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LIGHTNING SIGNATURE AS AN INDEX FOR THE DETERMINATION OF THE BEGINING OF THE PLANTING SEASON IN NIGERIA

Nymphas, E.F., Adeniyi, M.O. Ogolo, E.O. and Oladiran, E.O.

Department of Physics, University of Ibadan, Ibadan, Nigeria.
* Adeyemi College of Education, Ondo, Ondo State, Nigeria.

ABSTRACT:- *West African rains are mainly due to the squall-line activities. Squall lines are groups of active thunderstorm clouds that are aligned with the ITCZ in front. The clouds are electrically active and 90% of lightning recorded occurs during squall lines associated thunderstorms. The results of measurements of lightning count from 1986 to date for Nigeria are presented in this work. Data obtained from other West African countries are also compared with them. The maximum lightning count occur mid-way between the north most position to the ITCZ and the ocean; shows a diurnal variation dependent on the movement of ITCZ that has very strong dependence on solar activities via evaporation and wind speed and direction. The minimum count is recorded during the ITCZ's recession and behind it. The applications to agricultural practices in West Africa are discussed.*

INTRODUCTION

Lightning as one of natural phenomena, is a disturbed weather activity displaying the electromagnetic manifestations resulting from cosmic rays (Ojo and Oladiran, 1996); atmospheric dynamical activities (Jennings and Latham 1974), streamer intensification (Oladiran, 1985); earth's magnetic fields and telluric currents (Webb, 1968, and Lobodin, 1968) and other planetary effects. In all cases, it is usually associated with rain (in solid and liquid forms) and dust storms. The varied causes indicate a spatial variation depending on the nature and topography of the earth's surface, the climate conditions prevailing and the human activities of the locality.

The seasonal weather variation in West Africa can be classified into two: the wet season and the dry season. The south westerlies supply about 90% of rainfall in West Africa via squall line activities. The peak rainfall period depends on the location – two peaks in the southern region (July and October), and one peak in the north (July).

In West Africa there are two types of thunderclouds: the warm and the cold thunderclouds. The top of the former has a temperature greater than 0°C while the top of the latter has a temperature less than 0°C (Oladiran, 1985). The ratio of warm to cold thunderclouds is of the order 1:9 and bring about 1/6 of the total rainfall. They are usually orographic rains.

The agricultural practices in West Africa are mostly rain fed. Irrigation accounts for less than 10%. In Nigeria, agricultural practices are predominantly based on traditional modes and the perceived long-term climatic changes: (i) by November through December, the farmers get their plots ready for planting hoping that the soil moisture would not be enough for premature vegetation growth during the remaining dry period; (ii) planting normally commences at the end of January/early February in expectation of rainfall in March, the accepted commencement of the raining season, without consideration of the abberative shifts in the beginning of rainfall brought about by El-Nino ENSO shifts, ITD movements and other regional weather modifications. These shifts have caused immense agricultural loses. By applying the lightning signature to fix the start of rainfall, we have demonstrated over a period of 8 years that it is a valid and more reliable index of fixing the start of rainfall and the results are presented in this paper; (iii) there are two seasons, the rainy (wet) season (April – October) and the dry season (November – March) with slight shifts in the months as one move from the south to the north. In the south, there is a short interval between the rainfall peaks of July and October known as the August break. This is the period when land is prepared for the second planting of crops such as maize, beans and millet.

The vegetation in Nigeria can be divided into three groups: (a) the forest areas situated in the swampy forests of the Delta regions of the south and those of the highlands extending to latitude 8°N. These sections will support perennial crops and annual/biannual crops. (b) The Savannah region, consisting mainly of grasslands and extending to the uppermost north of the country and bounded by the Savannah encroached areas (Middleton, 1987; Hamilton and Archibong, 1945). A 100-year rainfall analyses for Nigeria estimated the start of rainfall for various locations (Akintola, 1986) as shown in Table 1. The defect of this attempt is the wide range of uncertainty, which makes it inapplicable for most staple food crops (maize, millet, yam, rice, etc). Because of the paucity of data for forecasting, it has not been possible to validate these data for appropriate application. Also, because of tendency to failure (leading to crop loss) its application has either been completely abandoned or applied on a very limited basis. Lightning signature application has yielded accuracy greater than 85%, and the results are hereby presented for staple foods.

Therefore, an accurate determination of the start of the rainfall season, which is beneficial to agricultural practices, is desirable. Lightning index is the term used to estimate the beginning of rainfall season using the number of lightning discharge per cloud cell. The result of the variation of this lightning index for Nigeria is presented in this paper.

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Table 1: Expected mean onset dates of rainy season in Nigeria (After Akintola, 1986)

Location	Expected	Early	Late
Abuja	9-Apr	25-Mar	24-Apr
Agbor	18-Mar	3-Mar	2-Apr
Bauchi	5-May	20-Apr	20-May
Benin	17-Mar	2-Mar	1-Apr
Bida	20-Apr	5-Apr	5-May
Birni Kebbi	20-May	5-May	June 4
Calabar	2-Mar	15-Feb	17-Mar
Enugu	23-Mar	8-Mar	7-Apr
Gusau	27-May	12-May	11-Jun
Ibadan	21-Mar	6-Mar	5-Apr
Ibi	20-Apr	5-Apr	5-May
Ikeja	14-Mar	27-Feb	29-Mar
Ikom	8-Mar	21-Feb	23-Mar
Ilorin	10-Apr	26-Mar	25-Apr
Jos	15-Apr	31-Mar	30-Apr
Kaduna	20-Apr	5-Apr	5-May
Kano	30-May	15-May	14-Jun
Kontagora	29-Apr	14-Apr	14-May
Katsina	7-Jun	23-May	22-Jun
Lagos	11-Mar	24-Feb	26-Mar
Lake-Chard	9-Jun	25-May	24-Jun
Lokoja	5-Apr	21-Mar	20-Apr
Maigana	4-Jun	20-May	19-Jun
Markudi	10-Apr	26-Mar	25-Apr
Minna	22-Apr	7-Apr	7-May
Nguru	9-Jun	25-May	24-Jun
Ogoja	22-Mar	7-Mar	6-Apr
Ondo	19-Mar	4-Mar	3-Apr
Onitsha	20-Mar	5-Mar	4-Apr
Oshogbo	28-Mar	13-Mar	12-Apr
Owerri	16-Mar	1-Mar	31-Mar
Port/Harcourt	11-Mar	24-Feb	26-Mar
Potiskum	29-May	14-May	13-Jun
Sapele	15-Mar	28-Feb	30-Mar
Shinkafi	28-Apr	13-Apr	13-May
Sokoto	5-Jun	21-May	20-Jun
Warri	13-Mar	26-Feb	28-Mar
Yelwa	5-May	20-Apr	20-May
Yola	28-Apr	13-Apr	13-May
Zaria	3-May	18-Apr	18-May

Therefore, an accurate determination of the start of the rainfall season, which is beneficial to agricultural practices, is desirable. Lightning index is the term used to estimate the beginning of rainfall season using the number of lightning discharge per cloud cell. The result of the variation of this lightning index for Nigeria is presented in this paper.

Data Collection

For this study modified lightning flash counters with a range of 140km (Oladiran, *et al* 1988a) were deployed in 3 places over a period of 6years and were compared with available meteorological and agricultural data over the area of deployment. Ibadan was used as the primary center of study so that lightning density variation were also obtained for Ibadan.

Using our meteorological appreciation of this environment, deployment of the counters was tuned to periods of expected times of rainfall- e.g. for Port Harcourt and Lagos, counter was deployed in February; Minna (March); Kaduna (April) etc. so that early and local rains could also be monitored*. The arrangements were complimented by satellite data obtained from the International Institute of Tropical Agriculture (IITA) in Ibadan. The satellite data were cloud cover, temperature profile, vegetation cover, amount of precipitable water, rainfall, and dust loading (via extinction coefficient parameter). Presently, we are analyzing the ground and satellite data in order to determine the ground truth. For this we are grateful to European Space Agency and NASA Langley Atmospheric Sciences data center. Oral data from farmers of conditions leading to crop failure were collected. These are varied in accordance with type of crop and the season of planting.

RESULTS AND DISCUSSIONS

Results from many of the stations confirmed our earlier results for Ibadan, Calabar and Uyo, and we give a brief summary:

(a) The majority of storms that occur in the early morning exhibit characteristics that differ considerably from the other average storms (duration, rainfall intensity, lightning discharge distribution, (Oladiran, *et al* 1988b).

(b) Thunderstorms resulting from squall–lines have similar electrical characteristics even when vegetation of the locality differs (Oladiran and Aina, 1987).

(c) 85% of lightning occurs in the evenings, with long term average peak around 1800 hours local time, coinciding with the time of maximum rain current density and maximum point discharge density (Ette and Oladiran, 1980; Oladiran, *et al*, 1988b).

(d) The time interval between flashes over a long sequence of storms is normally distributed; while for a single storm it is Weibull distributed. The current results indicate that the parameters of the Weibull distribution are associated with the meteorological conditions, the orographic and vegetation conditions, and there is strong indication that industrial effluents also affect them (especially for data obtained for Ibadan, Lagos and Port Harcourt). The Weibull distribution can be represented in the form:

$$f(x)=\begin{cases}0 & ; \quad x\le c\\ \dfrac{b}{a}\left(\dfrac{x-c}{a}\right)^{b-1}\exp\left[-\left(\dfrac{x-c}{a}\right)^{b}\right], & x>c\end{cases}$$

$$F(x)=\begin{cases}0 & , \quad x\le c\\ 1-\exp\left[-\left(\dfrac{x-c}{a}\right)^{b}\right] & ; \quad x>c\end{cases}$$

where $f(x)$ is the probability density function, and $F(x)$ is the cumulative distribution.

In order to understand the local weather conditions and its effects on lightning counts, we give a sample characterization in Table 2 for rainfall duration characterization.

The parameters a, b and c are found to have the following properties:

(i) Shutte, *et al* (1987) had defined a as a scale factor. When 3 antennae ranges were deployed at Ibadan with ranges 43, 90 and 140 km, a was observed to decrease with increasing range (there was a 365 % variation). Since long range will imply inclusion of neighbouring, but unrelated storms, this is not surprising. Beyond a range of 368km, there is no

* The Nigeria meteorological stations were used for all counter deployments except for Ibadan

Table 2. Normalized variations of the Weibull parameters (The values were normalized with the corresponding values for Ibadan)

Storm duration (hrs)	Lagos			Port Harcourt			Kaduna			Minna		
	a	b	c	a	b	c	a	b	c	a	b	c
≤ 0.50	0.9	0.96	1.1	0.85	0.99	1.0	0.63	0.91	0.74	0.71	0.87	0.81
0.5 - 10	0.84	0.98	-	0.79	0.98	-	0.58	1.00	-	0.64	0.91	-
1.0 - 1.5	0.86	0.99	-	0.81	0.94	-	0.67	1.00	-	0.73	0.98	-
1.5 - 2.0	0.84	0.95	-	0.81	0.96	-	0.53	0.97	-	0.77	0.96	-
>2.0	0.85	0.97	-	0.83	0.98	-	0.59	0.96	-	0.68	0.93	-

significant correlation between long-range reading and the short-range reading (≤ 260km). We are unable to ascribe a reason for this behaviour.

(ii) The Weibull parameter b is very sensitive to the thundercloud characteristics as earlier reported (Oladiran, *et al* 1988a). It increases monotonically with the duration of the storm. When all the thunderstorms were grouped according to the time interval, Δt, between the first and the last recorded lightning flashes into the following groups: (a) $\Delta t \leq 30$ minutes (16%); (b) 30 minutes $< \Delta t \leq$ 1 hour (11%); (c) 1 hour $< \Delta t \leq$ 2 hours (43%); (d) 2 hours $< \Delta t \leq$ 4 hours (27%); and (e) $\Delta > 4$ hours (3%); the values of b shows a 430 % variation. The parameter b decreases monotonically from the time intervals (a) to (e). The average value of Δt for Ibadan is 137 minutes for a 12-year average, compared to an average of rainfall duration of 406 minutes. Similar results were obtained for 13 other locations in the country. It would appear that the thunderstorms in Nigeria are electricity active for only about a third of the time of their durations.

(iii) c is locally dependent. In our earlier report (Oladiran, *et al*, 1988b), we reported that for Ibadan the parameter c did not show any significant variation. In this study c is found to undergo a 560% variation from Port Harcourt to Jos, depending on such local condition of flatness, mountain, forest cover and metallic and radioactive minerals (since its value varies from one mountain area to another). In short, it is indicative of independence on local soil characteristics.

When a, b and c are compared for stations where characteristics are very similar it is amazing how close the values are. Hence, an algorithmic index of comparison of the weather of contiguous localities can be made. The data for Niamey and Kano shows a remarkable close relationship.

Prentice and Mackerras (1977) suggested a latitude dependence of the ratio of the number of cloud discharges to ground discharges of the form:

$$P = 0.05 + \frac{\sin\lambda + 0.05}{(N_{ID} + 3)^{\frac{1}{2}}}$$

where

$$P = \frac{1}{1 + N_c / N_g}, \qquad 3\,(b)$$

N_{ID} = number of thunder days
N_c = number of cloud discharges
N_g = number of ground discharges.

Note that Jos is about 1400 m (4230 ft) above sea level and has uranium deposits; Enugu has coal deposits and about 250 m (745 ft) above sea level. As earlier reported (Oladiran, *et al* 1988b) the ground flash density for Ibadan was 0.39 flashes per km². Applying the empirical relation of Prentice and Makerras (1977), the cloud flash density for Ibadan was estimated as 5.7 flashes per km². Using this method in conjunction with accumulated data yields Table 3 for other locations of Nigeria.

Table 3: Lightning density variation for different locations in Nigeria

Location	Ground flash Density (flashes/km²)	Cloud flash Density (flashes/km²)	N_c/N_g
Maiduguri	0.29	4.2	14.48
PortHarcourt	0.51	6.7	13.14
Lagos	0.53	6.9	13.02
Jos	0.61	7.9	12.95
Kano	0.31	4.8	15.48
Enugu	0.46	6.9	15

Using lightning count signatures the number of thunder days varies from 98 in Kano to 147 in Ibadan to 157 in Port Harcourt, the maximum number of thunder days is approximately located mid-way between the northern most position of the ITCZ and the ocean for land variation. Equation (3) has been validated for this area (Oladiran *et al* 1988b). When applied to our data obtained by use of plate and vertical antenna with ground and cloud lightning counting signals (Oladiran, *et al*, 1988c), the ratio $N_c N_g$ varies for Kano for liquid precipitation. We are unable to explain this variation theoretically. A casual inspection of equation (3) will show that $N_{TD} = N_{TD}(N_c, N_g)$ so that this equation is not as simple as it appears. Also, the constant 0.05 is a factor of uniformity, which we have not been able to test. Work on this is still going on. When compared with the start of the raining season, it is found that this thunder signature can correctly be used to predict the start of planting season as per Table 4.

Table 4: Start of rainy season as a function of number of days between rainfall, duration of rainfall and the lightning counts for maize, rice and millet

	Maize	Yam	Millet	Rice
Days between rainfall	≤ 3 days	≤ 7 days	≤ 5 days	≤ 3 days
No of lightning counts	≥ 7	≥ 24	≥ 16	≥ 5
Duration (minutes)	≥ 25	≥ 30	≥ 20	≥ 15

In this Table three parameters were used in determining the start of the rainy season: (i) the duration of rainfall; (ii) The number of lightning flashes, and (iii) the interval between successive rainfalls. Because many parts of Nigeria experience orographic rainfall, which are locally influenced by the degree of evapotranspiration, farmers tend to confuse these spurious rains with the start of rainfall.

We have found that it is not when the first rain falls that is very important but when the rains would be able to supply the necessary moisture for the growth of the crops. It was found that these criteria when applied were sufficient for the last 8 years for the crops indicated. We must indicate here that for areas where irrigation is available these stringent conditions need not be applied, but even when applied, the farmers were not at any disadvantage. In areas where there are double peaks in rainfall and some crops are planted twice, the first rainfall with duration greater than 30 minutes and with the same lightning characteristics will mark the start of the planting for this season.

We also found that the lightning flash count has a diurnal variation dependent on the movement of the ITCZ that has very strong dependence on solar activities via evaporation and wind speed and wind direction, a variation that is almost coincident with cosmic ray activities (Ojo and Oladiran, 1996).

Lightning Signal Characteristics

Lightning can be very destructive to installations via their transient effects on power lines, fire to buildings and installations, forest fires etc. In order to be able to protect sensitive installations (e.g. computers and the like) from such destructions we have to be able to filter out the frequencies corresponding to the regime of maximum energy dissipation. This is shown in Table 5.

Table 5. Weather characterization of lightning signals

Storm duration (hr)	Rainfall rate (max & mean.) (mm/hr)	Peak frequency. Range & mean. (kHz)	Average discharge per storm	No. of signals studied	% Distribution	Peak field KV/m
0-0.5	Max.186 mean.92	8.4-14.2 Av. 12.4	36	46	8	16
0.5-1.0	Max.138 mean.67	6.8-20.6 Av. 8.9	148	183	26	108
1.0-1.5	Max.105 mean.52	10-15. Av. 13.6	302	198	31	63
1.5-2.0	Max.156 mean.43	9.3-21.8 Av.10.3	185	104	22	38
> 2.0	Max.122 mean.29	6.5-22.7 Av. 7.8	87	83	13	13

With the above characterization, protection based on appropriate cascaded screening as suggested by Ette, *et al*, (1978) or the modified Franklin rod arrangement of Nymphas (2001) will achieve the desired protection.

CONCLUSIONS

From the above analysis we draw the conclusion that the use of lightning signals for applications to agricultural practices is feasible, cheap and accurate. Soil type is known to affect the lightning properties of an area.

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