

# Interconnection Between Lightning Activity and Cosmic Ray Intensity in the Climatic Changes and Farming Seasons in Imo State

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**Abstract:** Lightning as one of the natural phenomena, is a disturbed weather activity displaying electromagnetic manifestations resulting from cosmic rays and atmospheric dynamical activities. There is an association of lightning activity linked to cosmic ray intensity, the amount of atmospheric water vapour, and its relation with climatic change in Imo state. The monthly energy outflow of the electromagnetic lightning and the corresponding vapour pressure were used to carry out linear regression analysis. There is a strong positive correlation between the two variables. Our result show that the distribution of lightning is directly linked to the Earth's climate, which is driven by solar insolation. The seasonal heating of secondary cosmic rays and lightning results in large fluctuations in temperature, influencing atmospheric stability and the amount of atmospheric water vapour. It depicts that the seasonal heating by the lightning activity linked to cosmic ray intensity is proportional to the atmospheric vapour pressure. Hence, very high amounts of lightning are possible in deep water clouds. The variation of lightning index linked to cosmic ray intensity and other climatic variables in Imo state can be beneficial to agricultural practices, as it will help to monitor the level of atmospheric water content and the beginning of rainfall season. Thus, this work and findings will inform and assist the farmers and especially government agencies in making policies for adaptation.

**Keywords:** Cosmic Ray, Lightning, Climate Change, Vapour Pressure

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## 1. Introduction

It has been proposed that Earth's climate could be affected by changes in cloudiness caused by variations in the intensity of galactic cosmic rays in the atmosphere [7]. This proposal stems from an observed correlation between cosmic ray intensity and Earth's average cloud cover during one solar cycle. Physical mechanisms have been proposed to explain how cosmic rays could affect clouds, but they need to be investigated further if the observation is to become more than just another correlation among geophysical variables [6].

However, there are concerns that some natural events such as cosmic rays and geomagnetic activities might have some influence on climate change [18].

Cosmic rays: a stream of very high energetic particles emanating mainly from outside the solar system [12] interact with the magnetosphere with a fraction of it penetrating inwards into the earth's atmosphere. Produced from various astrophysical processes, cosmic rays consist of 99% protons and alpha particles and approximately 1% of heavier nuclei [9]. It has been reported that cosmic rays are responsible for the continuous production of a number of unstoppable

isotopes in the earth's atmosphere [15].

From what was revealed, there is a relationship between cosmic rays and sunshine hours in the south-east and south-southern parts of Nigeria; the relationship is however very low with a correlation coefficient of 0.3. The implication of these results is that cosmic rays may be a factor influencing the climate of the regions under review, although its impact might be little and weak [17]. Further studies on the effects of cosmic rays on other weather parameters such as: rainfall, surface temperature, wind speed, etc. were recommended by them to give better insight on this subject of interest [10].

In a suggestion, cosmic rays play a major part in climate change through ionization of the air forming aerosols which may grow into cloud condensation nuclei (CCN) [14]. This CCN exerts a strong effect which can lower or raise the world's mean temperature [13]. This shows that a possible connection exists between cosmic rays (CR) and temperature, which is directly linked to sunshine hours, relative humidity and vapour pressure.

Besides, the distribution of lightning around the planet is directly linked to the Earth's climate, which is driven by solar insolation. The diurnal and seasonal heating of the continental landmasses results in large fluctuations in temperature, influencing atmospheric stability and the development of thunderstorms [2]. The importance of lightning for climate studies is increasingly recognized. Thunderstorms are major players in the global redistribution of water substances, a key mediator of both short and long wavelength radiation [19].

It has been argued in the technical literature, and widely reported in the popular press, that cosmic ray air showers (CRASs) can initiate lightning via a mechanism known as relativistic runaway electron avalanche (RREA), where large numbers of high-energy and low-energy electrons can cause the local atmosphere in a thundercloud to transit to a conducting state [5]. The observed cloud-to-ground electromagnetic lightning discharge has a fluctuating power and impulsive nature when propagating through atmosphere. The electromagnetic wave in line with lightning discharge has a significant factor that attenuates its power outflow. Partial differential and integration processes have to be applied to Maxwell's Equations for this investigation [16]. When lightning strikes a tree, the grounding (earthing) volume beneath the tree canopy within the soil is proportional to the energy of a strike. This energy surge has human and animal health and tree root consequences. The voltage across the ground contacts 50 feet from a tree lightning strike is approximately 2,000 volts [8]. This implies that there could be a possible relationship between cosmic rays, lightning activity, weather, and by extension the climate.

Water vapour is the most important greenhouse gas in the earth's atmosphere. Without it, the average temperature of the earth would be  $-17^{\circ}\text{C}$ . In particular, the earth's climate is extremely sensitive to changes in the amount of upper troposphere water vapour (UTWV); and global temperature influences the fluctuation of rainfall [5]. The agreement between the variability of regional/global lightning activity

and regional/global UTWV concentrations suggests that single-station measurements of the Schumann resonance could supply a cheap, continuous, long-term measure of the variability of UTWV [11].

Lightning has been directly observed or inferred on all giant planets, generally accepted to be occurring in their water clouds. For Uranus and Neptune, depending on their convective structures, very high rates of lightning are possible in deep water clouds; while deeper than on Jupiter or Saturn, lightning is predicted likely to peak above the water cloud base, at pressures around 100 bar [19].

Currently, farming seasons and climate change are threatening farming opportunities to feed a growing population. This makes it necessary for the investigation of the physical nature of lightning activity and cosmic ray variations in different time scales which affects farming. Faster variations of the order of minutes to hours and days, can be associated with solar transient events, geomagnetic disturbances, and Earth's atmospheric phenomena. The atmospheric effects on the flux of secondary particles of cosmic rays (CR) cannot be ignored [3]; the pressure and temperature effect produce significant variations noting that the internal energy shift is temperature dependent [4].

To ameliorate plant performance and reach the potential yield in a controlled environment, these systems should be based on the fine control of all microclimatic factors, among which vapour pressure deficit (VPD) plays a major role [1].

## 2. Materials and Methods

### 2.1. Sources of Data

Mexico City Observatory (<http://132.248.105.25/index.php>) is the source of highly energetic cosmic ray intensity data emanating from supernova explosions. The monthly data of vapour pressure was obtained from Nigerian Meteorological Agency (NIMET) for the study area (Imo State).

### 2.2. Materials Used

Cosmic ray intensity data.

Vapour pressure data.

The work of Dorman, 2004:

$$\left(\frac{\Delta I}{I}\right)_{p_v} = \beta \cdot \Delta p_v \text{ or } I = I_0 e^{\beta \cdot \Delta p_v} \quad (1)$$

where  $\left(\frac{\Delta I}{I}\right)_{p_v} = \frac{dI}{I}$  is the normalized deviation of the cosmic ray intensity related to the pressure effect.

$\Delta p_v$  is the atmospheric pressure deviation.

$\beta$  is the barometric coefficient, which depends on many factors, such as the nature of the secondary CR and the altitude where the observation is performed.

The work of Umahi, 2013 (power  $P$  in electromagnetic lightning discharge at time  $t$ ):

$$P = -P_0 e^{2j\omega t} \quad (2)$$

where  $P_0 = \frac{4\epsilon_0 v_L^2 K_c I}{z}$ ,

$\epsilon_0$  is the permittivity of free space in  $C^2 s^2 kg^{-1} m^{-3}$ .

$v_L$  is the speed of lightning discharge.

$K_c$  is the Coulomb's constant.

$I$  is the impulse; and attenuation coefficient,  $n \propto K_c \cdot I$

$z$  is the lightning discharge location (this location  $z$  is longitude and latitude dependent).

$j$  is the current density.

$W$  is the energy outflow.

Negative sign accompanying the electromagnetic discharge in equation (2) indicates that the electromagnetic wave is retarded towards the earth surface.

### 2.3. Method of Data Analysis

The cosmic ray intensity data were collected for a period of twelve months (year 2021). Linear regression analysis was carried out using the cosmic ray intensity data and vapour pressure data in Imo State. Both were presented in a logarithmic scale, where  $I$  is the cosmic ray intensity and  $p_v$  is the vapour pressure, which is the hidden driver behind plant morphofunctional traits in controlled environments. This gave us a straight line equation of the form:

$$\log I = m \log p_v + c,$$

where  $c$  is the intercept and  $m$  is the slope,

We related our results to the work of Dorman, 2004. This entails the mathematical relationship guiding the cosmic ray (CR) intensity, the atmospheric pressure deviation, and the barometric coefficient, which depends on many factors, such as the nature of the secondary CR and the altitude where the observation is performed.

On the other hand, the power  $P$  of electromagnetic lightning discharge at time  $t$  was considered.

The varying amplitudes of the electromagnetic lightning discharge are within the lightning discharge location  $z$  (Imo state: Lat. 4.75-7.25°N and Long. 6.83-7.42°E). Thus, the energy outflow,  $W$  of the electromagnetic lightning discharge was obtained in each month considering the respective vapour pressure  $p_v$ , land area  $A$  of Imo state and the electric potential  $V$  of lightning discharge.

Linear regression analysis was carried out using the monthly energy outflow  $W$  of the electromagnetic lightning and the corresponding vapour pressure  $p_v$ .

## 3. Results

Table 1. 2021 Monthly data of cosmic ray intensity and vapour pressure in Imo State.

MONTH	CR INTENSITY (I)	log I	VAPOUR PRESSURE (p <sub>v</sub> )	log p <sub>v</sub>
January	613,954,703	8.7881	24.0353	1.3808
February	555,819,569	8.7449	27.9059	1.4457
March	617,951,753	8.7910	30.2118	1.4802
April	598,555,713	8.7771	30.7529	1.4879
May	616,270,651	8.7898	30.2941	1.4814
June	595,115,186	8.7746	29.5588	1.4707
July	612,336,964	8.7870	28.8353	1.4599
August	612,607,621	8.7872	28.7294	1.4583
September	592,202,579	8.7725	29.1529	1.4647
October	612,030,630	8.7868	29.5412	1.4704
November	590,237,869	8.7710	29.2882	1.4667
December	612,118,652	8.7868	26.5529	1.4241

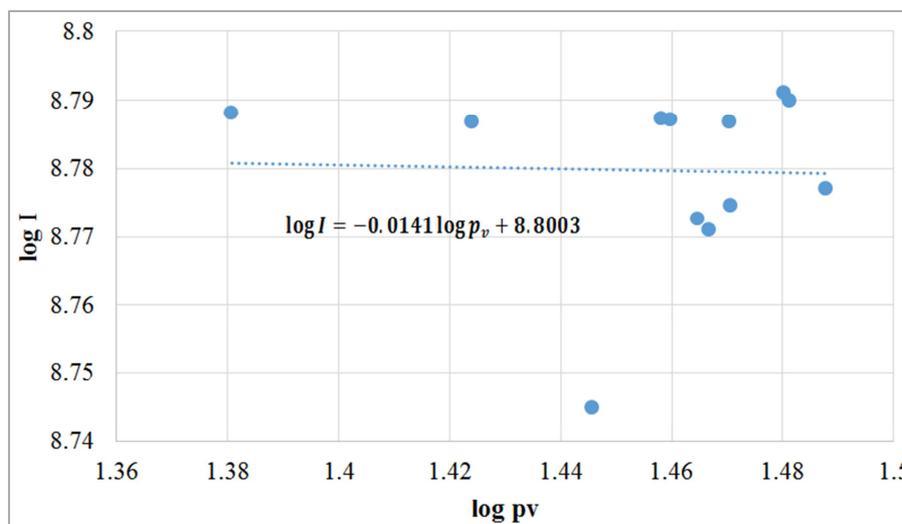


Figure 1. Plot of CR intensity  $I$  and Vapour pressure,  $p_v$  in Imo State.

The regression equation for Figure 1 becomes:

$$\log I = -0.0141 \log p_v + 8.8003 \quad (3)$$

According to Dorman (2004), the barometric effect is experimentally determined by the equation:

$$\frac{dI}{I} \propto \Delta p_v \text{ or } \frac{dI}{I} = \beta \cdot \Delta p_v \quad (4)$$

Taking the integral of both sides in equation (4), considering the variations in the cosmic ray intensity, we have:

$$\int_{I_0}^I \frac{dI}{I} = \int \beta \cdot \Delta p_v \quad (5)$$

Equation (5) becomes:

$$\ln\left(\frac{I}{I_0}\right) = \beta \cdot \Delta p_v \quad (6)$$

$$\frac{I}{I_0} = e^{\beta \cdot \Delta p_v} \quad (7)$$

$$I = I_0 e^{\beta \cdot \Delta p_v} \quad (8)$$

$$I = \beta \cdot \Delta p_v + \log I_0 \quad (9)$$

This equation (9) above is similar to our result (equation 3), where:

$\log I_0 = 8.8003 =$  the intercept.

$\beta = -0.0141 =$  barometric coefficient, which depends on many factors, such as the nature of the secondary CR and the altitude where the observation is performed.

$\Delta p_v =$  atmospheric pressure deviation.

Bearing in mind that cosmic rays can initiate lightning, we compared equations (1) and (2) as follows:

$$\beta \Delta p_v = 2jWt \quad (10)$$

Substituting for  $\beta = -0.0141$ , we have:

$$\Delta p_v = (141.84) \cdot jWt \quad (11)$$

Recall that the current density,  $j = \frac{I}{A}$  and the quantity of charge,  $Q = It$ , equation (11) becomes:

$$\Delta p_v = (141.84) \cdot \frac{QW}{A} \quad (12)$$

Considering the land area of Imo state (study area),  $A = 5530km^2 = 5530000000m^2$ , we have:

$$\Delta p_v = (2.57 \times 10^{-8}) \cdot QW \quad (13)$$

Sustututing for  $Q = \frac{W}{V}$  and  $V = 2000$  volts (voltage across ground contacts 50 feet from a tree lightning strike) into equation (13), it gives:

$$W = \sqrt{(7.78 \times 10^{10}) \cdot \Delta p_v} \quad (14)$$

Equation (14) shows the relationship between the energy outflow  $W$  of the electromagnetic lightning discharge and the vapour pressure deviation,  $\Delta p_v$  (see Table 2 and Figure 2).

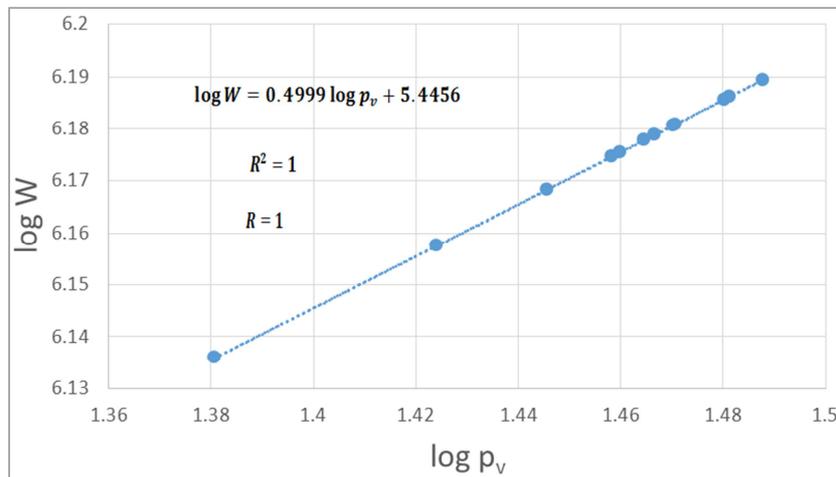


Figure 2. Plot of Lightning energy outflow  $\log W$  and Vapour pressure,  $\log p_v$ .

Table 2. Monthly values of the estimated energy outflow  $W$  of electromagnetic lightning discharge and vapour pressure,  $p_v$  in Imo State.

MONTH	VAPOUR PRESSURE ( $p_v$ )	$\log p_v$	ENERGY OUTFLOW, $W$ OF LIGHTNING DISCHARGE	$\log W$
January	24.0353	1.3808	1,367,459.8129	6.1359
February	27.9059	1.4457	1,473,458.1840	6.1683
March	30.2118	1.4802	1,533,126.8832	6.1856
April	30.7529	1.4879	1,546,795.2741	6.1894
May	30.2941	1.4814	1,535,213.6594	6.1862
June	29.5588	1.4707	1,516,467.8170	6.1808
July	28.8353	1.4599	1,497,793.8243	6.1755
August	28.7294	1.4583	1,495,040.9091	6.1747

MONTH	VAPOUR PRESSURE ( $p_v$ )	$\log p_v$	ENERGY OUTFLOW, $W$ OF LIGHTNING DISCHARGE	$\log W$
September	29.1529	1.4647	1,506,019.7940	6.1778
October	29.5412	1.4704	1,516,016.2796	6.1807
November	29.2882	1.4667	1,509,510.5034	6.1788
December	26.5529	1.4241	1,437,294.5488	6.1575

The regression equation for Figure 2 above is:

$$\log W = 0.4999 \log p_v + 5.4456 \quad (15)$$

with a good correlation coefficient,  $R = 1$ .

Simplifying equation (15) further, we took anti-log on both sides to obtain:

$$W = 10^{(0.4999 \log p_v + 5.4456)} \quad (16)$$

Opening the bracket in equation (16), we obtained:

$$W = 10^{(0.4999 \log p_v)} \times 10^{5.4456} \quad (17)$$

Re-arranging equation (17), it gives:

$$W = (1.0 \times 10^{5.4456}) \cdot 10^{(0.4999 \log p_v)} \quad (18)$$

$$W = (1.0 \times 10^{5.4456}) \cdot 10^{\log p_v \cdot 0.4999} \quad (19)$$

$$W = (1.0 \times 10^{5.4456}) \cdot p_v^{0.4999} \quad (20)$$

Equation (20) simply suggest that the energy outflow of the electromagnetic lightning  $W$  varies with the vapour pressure,  $p_v$  according to the relation:

$$W \sim p_v^\psi \quad (21)$$

where  $\psi$  is the slope of the plot which represents the volume of water level in the atmosphere.

## 4. Discussion

In the investigation of the interconnection between lightning activity and cosmic ray intensity in the climatic changes and farming seasons in Imo state, there is a good correlation coefficient ( $R = 1$ ). This shows that there is a positive relationship between the two events. Looking closely to our results, equation (21) shows the relationship between the monthly energy outflow  $W$  of the electromagnetic lightning and the corresponding vapour pressure  $p_v$ . Thus, the lightning activity is proportional to the atmospheric vapour pressure in Imo State.

Our result show that very high rates of lightning are possible in the deep water clouds; and lightning is predicted likely to peak above the water cloud base. In the other word, farmers can predict the farming season by monitoring the rate of occurrence of lightning activity.

Besides, our result show that the distribution of lightning is directly linked to the Earth's climate, which is driven by solar insolation. The seasonal heating of secondary cosmic rays and lightning results in large fluctuations in temperature, influencing atmospheric stability and the amount of atmospheric water vapour.

Our results support the work of Hare *et al.* (2017) and

Colin (2008): “that cosmic ray air showers can initiate lightning activity; and there is a possible relationship between cosmic rays and sunshine hours”.

In our work, a new and different approach was taken to investigate the interconnection between lightning activity and cosmic ray intensity in the climatic changes and farming seasons in Imo state. This result has attempted to solve to some extent the recommendation given by Okoye *et al.* (2018) that: “further studies should be done on the effects of cosmic rays on other weather parameters such as: rainfall, surface temperature, vapour pressure, wind speed, etc. to give better insight on this subject of interest.

Hence, this variation of lightning index in Imo state can be beneficial to agricultural practices, as it will help to monitor the level of atmospheric water content and the beginning of the rainfall season.

## 5. Conclusion

There is a high positive correlation between lightning activity linking CR fluxes and atmospheric vapour pressure. This work and findings will inform and assist the farmers and especially government agencies in making policies for adaptation.

## Data Availability

The data that supports the findings of this research are available from the corresponding author (Aniezi, J. N.), upon reasonable request.

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