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Preliminary Investigation of Total Ozone Column and Its Relationship with Atmospheric Variables

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Abstract

This study attempts to investigate the interaction between lower and upper atmosphere, employing daily data of Total Ozone Column (TOC) and atmospheric parameter (cloud cover) over Nigeria from 1998-2012; in order to study the dynamic effect of ozone on climate and vice versa. This is due to the fact that ozone and climate influence each other and the understanding of the dynamic effect of the interconnectivity is still an open research area. Monthly mean daily TOC and cloud cover data were obtained from the Earth Probe Total Ozone Mass Spectroscopy (EPTOMS) and the International Satellite Cloud Climatology Project (ISCCP)-D2 datasets respectively. Bivariate analysis and Mann Kendall trend tests were used in data analysis. MATLAB and ArcGIS software were employed in analyzing the data. Results reveal that TOC increased spatially from the coastal region to the north eastern region of the country. Seasonally, the highest value of TOC was observed at the peak of rainy season when cloud activity is very high, while the lowest value was recorded in dry season. These variations were attributed to rain producing mechanisms and atmospheric phenomena which influence the transport and distribution of ozone. Furthermore, the statistical analysis reveals significant relationship between TOC and low and middle cloud covers in contrast to high cloud cover. This relationship is consistent with previous studies using other atmospheric variables. This study has given scientific insight which is useful in understanding the coupling of the lower and upper atmosphere.

Keywords

Total Ozone Column, Cloud Cover, Ozone Depletion, Atmospheric

Variables, EPTOMS, Nigeria

1. Introduction

Ozone is one of the gases that make up the Earth's atmosphere. It comprises about 0.0012% of the total mass of the Earth's atmosphere [1] [2]. Ozone is found in the upper stratosphere at about 15 to 48 km above the Earth's surface. The concentration varies from about 2 to 8 parts per million (ppm) based on altitude and season.

Ozone plays a vital role in the survival of life on Earth as it shields the Earth from harmful solar ultraviolet (UV) radiation. In fact, without ozone, Earth would have been a difficult place for habitation [3]. The efficiency of the absorption of solar UV by Total Ozone Column (TOC) depends on the thickness of the ozone layer. This thickness which is the total amount of ozone in a column of air extending from the surface to the top of the atmosphere is known as Total Ozone Column [4].

About 90% of ozone is found in the stratosphere, approximately 10 - 50 km above the Earth's surface. Apart from the ozone in the stratosphere (*i.e.* stratospheric ozone), about 10% of ozone also exists in the troposphere about 10 km from the Earth's surface in a lower concentration (*i.e.* tropospheric ozone). Higher concentrations of tropospheric ozone are harmful and a threat to human health and the environment. This is because tropospheric ozone acts as a very powerful pollutant in the troposphere [4]. Therefore, ozone in the lower atmosphere is an indication of pollution and, hence a clear indicator of air quality. Ozone is also one of the greenhouse gases. Hence, it contributes to global warming and climate change [5].

Stratospheric ozone is measured using satellite. A spectrophotometer (the Dobson meter) is also used to measure ozone from the Earth's surface [3]. The most common unit of measurement is the Dobson Unit (DU), which is the columnar density of a trace gas in the Earth's atmosphere. According to [6], one Dobson Unit (DU) is a layer of gas that is 10 μm thick at standard temperature and pressure.

The formation and destruction of ozone is a natural process. With this natural balance, the amount of ozone in the stratosphere is maintained [5]. However, over the years, it was reported that the ozone layer has been depleted due to the release of harmful substances from human activities. In line with that, there have been a series of warnings as well as awareness by different agencies on the danger of releasing harmful chemicals, capable of destroying the ozone layer [7].

Many research works have been carried out on stratospheric ozone depletion [3] [8] [9], ozone layer depletion and climate change [10] [11], variability of TOC [2] [6] [12] [13] [14], variability of ozone and solar activity [15], and TOC and climatic parameters [16] [17] [18], among others. According to [3], depletion of ozone, as well as pollution of ground-level ozone, poses a serious threat to the quality of life on Earth.

Reference [14] noted that the variability of tropical TOC was linked to the equatorial stratospheric Quasi-Biennial Oscillation. He concluded that TOC was less during the easterly phase and high during the westerly phase of Quasi-Biennial Oscillation. Reference [17] reported that there was significant interconnectivity between TOC variability with precipitation and temperature. Similarly, using rainfall, temperature, sunshine hour, and relative humidity as atmospheric parameters, [18] observed good relationship between TOC and these parameters over the study area.

Working on long-term temporal trends and spatial distribution of total ozone over Pakistan from 2003-2011, [2] observed that TOC varied from 275 - 278 DU in the southern regions to 297 - 300 DU in the Northern Province. Furthermore, the highest value was observed in the summer season (JJA) with the lowest in the winter season (DJF). Similarly, [6] recorded the highest amount of Ozone (344 DU) over Kathmandu in March and the minimum value (219 DU) in December. Reference [19], observed the maximum value of 287.80 DU between July and August and minimum value of 192.73 DU between December and March in Lagos from 1997-2005. A similar result was reported by [16].

According to [13], ozone varies from day to day, season to season and year to year. Therefore, the thickness of the ozone layer varies with time. Reference [16] observed that in Nigeria, column ozone thickness has been decreasing at an average rate of about 0.32 DU per year.

Reference [20], noted that larger percentage of human population lives in the tropical region where the amount of UV radiation received is very high. Thus, it is good to continuously investigate the variation of ozone in the tropical region. This probably depicts the need for more studies on the variation of ozone in the tropical region like Nigeria. Hence, this study investigates the spatio-temporal variability of TOC over Nigeria.

This research is very significant as it hopes to give information on the variation of ozone over the country; due to its location in the tropical region close to the equator where the intensity of solar radiation is very high. The objectives of this research were: 1) To assess the spatio-temporal variability of TOC over Nigeria; 2) To assess the distribution of ozone if it is above the baseline value (220 DU) chosen as the starting point for ozone hole; 3) to use cloud cover as one of the climatic variables to investigate the relationship between TOC and climatic parameter. This depicts the teleconnection between lower and upper atmosphere.

Nigeria is located in West Africa between latitudes 4˚N - 14˚N and longitudes 2˚E - 15˚E. It occupies an area of about 923,768 km^2. The country experiences high temperature due to its location in the tropical region close to the Equator, where the Sun is overhead twice a year. It experiences two seasons, dry and rainy seasons. The climatic and atmospheric conditions over Nigeria are greatly influenced by the interplay of the tropical-continental air mass (originating from the Sahara desert) and the tropical-maritime air mass (originating from the Atlantic Ocean) [21]. Considering the significant role of stratospheric ozone in the atmosphere and the impacts of its depletion, it is very important to assess its variation; thus, the need for this study.

2. Sources of Data and Method of Data Analysis

Monthly mean daily TOC data for Nigeria were obtained from the Earth Probe Total Ozone Mass Spectroscopy (EPTOMS) from the NASA TOMS website. The data spanned for 15 years (1998-2012). Monthly mean daily global cloud cover data (*i.e.* high, middle and low clouds) based on infrared radiation (IR) measurement, spanning from 1998-2009 (12 years) were obtained from the International Satellite Cloud Climatology Project (ISCCP)-D2 datasets. The periods, 1998-2012 and 1998-2009 considered in this study was largely due to the data available to the researcher. The data were analysed as follows.

Daily TOC datasets for 20 stations in Nigeria were extracted from the global TOC data using MATLAB. Time series analysis was performed to compute monthly mean TOC ($\bar{M}_s$) from the daily values (D_s) using Equation (1).

$$\bar{M}_s = \frac{1}{n}\sum_{i=1}^{n} D_{si} \tag{1}$$

where n is the number of days in the month (*i.e.* 28, 29, 30, or 31 as the case may be).

Subsequently, spatial distribution of TOC over Nigeria were determined by Inverse Distance Weighting method using ArcGIS software 10.2. Annual mean TOC ($\bar{A}_s$) from 1998-2012 were computed from the monthly mean daily values using Equation (2), while Mann Kendall trend test was employed to determine the significance of the trend.

$$\bar{A}_s = \frac{1}{12}\sum_{i=1}^{12} \bar{M}_{si} \tag{2}$$

Furthermore, the averages of the monthly cloud covers for high, middle and low clouds were computed from the monthly mean daily dataset using Equation (1). Standard errors were computed for TOC and cloud covers. Finally, a statistical (bivariate) analysis was performed to investigate the relationship between TOC and cloud covers from 1998-2009 (for both data) at 0.05 significant level.

3. Results and Discussion

The results of the analyses are shown in **Figures 1-7** and **Tables 1-5**, while the standard errors are presented as vertical bars in the plots. It could be observed that TOC increases from the coastal region to the north eastern region of the country (**Figure 1**). This distribution is opposite to the rainfall pattern across Nigeria based on the two seasons experienced in the country [22]. The lowest value (259.1 - 259.8 DU) for the period under study was observed in stations

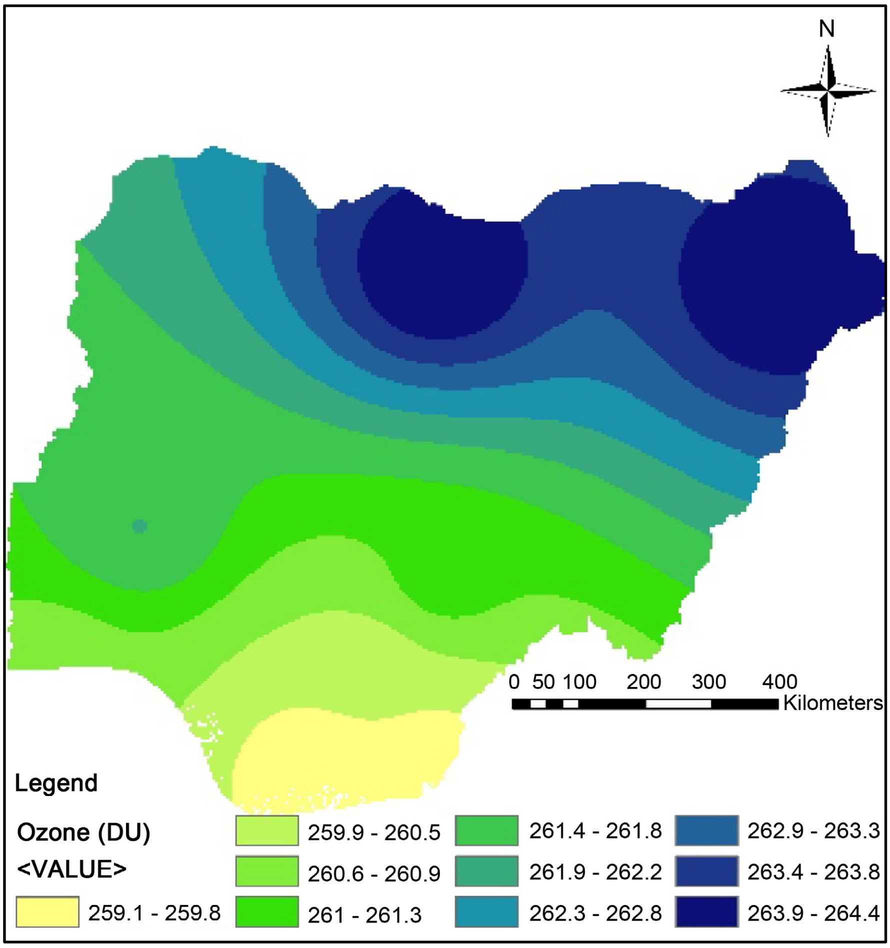

Figure 1. Spatial distribution of overall averages of TOC over Nigeria (1998-2012).

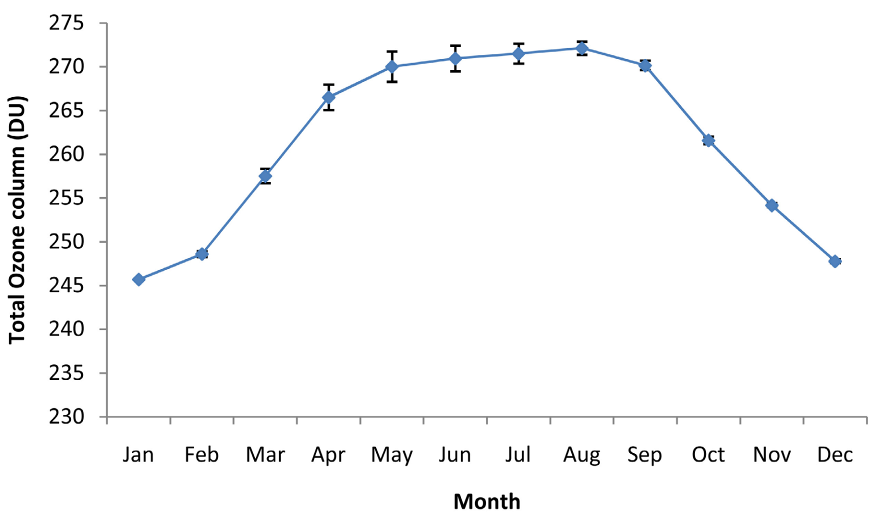

Figure 2. Variations of monthly averages of TOC over Nigeria (1998-2012).

such as Calabar, Oyo, Port Harcourt, Delta, etc. in the coastal region, while the highest value (263.9 - 264.4 DU) were recorded in stations such as Maiduguri, Gombe, Dutse, etc. in the north eastern region. It is interesting to note that the

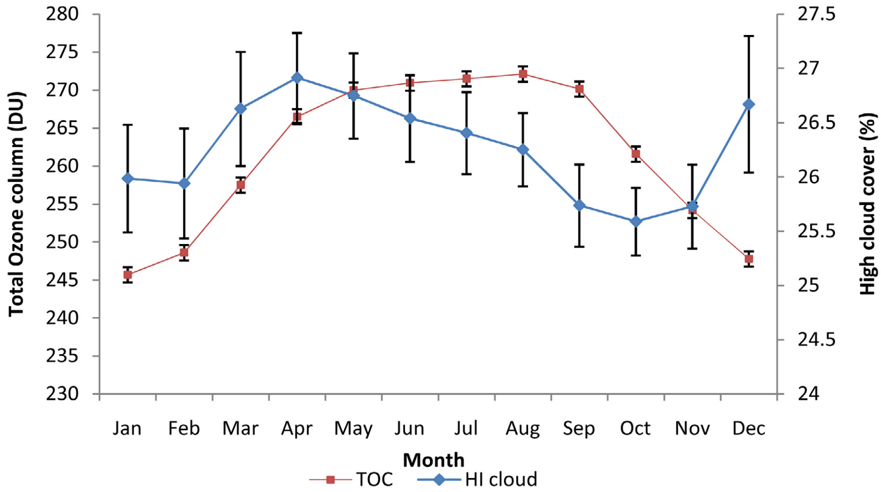

Figure 3. Comparison between monthly averages of Total Ozone Column (TOC) and high cloud (HI) (1998-2009).

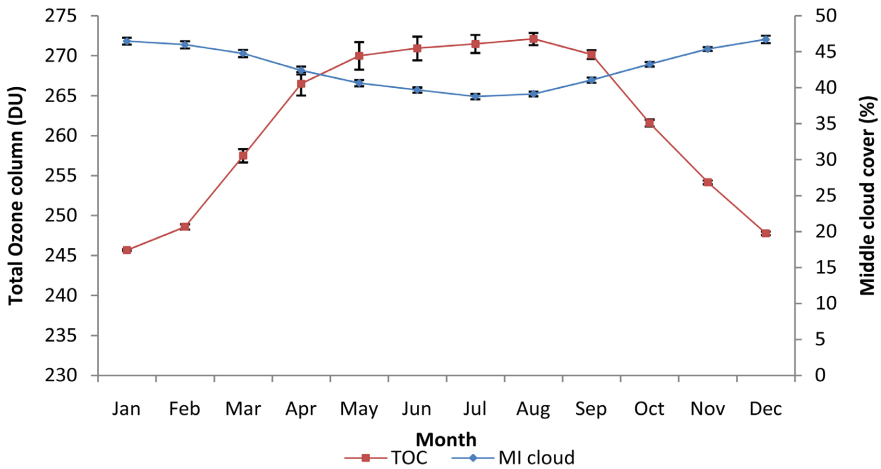

Figure 4. Comparison between monthly averages of Total Ozone Column (TOC) and Middle Cloud (MI) (1998-2009).

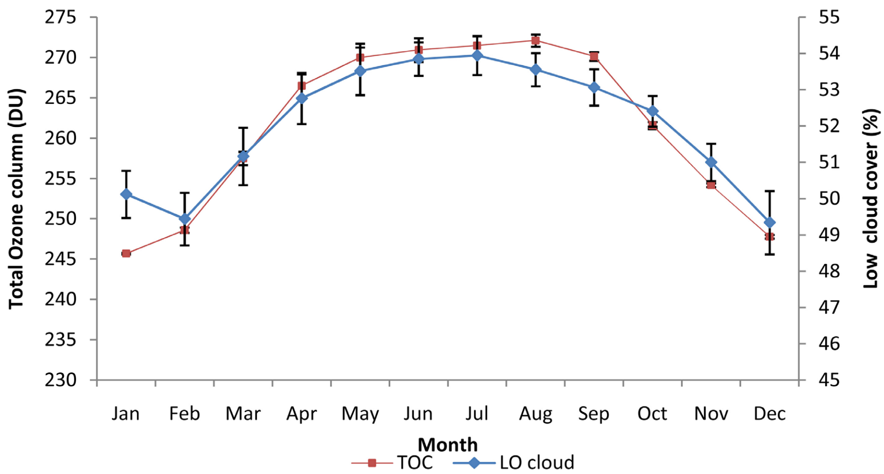

Figure 5. Comparison between monthly averages of Total Ozone Column (TOC) and Low Cloud (LO) (1998-2009).

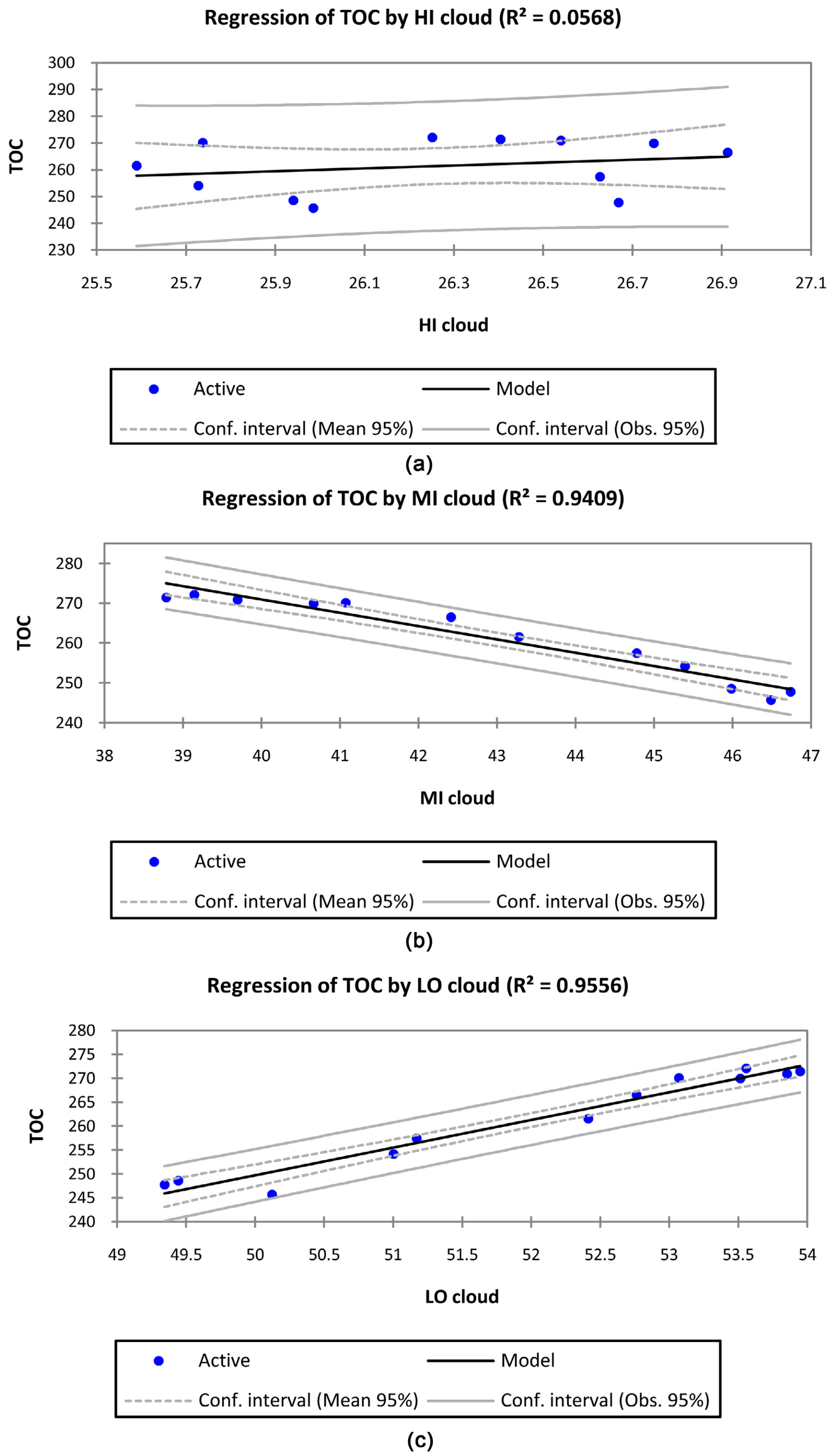

Figure 6. Plot of monthly averages of TOC with (a) high, (b) middle, and (c) low clouds.

TOC varies with latitude (*i.e.* TOC increases as the latitude increases and vice versa). This was also observed by other researchers [6].

The spatial distribution of TOC so observed may probably be attributed to the

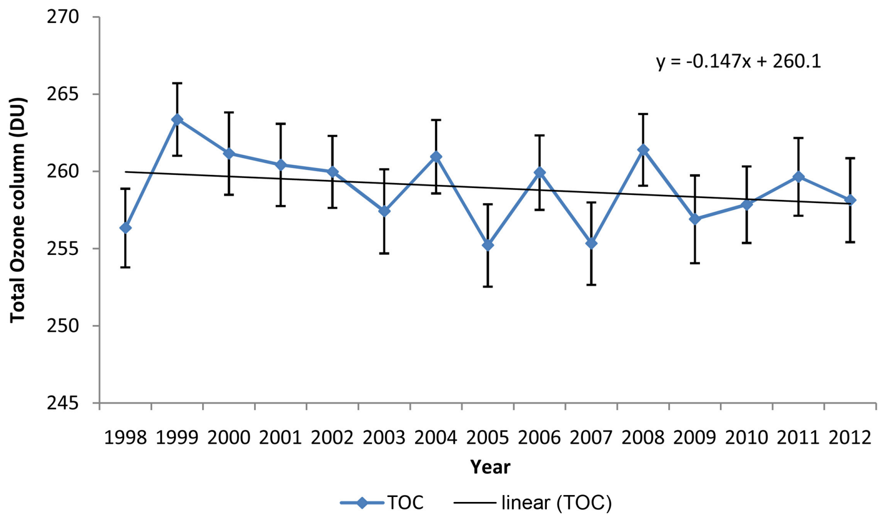

Figure 7. Temporal trends of averages of annual mean TOC over Nigeria (1998-2012).

Table 1. Correlation coefficient, r of TOC with cloud covers.

		HI Cloud	MI Cloud	LO Cloud
Total Ozone Column (TOC)	Pearson Correlation	0.238	−0.970**	0.977**
	Sig. (1-tailed)	0.213	0.000	0.000

**Correlation is significant at the 0.05 level (1-tailed).

Table 2. Regression model analysis of cloud cover.

Cloud type	Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
HI cloud	1	0.238[a]	0.0568	−0.029	0.45890
MI cloud	2	0.970[a]	0.9409	0.941	0.72288
LO cloud	3	0.977[a]	0.9556	0.951	0.38177

[a]Predictors: (Constant), Ozone.

Table 3. Empirical relations between TOC and cloud cover.

Cloud type	Empirical relations	R Square
HI cloud	TOC = 120.03273 + 5.38231 × HI cloud	0.0568
MI cloud	TOC = 404.45585 − 3.33758 × MI cloud	0.9409
LO cloud	TOC = −40.10288 + 5.79593 × LO cloud	0.9556

seasonal variation of global solar intensity incident on the Earth's atmosphere, due to the interplay of the two air masses controlling the climatic and atmospheric conditions over Nigeria. According to [17], the rate of production of ozone depends on the intensity of global solar radiation incident on the Earth's atmosphere. Many researchers have reported that the formation and destruction of stratospheric ozone are due to photochemical processes, while its distribution

Table 4. Testing the significant level of the regression model.

	Model	Sum of Squares	df	F	Sig.
	Regression	0.145	1	0.687	0.426[b]
1	Residual	2.106	10		
	Total	2.251	11		
a. Dependent Variable: HI cloud					
b. Predictors: (Constant), Ozone					
	Regression	91.718	1	175.519	0.000[b]
2	Residual	5.226	10		
	Total	96.944	11		
a. Dependent Variable: MI cloud					
b. Predictors: (Constant), Ozone					
	Regression	31.193	1	214.028	0.000[b]
3	Residual	1.457	10		
	Total	32.651	11		
a. Dependent Variable: LO cloud					
b. Predictors: (Constant), Ozone					

Table 5. Contribution of cloud cover to the regression model.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	23.432	3.414	0.254	6.863	0.000
	Ozone	0.051	0.053		0.829	0.426
a. Dependent Variable: HI cloud						
2	(Constant)	114.072	5.379	−0.973	21.209	0.000
	Ozone	−0.272	0.021		−13.248	0.000
a. Dependent Variable: MI cloud						
3	(Constant)	10.491	2.840	0.977	3.693	0.004
	Ozone	0.159	0.051		14.630	0.000
a. Dependent Variable: LO cloud						

is through transport process; based on the variations of weather pattern of the region. Besides, the variation of total ozone was linked to photochemical coupling between ozone and temperature [10]. Thus, we tend to suggest that the variation of global solar intensity due to changes in climatic and atmospheric conditions may probably explains the spatial distribution of TOC over Nigeria as observed in this study.

From **Figure 2**, TOC increases gradually from January to its peak in August. It then decreases steadily from August to December. Total Ozone Column is very high during the rainy season with the highest value in August (272.12 ± 0.75 DU). This coincides with the peak of the tropical rainy season over West African region (*i.e.* from June - September). This may be due to the high intensity of solar radiation incident on the Earth's atmosphere during this period; resulting in the high production rate of ozone [6]. On the other hand, TOC is relatively low during the dry season with the lowest value in January (245.69 ± 0.10 DU). This also coincides with the period of dry season over West Africa region (i.e. from November to March).

It is pertinent to note that the seasonal variation of TOC (**Figure 2**) is similar to the variations of rainfall across Nigeria [22]. That is, heavy rainfall during the rainy season (April - October) with little or no rainfall during the dry season (November to March). This implies that TOC has similar seasonal variation trend with rainfall patterns in the country.

The seasonal variation of TOC so observed is consistency with the report of several researchers [2] [6] [12] [16] [19] who observed maximum TOC during rainy season/summer season (JJA) with the minimum value in the dry/winter season (DJF). Furthermore, the values of the TOC obtained in this study are within the range reported by other scholars [2] [6]. This shows that our result is consistence with previous studies.

We tend to suggest that the variation of TOC so observed may probably be linked to factors influencing rain formation. It is a known fact that rain producing mechanism controls the formation of rainfall. From the findings of [17], they reported that rain producing mechanism and atmospheric phenomena influence the distribution and transport of ozone. This could be the possible reason for the seasonal variations of TOC observed in this study.

The averages of the overall mean of TOC variations over Nigeria for the period under study was 261.38 ± 0.73 DU. This value is above the baseline value of 220 DU chosen as the starting point for ozone hole. The term "ozone hole" is applied to regions where stratospheric ozone depletion is so severe that its value fall below 220 DU. Normal ozone is about 300 - 350 DU. Therefore, the spatial distribution of ozone over Nigeria so observed, depicts that ozone is not depleted and it is not above the normal value.

Some scholars have reported significant relationship between TOC variability and climatic variables like precipitation and temperature [17] [18] [23]. However, non-have used cloud cover which is also a climatic variable. Based on the similarity observed in the seasonal variability of TOC and the seasonal patterns of rainfall across the country, we investigate the relationship between TOC and cloud covers (high, middle and low clouds); since the maximum TOC was observed in August, the peak of cloud activities.

Global cloud cover data were used in this study since we could not obtain cloud cover data for high, middle and low clouds for Nigeria. From the monthly variation of TOC and high cloud cover (**Figure 3**), it depicts that no relationship exist between TOC and high cloud cover. Similarly, middle cloud cover varied in opposite direction with TOC (**Figure 4**). On the other hand, low cloud cover has a similar variation pattern with TOC as shown in **Figure 5**.

Statistical analysis was performed using a Special Programme for Social Science (SPSS) to ascertain the level of the relationship between TOC and cloud covers at 0.05 significant level. The correlation coefficient, R obtained between TOC and high, middle and low cloud covers are 0.238, −0.970 and 0.977 respectively (**Table 1** and **Table 2**). This implies that high cloud is positively but weakly correlated with TOC, middle cloud is negatively but strongly correlated with TOC, while low cloud is positively and strongly correlated with TOC. This was further confirmed from the linear regression analysis using straight line probabilistic model. The result of the analysis is presented in **Figure 6**, while the empirical relation between TOC and cloud covers is shown in **Tables 3-5**. It could be observed that a linear relationship exists between TOC and cloud covers (**Tables 3-5**). This relationship may be due to the fact that cloud influence the formation of rainfall and rainfall on the other hand may be link to TOC. This suggests possible relationship between TOC and cloud cover.

According to [24], low and middle clouds have a long-term association between water content and cloud cover; in contrast to other cloud types which show little association. In addition, low clouds are the only recognized rain producing clouds since they comprise primarily of liquid water droplets with little or no supercooled water droplets unlike middle and high clouds [25] [26]. This implies that low clouds influence rain formation. This may probably be the reason for the significant positive relationship between TOC and low cloud covers observed in this study.

Reference [17] reported that rain producing mechanism and atmospheric phenomena such as extratropical suction pump (ETSP) affect the transport and distribution of ozone. Rain producing mechanism over West Africa region such as the moist south westerly from the Atlantic Ocean enhances ozone acculation; leading to a high amount of ozone during the rainy season. The north easterly, on the other hand, depletes ozone; leading to a low amount of ozone during the dry season. This possibly explains the seasonal variation of TOC observed earlier.

The reduction in the strength of extratropical suction pump (ETSP) action was reported to affects the transportation of ozone. According to some scholars [10] [19], the ETSP affect the distribution of ozone during the tropical rainy season. Similarly, [17] observed that the prevalence of active weather system which enhances the transportation of ozone from the tropical stratosphere to the mid and high latitudes during the peak of tropical rainfall was linked to TOC and rainfall. This depicts that a significant relationship exists between TOC and rainfall.

This is consistency with [23] who observed a positive correlation between rainfall amount and total ozone over Kodaikanal of Tamilnadu in India. This shows that the variability of TOC is due to rain producing mechanism and atmospheric phenomena which influence the transport and distribution of ozone.

This could be the connection between TOC and climatic variables.

From the foregoing, we tend to suggest that a possible link exist between rainfall and TOC; and since cloud influences rain formation, it implies that a relationship may also exists between TOC and cloud cover. This might be the possible reason for the relationship between cloud cover and TOC as observed in this study. We therefore, recommend further studies using cloud cover data of the study area instead of the global data.

It is interesting to note that many researchers have used other climatic variables to study the relationship between TOC and climatic variables as stated earlier. The result of this study is in conformity with the findings of [16] [17] [18] [23] [25] [27] [28] [29], who used sunshine hour, rainfall, precipitation and temperature as climatic variables to investigate the interconnectivity between TOC variability and variation of climatic variables.

A decreasing trend was observed in the annual mean variation of TOC over Nigeria as shown by the linear plot (**Figure 7**). From the Mann Kendall trend test, the trend is not significant at 0.05 level. This confirmed the result of [16], who observed decreasing trends in the variation of ozone over Nigeria from 1997-2005. This could be attributed to the slow recovery of stratospheric ozone due to the long lifetime of the precursor molecules [9]. In contrast, an increasing trend was reported in the long-term variability of TOC over Kathmandu by [6]. The findings of this study has given scientific insight which will be useful in understanding the coupling of the lower and upper atmosphere.

Generally, the relationship observe between TOC and cloud cover in this study is in conformity with the significant relationship reported between TOC and other climatic variables by [17] [18] [23] [30]. By comparing the seasonal and spatial distribution of TOC with climatic variables over Nigeria, TOC has similar and opposite variation trend with climatic variables as reported earlier. Reference [18] [23] [30] have obtained both direct and inverse relationships between TOC and climatic variables. We hereby recommend further studies to ascertain the seasonal and spatial distribution of TOC with climatic variables in low, middle, and high latitudes as well as other tropical region; as this will enhence the understanding of the interconnectivity between the lower and upper atmosphere.

4. Conclusion

For the period under study, TOC increases spatially from the coastal region to the north eastern region of the country. It ranges from 259.1 - 259.8 DU in the coastal region to 263.9 - 264.4 DU in the north eastern region. Thus, the observed TOC is above the baseline value (220 DU) chosen as the starting point for ozone hole. TOC was observed to be high during rainy season, but relatively low during the dry season. The variation of TOC was similar to the seasonal rainfall pattern across Nigeria based on the two seasons experienced in the country. The statistical analysis reveals linear relationship between cloud covers and TOC.

The result of this study is consistent with the findings of [16] [17] [18] [23] [30], who separately observed good relationship between TOC variability and other climatic variables. The implication of the observed relationship between TOC and climatic parameters is that, it will enhance the understanding of how the lower and upper atmospheres are interconnected.

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Conflicts of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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