 10^{-2})	0. 56 (5.25 10^{-3})
	négatif	0.62 (2.04 10^{-3})	0.39 (1.08 10^{-2})	0.49 (2.19 10^{-4})
	all	0.60 (2.54 10^{-4})	0.59 (1.27 10^{-5})	0.65 (3.72 10^{-7})
Intra-cloud	positif	0.29 (0.17)	0.41 (0.01)	0.60 (1.38 10^{-4})
	négatif	0.12 (0.83)	0.58 (6.68 10^{-4})	0.45 (1.81 10^{-3})
	all	0.32 (0.20)	0.54 (3.86 10^{-4})	0.55 (4.76 10^{-5})

Figure-4a shows the case where the highest correlation coefficient was recorded. The linear regression line is adjusted to the scatter plot obtained within a radius of 15 km around the synoptic station of Natitingou. One can notice a line of increasing regression, sign of a positive relation between the correlated parameters.

The Jarque and Bera test on residual normality proved conclusive because the observed quantiles and the theoretical quantiles (obtained if the distribution is normal) form a straight line and the cloud of residues is correctly distributed (Figure-4b). The residuals and the predicted values are not correlated, proof that the conditions of the linear model used are validated. These observations are agreement with those made in Brazil by Pinto N.O. and alt[10].

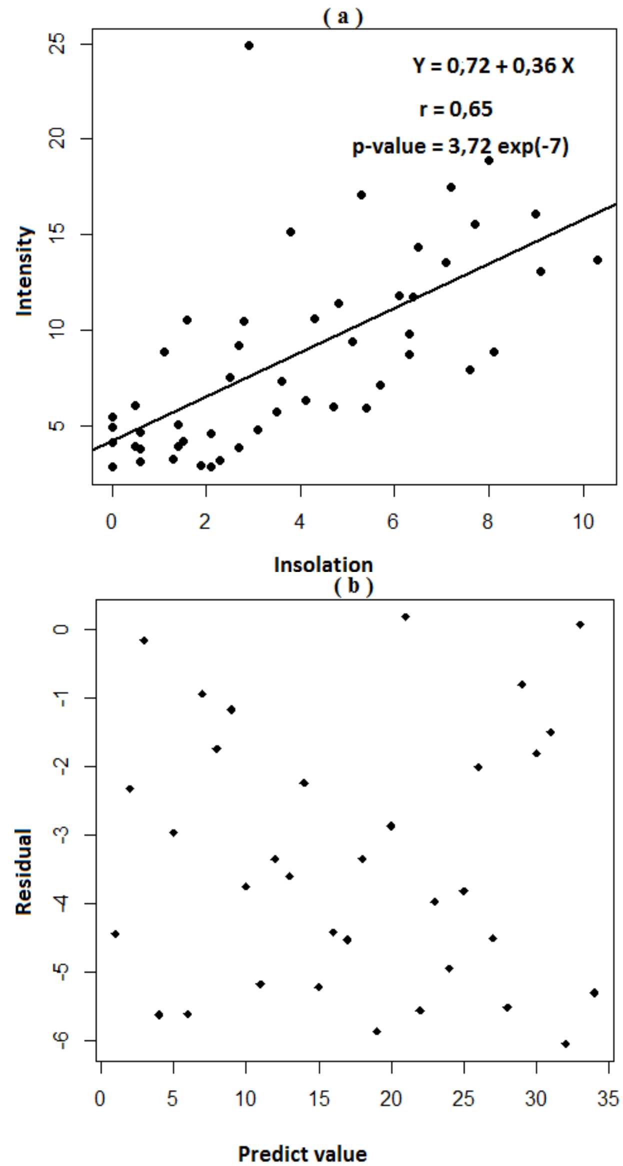

Figure-4: (a) Representation of regression line of least squares on dot points of cloud-to-groundlightning intensity (kA) andinsolation(in hour). (b) Residuals and the intensity predictedvalues plot.

Conclusion

The aim of this work is to investigate possible relationships between storm-induced electrical discharges and insolation. To achieve this, we used light data collected by the LINET network and, on the other hand, the insolation data provided by the heliograph installed at the Natitingou synoptic station.

The simple linear regression model was used to quantify the relationship between insolation and two intrinsic parameters of flashes, namely intensity and occurrence. The main results obtained show that of these two parameters, the most tributary of the insolation is the intensity. This observation is verified whatever the radius (5 km, 10 km or 15 km), the type of lightning (cloud-ground or intra-cloud) and the polarity of the lightning (positive or negative) considered. The highest correlation coefficient (0.65) is obtained with the cloud-ground lightning within a radius of 15 km around Natitingou synoptic station.

We think that taking into account other parameters (such as total net radiation, heat flux, irradiance, etc…), will certainly make it possible to improve these coefficients in order to reach a reliable prediction of the intensity of electric discharges from storm based on the knowledge of insolation data.

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