Assessing the Influence of Inter Tropical Discontinuity on Total Column Ozone Variation Over West Africa

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ASSESSING THE INFLUENCE OF INTER TROPICAL DISCONTINUITY ON TOTAL COLUMN OZONE VARIATION OVER WEST AFRICA

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ABSTRACT

The focus of this study is to evaluate the influence of Intertropical Discontinuity (ITD) on the variation of Total column ozone (TCO). Relevant information is supplied on the temporal and spatial variability of TCO along the ITD zone, which is an important factor influencing the earth's atmosphere. Several studies over the years have established the relationship and influence several atmospheric processes have on TCO. However, the relationship between Intertropical discontinuity and TCO over West Africa has a gap. This study tends to examine the influence ITD has on TCO variation using the West Africa region as a case study. The study used Wind, ozone and dewpoint temperature data for the period between 1980-2019. To assess the variability and trend over the study region, several statistical methods were used, including Pearson correlation, Mann-Kendall, and linear regression model. The Mann-Kendall test shows an increasing trend throughout the months over the study region. Spatial analysis also revealed that regions North of the ITD has a higher concentration of TCO that the southern region of the ITD. however, ITD influence was more visible during the wet month of June to August (JJA) as the highest concentration of TCO was observed during this period across all latitude but more deviation was observed between latitude 10^0N to 18^0N, while the least occurrence is observed when ITD is at its minimum position in the month of December to February (DJF). The ACRV shows that 14^0N exhibit the highest variation with a value of 4.84, while the deviation is also at its highest with value of 13.65. The monthly position of ITD for Forty years was also analysed to observe the monthly deviation along the ITD region forty years and the spatial distribution of TCO was analysed from January to December. It’s of note that during the cause of this study, ozone hole which is designated by concentration less than or equal to 220DU was not recorded. The highest and the lowest value of TCO is 295DU and 227DU respectively with an average range of 68DU.

Keywords: Total column ozone, Inter-tropical discontinuity, Mann-Kendall, West Africa.

1. Introduction

The study of ozone has been on the increase by climate researchers all over, in the past few decades, this is due to the known effect and influence Ozone has on atmospheric processes which cannot be over emphasized. Ozone, with the empirical formula (O3), is a triatomic molecule composed of three oxygen atoms which is mostly found in the stratosphere, where it shelters humans from the Sun's unhealthy ultraviolet radiation (UV) (Akinyemi and Oladiran, 2007, Eresanya et al., 2017). its quantity in the atmosphere is very small when compared with other gases. (Kondratyev and Varotsos 1996, Efstathiou et al. 1998). O3 is an essential chemical element of the atmosphere that affects the energy budget and chemistry of the atmosphere along with air quality and global climate change (Duenas et al., 2004; Ahammed et al., 2006; Lin et al., 2008; Nishanth et al., 2014). This gas is mostly created by photochemical processes, although it may also be produced when a soothing electric discharge passes over oxygen. (Akinyemi, 2010). As a result, during electric storms, it can be produced in exceptionally small quantities. Because of its capacity to absorb both incoming solar UV and portion of visible light, as well as re-emit and absorb outgoing terrestrial infrared (IR) radiation, ozone has been acknowledged being one of the most prominent radiative gases in the stratosphere and upper troposphere. As a result, variations in ozone concentrations have an effect on climate, which is dependent on the altitudes at which the changes occur. (Bojkov and Fioeltov, 1995; Orsolini et al., 1998).

Transport mechanisms are the primary source of changes in the lower atmosphere. Ozone in the lower stratosphere serves as a tracer of atmospheric movements as a result of this activity. The dynamics of motion in the atmosphere are linked to this motion. The stratosphere's transport and wind motion are linked to that of the troposphere; For instance, at the tropopause, ascending air is carried into the stratosphere and expelled from the column at higher heights above a tropospheric high-pressure system. Because the ozone-mixing ratio in the lower stratosphere rises with altitude, the air entering this column has less ozone than the air leaving it. The quantity of ozone in the column drops as a result. As it advances, this high-pressure system drags the low-ozone column after it. This explains why high-pressure systems are connected to reduced stratospheric ozone levels.

A low-pressure system has the opposite effect, causing a rise in ozone levels (Cordero and Forster, 2006).

The tropical region produces the maximum stratospheric ozone, which slowly disperses towards the mid-latitude and polar regions due to the effect of Brewer-Dobson circulation. In this circulation, Tropical air ascends from the troposphere to the stratosphere, moving towards higher latitudes, and then descends into the troposphere around mid-latitude while in the stratosphere over the polar area in this cycle.

(Brewer, 1949 and Butchart 2014). The highest concentration of ozone over the mid-latitude and polar regions is due to this phenomenon, as opposed to the tropical area. The majority of ozone research is conducted in the mid-latitude and polar areas, where ozone depletion is more severe than it is in the tropics. (Farman et al., 1985). The variations in stratospheric ozone are sensitive to solar activity, atmospheric circulation and the angle of the sun's radiation.

The convergence of the trade winds of the two hemispheres is the fundamental description of Inter-Tropical Discontinuity (ITD) (southern and Northern). Low pressure, rising motion, clouds, and precipitation characterize this system. In other words, the onset, retreat, and length of the rainy season in the tropical area are governed by two air masses meeting at a slanting surface with a sun synchronous movement.

During the months of March and April, ITD spreads from the Gulf of Guinea coast to the north. This signifies the beginning of the first rainy season along the Guinean coast south of 100°N. (Sultan and Janicot,2003). The ITD continues to spread inland over the next few months (Lothon et al., 2008), reaching its northernmost climatological location in July and August at around 210N. (Sultan et al., 2007).

The ITD location does not change over several months, but it is influenced by a variety of processes at different time scales, ranging from daily low-level jets (Flamant et al., 2009) to multi-day pulsations with cycles of approximately 5 days (Couvreux et al., 2010). The ITD is positioned in the equatorial trough, a continuous low-pressure region that marks the geographic equator. Surface trade winds converge to generate a zone of heightened mean convection, cloudiness, and precipitation, transporting heat and moisture from surface evaporation and sensible heating.

2.0 Data and methods

2.1 Description of the area of study

This research focuses on the West Africa subcontinent, which is formed from the Africa continent. As indicated in Figure 1, the area spans latitudes 0OS to 25ON and longitudes 20OW to 20OE. Geographically, the Gulf of Guinea forms the southern border, while Mauritania, Mali, and Niger form the northern border. Its eastern and western boundaries are Mount Cameroun and the Atlantic Ocean, respectively. Nigeria, Benin, Ghana, Niger, Togo, Cape Verde, Senegal, Gambia, Guinea-Conakry, Ivory Coast, Guinea Bissau, Liberia, Mali, Mauritania, Sierra Leone, and Burkina Faso are among the 16 nations that make up the region, which spans over 5 million square kilometres. The climatology of the West

Africa region is governed by the Inter-Tropical Discontinuity's latitudinal movement (which is a north-south movement), and the three main climatic zones are: Guinea coast (4ON – 8ON), Savannah (8ON – 11ON), and Sahel (11 O N – 16 ON) according to the classifications defined in (Omotosho and Abiodun, 2007; Akinsanola et al., 2015). The Guinea coast is the southernmost point of the Atlantic Ocean, and it has a sub-humid climate with annual rainfall ranging between 1250 and 5000 mm. This is the realm of the deciduous or semi-deciduous forest that is moist and dry throughout the year.

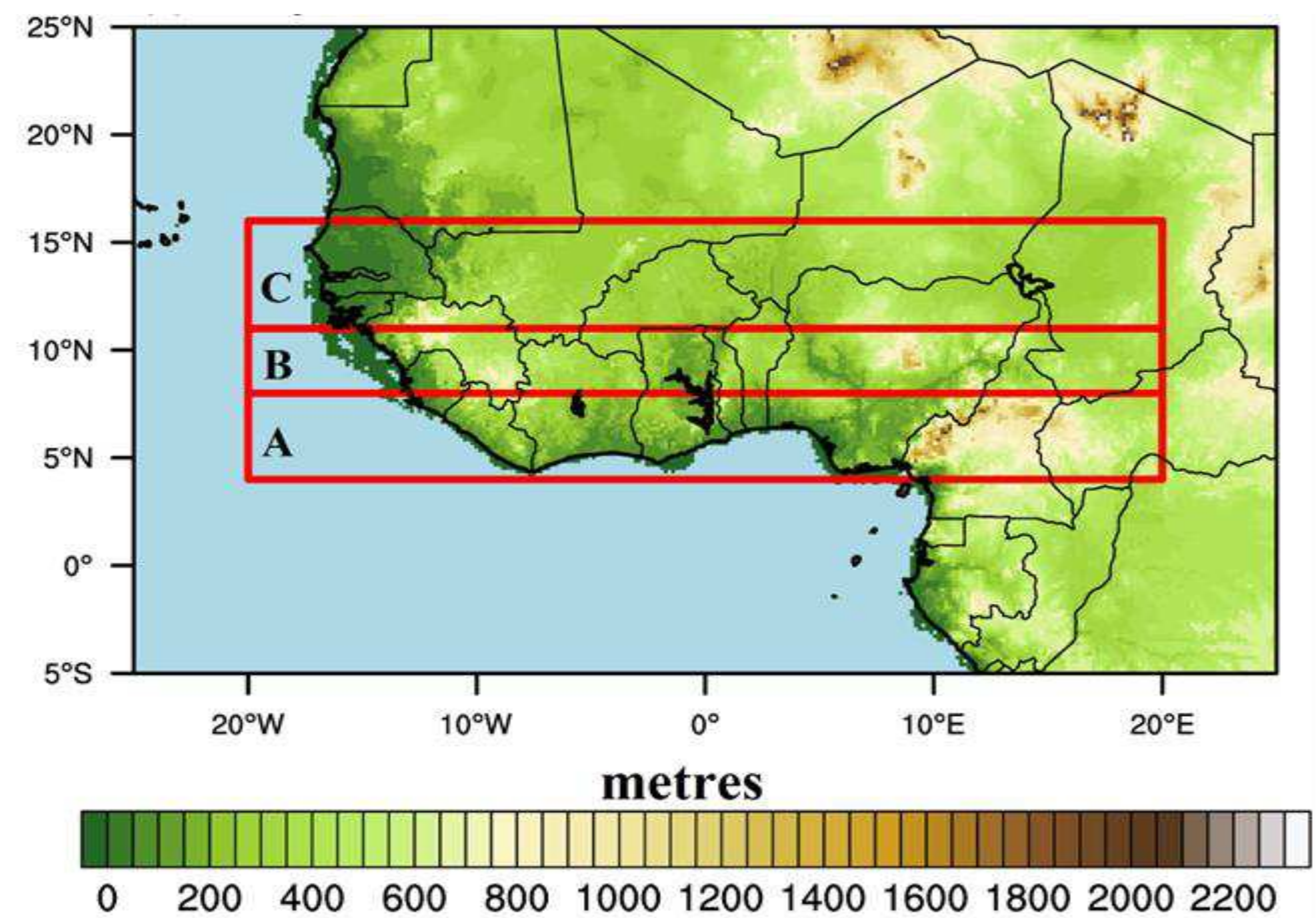


Fig. 1 Map of the study area, showing the western boundaries

The savannah zone is a semi-arid region with annual rainfall ranging from 750 to 1250 millimetres. The Sahel zone, which spans along the northern borders of Mauritania, Mali, and Niger, is characterized by a single rainfall peak (June to September) with an annual rainfall of approximately 750mm. The average annual temperature is usually over 18 degrees Celsius. The mean annual temperature in areas within 10 degrees north of the equator is roughly 26°C, with a range of 1.7–2.8°C and a diurnal range of 5.6–8.3°C. Even though the yearly range is 9°C and the diurnal range is 14° to 17°C, monthly mean ***temperatures*** between latitudes 10°N and the southern section of the Sahara can reach 30°C. The average yearly temperature in the middle Sahara varies between 10°C and 35°C (Food and Agriculture Organization, 2001).

2.2 Data Acquisition and Analysis

Three datasets were utilized in this study: total column ozone, zonal wind, and dew point temperature. The total column ozone dataset was derived from MERRA-2, the most recent global atmospheric reanalysis for the satellite era generated by NASA's Global Modelling and Assimilation Office (GMAO) using the Goddard Earth Observing System Model (GEOS) version 5.12.4. Zonal wind and dewpoint Temperature was obtained from ERA-Interim which is produced by the European Centre for Medium Range Weather Forecast (ECMWF). All data was obtained for the period between January 1980 to December 2019 at 25km x 25km resolution.

In order to delineate the position of Inter-Tropical Discontinuity (ITD) over the study region, the monthly mean convergence of the zonal winds for the study period was plotted and the line of vector discontinuity was derived. The delineated position was assessed with Monthly analysis of Spatio-Temporal variation of total column ozone. This was carried out in order to determine the spatial distribution and temporal variation along the inter-tropical discontinuity.

Long term variation of Total Column Ozone is represented by a linear regression equation given as;

$$\mathrm{Y} = \mathrm{bx} + \mathrm{c} \qquad (1)$$

Where x is the monthly value of Total Column Ozone,

And Y is the monthly mean of Total Column Ozone;

where b and c are constants of regression. An equation which describes the temporal change of TCO concentration. The equation for the trend is therefore given as:

$$\mathrm{Trend} = \frac{\mathrm{b} \times 12 \times 10}{\mathrm{AvGTC0} \times 100} \qquad (2)$$

Also, the annual coefficient of relative variation (ACRV) is given as;

$$\mathrm{ACRV} = \frac{\mathrm{ANNUAL\ SD}}{\mathrm{ANNUAL\ MEAN}}\ \mathrm{X}\ 100 \qquad (3)$$

Where SD= standard deviation.

Where x is the observed TCO, and $\bar{x}$ and Sx are the mean and standard deviation of TCO.

Mann-Kendall test (Mk) (Mann 1945; Kendall 1975; Wang et al., 2005) was also used for the trend analysis. This was used to determine discontinuities due to inhomogeneous time succession. It is unique as it does not need presumptions analogous to data distribution. (Mondal et al., 2012). This makes it widely acceptable for trend analysis. (Ilori and Ajayi, 2020; Khan et al., 2020; Jonah et al., 2021) Mk statistic can be described as:

$$K = \sum_{i=1}^{n}\sum_{j=1}^{i-1} \text{sign}\,(xi - xj) \qquad (4)$$

Where xi and xj are the value of the sequential generic data, n is the data total length, while sign(xi-xj) can be defined as;

$$\text{Sign}(x_i\text{-}x_j) = \begin{bmatrix} 1, & \text{if}(xi - xj) & > 0 \\ 0, & \text{if}(xi - xj) & = 0 \\ -1 & \text{if}(xi - xj)\cdots & < 0 \end{bmatrix} \qquad (5)$$

The variance Var(S) was calculated as follows when S statistic is approximately distributed with the E(S) mean:

$$E(S) = 0, \qquad (6)$$

$$\{n(n-1)(2n+5) - \sum_{t} t(t-1)(2t+5)\} \qquad (7)$$

Where t is any given tie extent, $\sum$t represents the summation of all values of the tie number, while n denotes length of the series. The Z standardized statistics for the test can then be evaluated using the equation below:

$$Z = \begin{pmatrix} -1, & \text{if} & K < 0 \\ 0, & \text{if} & K = 0 \\ \frac{S+1}{\sqrt{\text{Var}(S)}} & \text{if} & K > 0 \end{pmatrix} \qquad (8)$$

When a dataset of n variables is randomly distributed independently without trend and ordering is equally likely, the null (H_0) hypothesis is accepted. The absolute value of Z (test statistic) is then compared with the value of $Z\left(1 - \frac{p}{2}\right)$ at p level of significance obtained from the table to reject or accept the H_0 hypothesis.

Data Description

DATA	SPATIAL RESOLUTION	TEMPORAL RESOLUTION	SOURCES	UNITS
Total column Ozone	0.25 x 0.25	Monthly	GIOVANNI	Du
Dew Point Temperature	0.25 x 0.25	Monthly	ERA Interim	Kelvin
Uwind, Vwind	0.25 x 0.25	Monthly	ERA Interim	m/s

Table 1: Data source, type and description.

The zonal and meridional wind data were downloaded at standard height of 10m above the ground level

RESULTS AND DISCUSION

The Inter-Tropical Discontinuity over land is a low-pressure system generated when the northeast and southwest trade winds meet near the Earth's equator in West Africa. It's important to stress that the ITD is a zone rather than a demarcation line; however, the Inter-Tropical Front (ITF), which is the same as the ITD's northernmost boundary, is defined as a line. ITD which is generally used to represent the boundary between the dry north winds and the warm humid winds to the south (Griffiths & Soliman, 1972; Kalu, 1977; Dubief, 1979; Adeyefa et al., 1995).

The convergence points of the northeast and the southwest wind streamlines was considered to be the average surface position of the ITD over the region on daily basis.

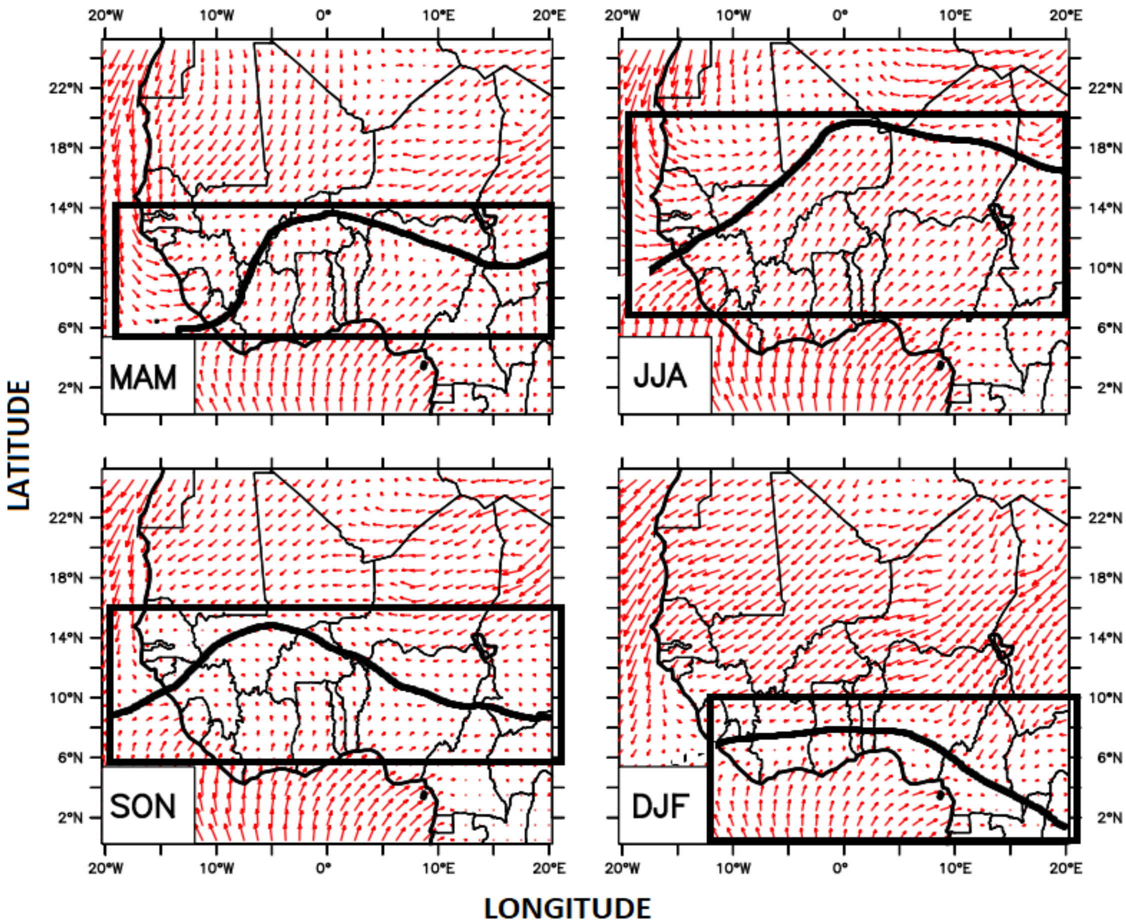


Fig. 2 Seasonal position of ITD over the study region

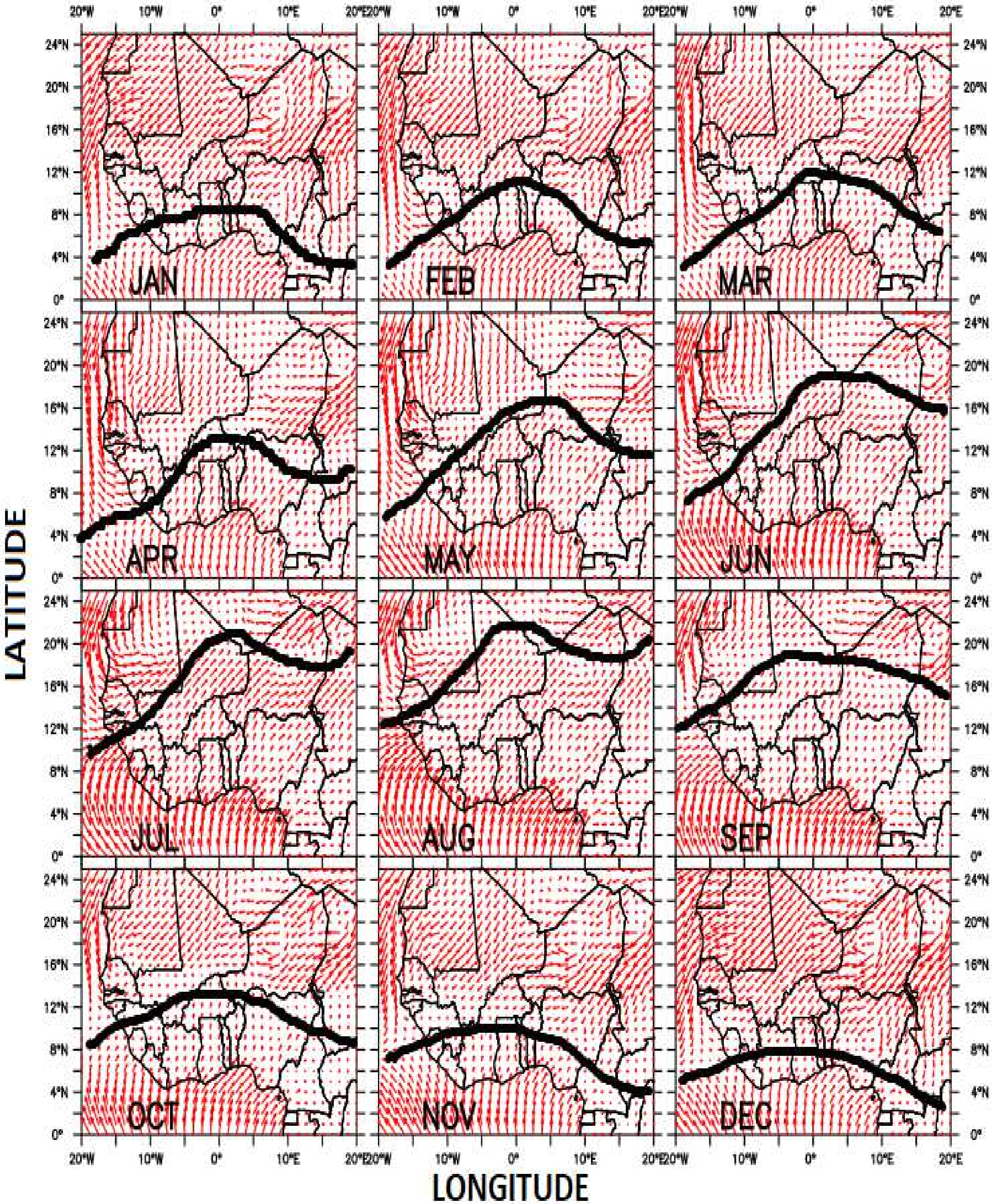


Fig. 3 Monthly mean position of ITD from January to December

The figure 3 shows the monthly mean position of ITD for a period of 10 years (2010-2019). While figure 2 shows the seasonal position of ITD for a period between 1980 to 2019. ITD can be observed to be between 2-22^{0}N for the monthly position and between 2-20^{0}N for the seasonal position. The surface wind convergence and dew-point temperature of 15^{0}C was used to delineate this position. Using surface wind convergence to delineate the position of ITD over West Africa is a widely accepted method as it takes into consideration the surface level wind convergence which denotes the meeting point of two airmasses. (Odekunle, 2010; Lele and Lamb, 2010; Oluleye and Jimoh., 2017) The northernmost position is seen to be at the northern boundary of West Africa at 22^{0}N. The black continuous line shows the position of ITD at each month over the region, as illustrated in figure 2 and 3.

Wind direction and dewpoint temperature for each month was averaged through a span of 10 years and the monthly and seasonal mean value was derived over the study area. The most significant movement of ITD was observed at June, July, August (JJA) with its northernmost position at 20^{0}N, while it extended from 10^{0}N. While the season with the least variation was observed at MAM (March, April, May) which span between 6-14^{0}N, similar observation was also made at SON (September, October, November). West Africa has two major distinct seasons, namely wet and dry season. Wet season ranges from JJA and SON, while dry season range from MAM and DJF. These dry months has the lowest propagation of ITD, while significant observation was recorded during the wet months as in JJA and SON.

The positions of ITD in this study can be seen to be symmetrical with rainfall pattern over West Africa, as ITD is the major indicator of rainfall system as observed by kalita et al., 2011.

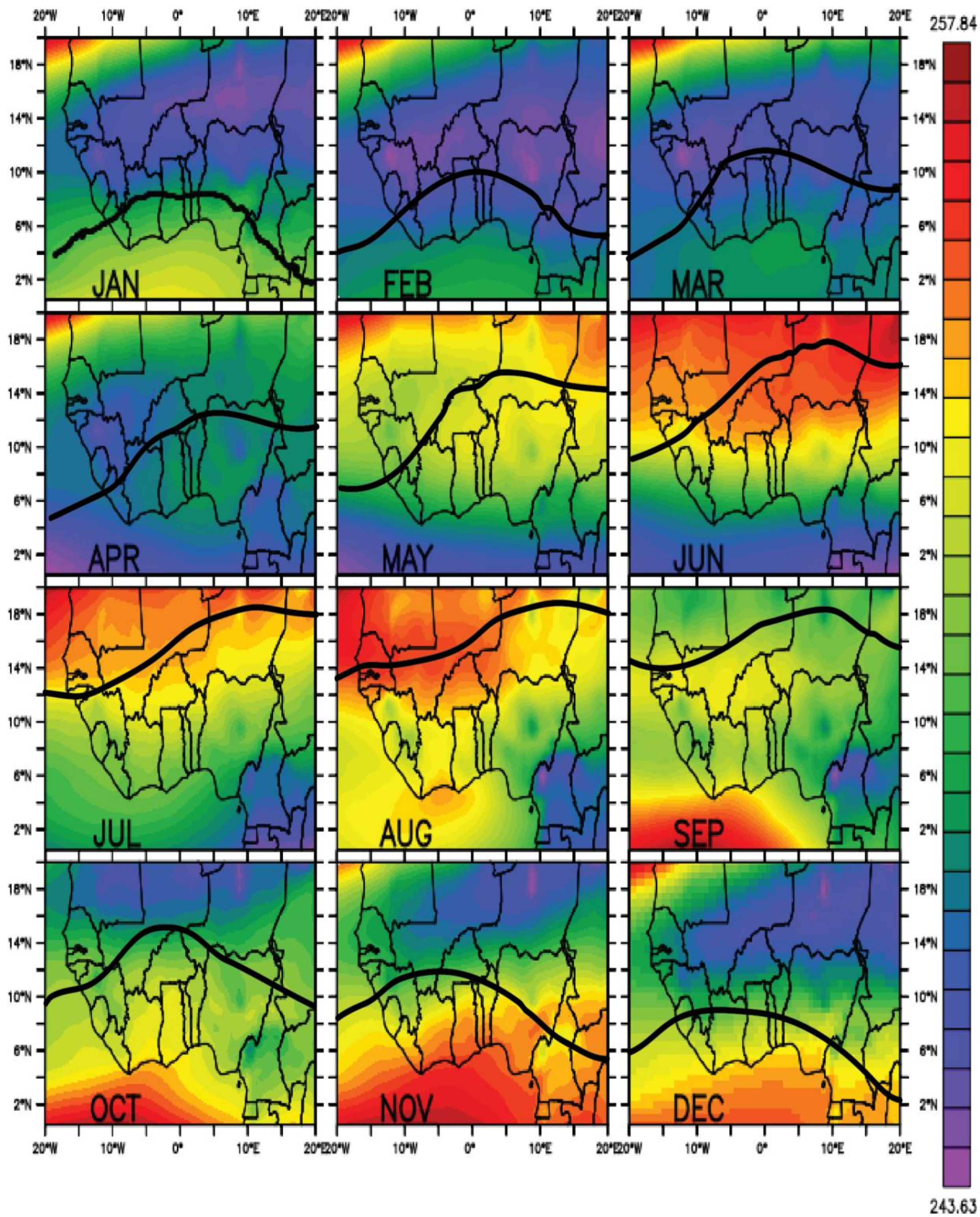


Fig. 4 Monthly distribution of Total column ozone over the West Africa Region, For a period between 2000 to 2019.

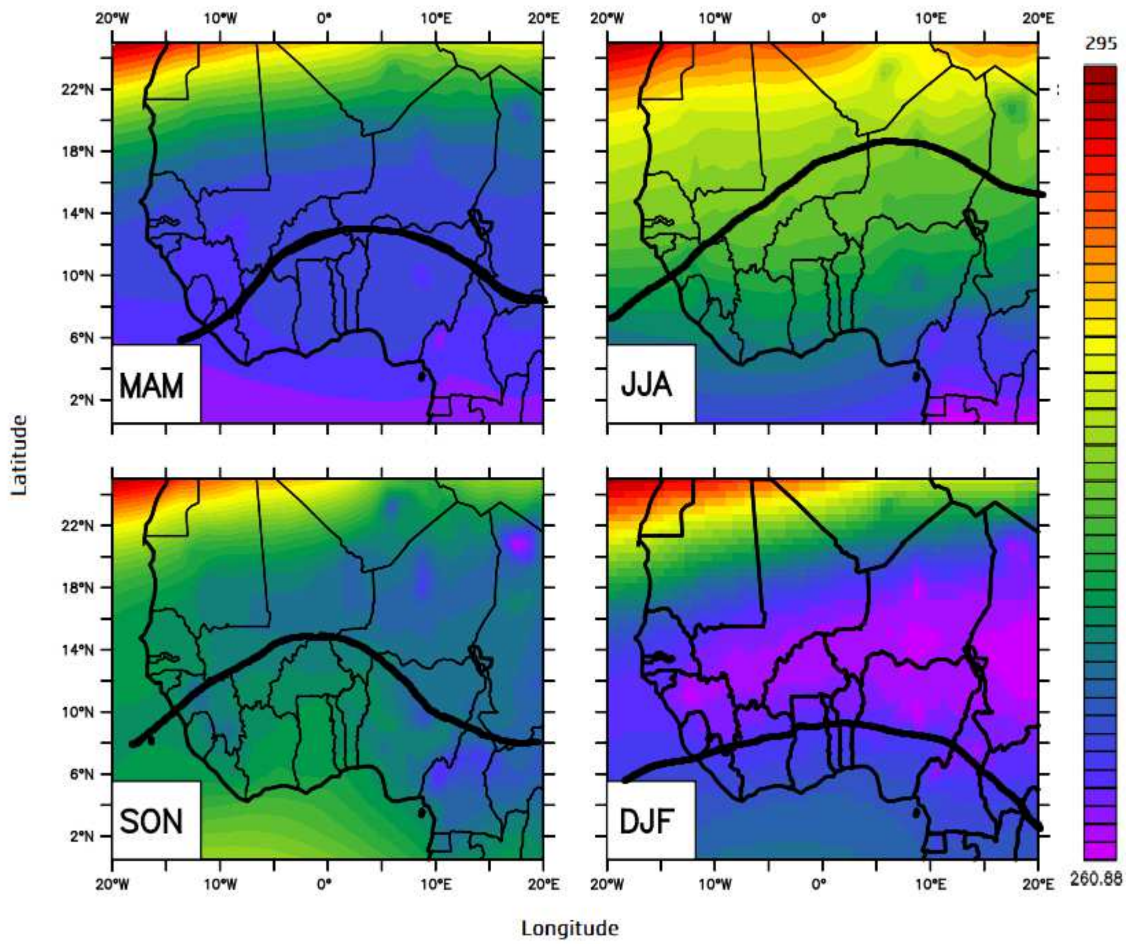


Fig. 5 Seasonal position of ITD with spatial distribution of Total column ozone over West Africa from a period between 1980 to 2019.

Figure 5 depicts TCO range to be between 227-295 DU from January to December which shows a difference of 68 DU. The black line shows the position of ITD over the region for each month as previously delineated and observed in figure 2 and 3. From figure 4 ITD position over West Africa in the dry months shows that regions south of the ITD which is dominated by the southwest trade wind exhibit a higher concentration of TCO while region north of the ITD which is dominated by northeast trade wind has a lower concentration between depicted between latitude 8-14^{0}N, this phenomenon may be attributed to the dominance of the Northeast trade wind over the region. The ITD trough itself is seen to have a considerable low concentration of TCO which is considered to be averagely low in the dry months. As also observed in figure 5. In DJF, north easterly wind dominates most of West Africa region as indicated, also the concentration of TCO over DJF is seen to be at its lowest. The ITD position slants, propagating along the West African coast lines from latitude 9^{0}N to 2^{0}N across the West to east region of West Africa, indicating a dry period of the year when an observation at the wind system for the month of April indicates that southwesterlies have gained momentum over the northeasterlies this is observed as the ITD position is seen to be located at 13^0N and this also signals the beginning of rainfall for most West African region. In February also, the concentration is also low along the ITD trough, but with a considerably higher value than TCO concentration in January. In comparison, TCO has a higher concentration in January than February. Also in March, the ITD position is seen to have moved northward by 2^0N, region of the ITD trough is also observed to have a lower concentration of TCO than the surrounding region. April and May also have the same low concentration along the ITD trough.

JJA have different condition, the concentration of TCO in this month is relatively higher than other months, these months are also months when ITD is at its peak and the southwesterlies wind are dominant which is also regarded as the rain peak over west Africa.

As the moist south westerly wind stabilizes over the region in JJA when ITD is reaching its northernmost position as observed in figure 2 and 3, ozone concentration is seen to significantly increase in concentration and propagation of ITD is observed to be at its peak. however, in September when ITD begins to retreat, also marks the beginning of ozone decrement which wind up in returning to January situation as the dry north easterly wind, once again, takes over the region in December. This illusive transition of ITD corresponding changes in ozone concentration during the course of the year may be a factor that makes weather activity most influencing factor, controlling TCO in West Africa as also observed by Oluleye and Okogbue, 2013.

The totality of West Africa generally has a higher concentration of TCO in the month of JJA. It is also observed that ITD region maintained it lower concentration while south of ITD has the highest concentration of TCO. The trend also increased progressively from January and peaked at September, which is also denoted as the ITD peak, and starts decreasing from October through February as previously explained. In a recent study by Nishanth et al., 2021, similar observation was made over India which share the same regional characteristics as west Africa as it is also a tropical region, he however attributed these changes to some other meteorological variables. In a model study by (Haigh, 1994) revealed that a 1% increase in Ultra-violet (UV) radiation at the maximum of a solar cycle will generate a 2% increase in ozone concentrations in the stratosphere. The results from this study agrees with a study by Nishanth et al., 2021, where he also observed significant increase in TCO concentration in months of June, July and August which also has the highest concentration in this study, which he attributed to south-West monsoon over the delineated locations.

TCO Variation across Latitudes

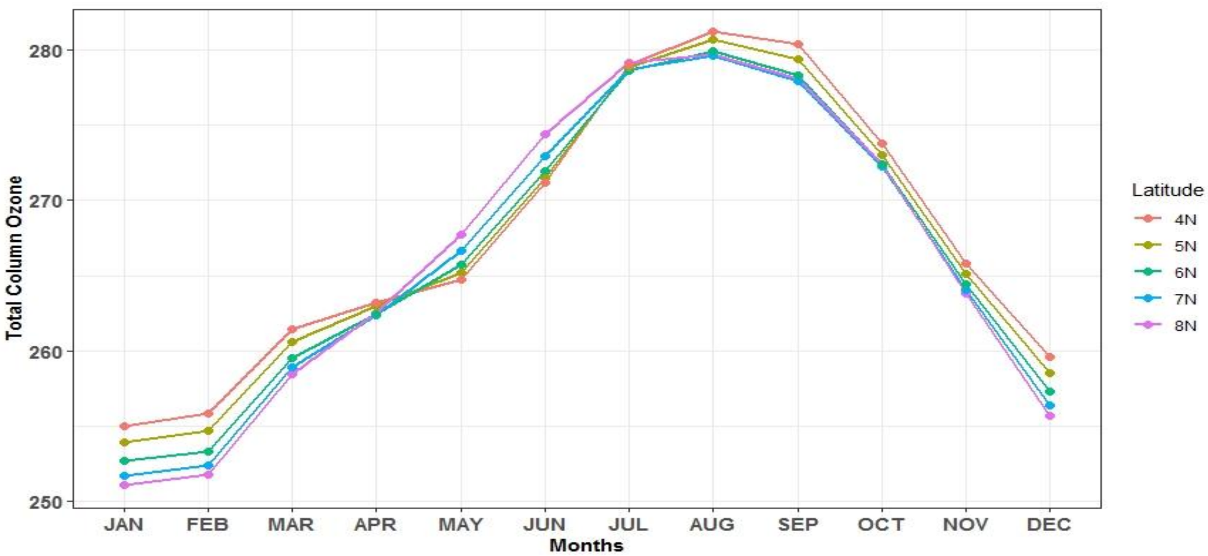


Fig. 6 Monthly variation of Total column ozone over the Guinea-Coast

TCO trend over the guinea coast established a relationship between ITD and Ozone as shown in figure 6. The guinea coast is a region of maximum precipitation, when compared to the Savannah and Sahel, it lies between 4-8^{0}N. The maximum concentration of TCO occurred in August. while July, August, September is observed to have the highest concentration of TCO over the guinea coast. This feature is most likely linked to increase rainfall, cloud cover, large wind speed and lower atmospheric temperature which are the features of wet season in the guinea coast.

During the month of January, February, March and December, which has notably the lowest concentration of TCO, this may also be linked to atmospheric phenomenon associated with the dry period which include, more sunshine hours, high temperature, low humidity, sparse cloud cover. The highest concentration of TCO occurred in July over the guinea coast, while the minimum concentration occurred at January, February and December, which is associated with little or no rainfall over the West Africa region. Generally, High concentration were observed between June to September, with concentration between 270DU-282DU, which can be attributed to increased monsoon rainfall. While low concentration was observed between January-March, which signals the Northward advancement of ITD and November-December, which also signals the retreat of ITD over West Africa.

Also, across the latitude, lower latitude is observed to have a higher concentration of TCO, while higher latitude is observed to have a lesser concentration as seen in figure 6, the study of the trend between latitude 4^{0}N and 8^{0}N revealed the variability between the latitudes. As they all increase steadily between

January and march, interchanging positions at April, as it is observed that concentration at 8^0N is now higher that TCO concentration at 4^0N. From May through July, this progression is continued before reverting to the initial position. The presence of ITD, which influences the concentration of ozone across this latitude, is responsible for this divergence.

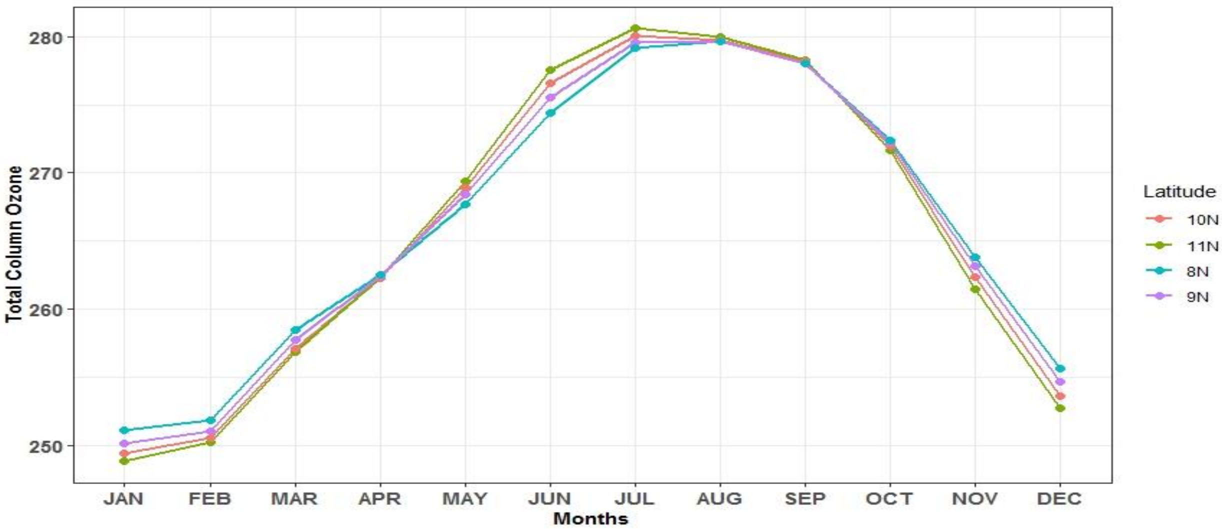


Fig. 7 Monthly variation of Total column Ozone over the Savannah

Figure 7 further describe TCO variation across latitude as observed over the savannah region. Savanah region is situated between latitude 8-11^0N, it has lesser precipitation when compared to the guinea coast. Maximum concentration is also at July with a TCO concentration of 280DU at 11^0N as compared to Guinea coast which peaked at august and a TCO peak of 282DU. Over the savannah region, June, July, august and September has the highest concentration with a difference of less than 5DU as compared to the Guinea coast which has a difference of about 10DU, while DJF still maintained the lowest concentration over the region.

This region exhibits a significant difference from the Guinea coast has observed in January, latitude 8^0N has the highest concentration of TCO till April, which signals the movement of ITD to this latitudinal position. The concentration drops to being the lowest at April. The concentration is reversed from 11-8^0N throughout till TCO peak at July as opposed August of the previous zone. Then at august, the latitudinal position concentration is maintained till October which is also revert back the TCO concentration at each latitude to the initial position. These changes can also be attributed to the presence of ITD at this region in the month such as January, April, August and October.

The savannah region is observed to be less concentrated than the guinea coast. As it has much lower concentration in December, January, February progressively till it peaked at July when compared to Guinea coast.

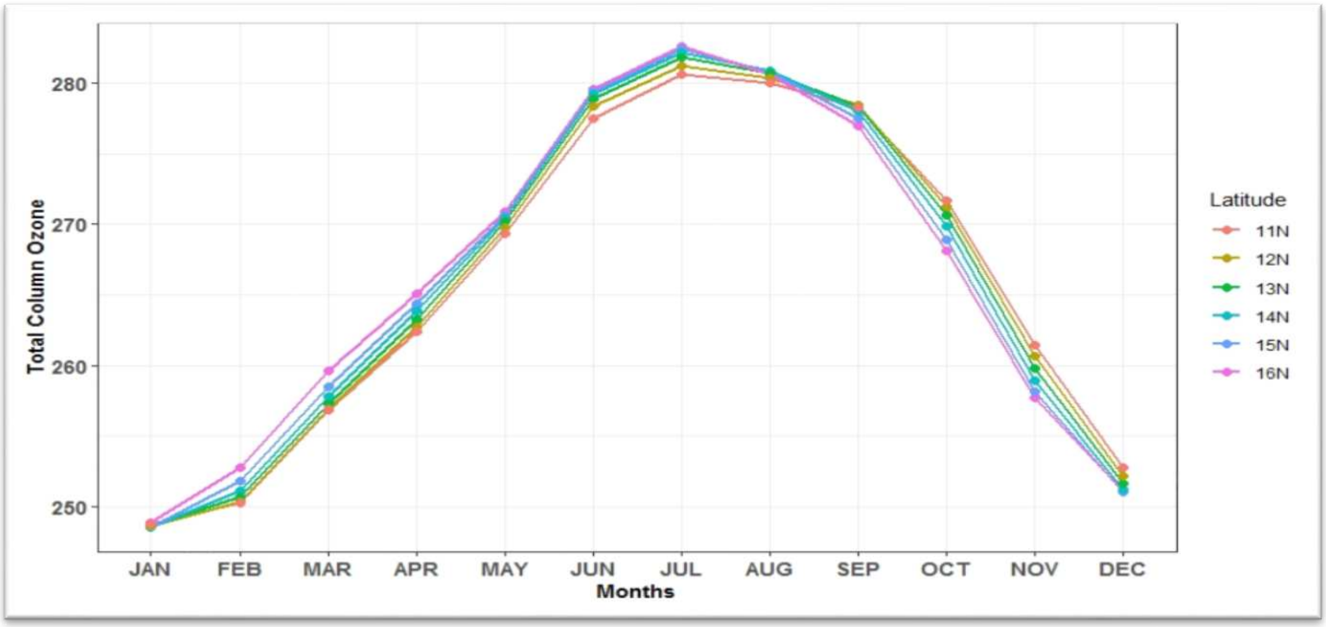


Fig. 8 Monthly variation of Total column Ozone over the Sahel

While over the Sahel, which is regarded as the driest region which has the least impact of ITD. TCO is observed to have the same value for January across the six Sahelian latitudinal region. It is also observed to peak at July as same with the savannah region. However, latitudinal positions are maintained till august, which over Sahel region signifies the beginning of the dry season. This also correlated with the position of ITD as observed in figure 4, over the months and across latitudinal regions shows that June, July, August and September are months were ITD position is northernmost.

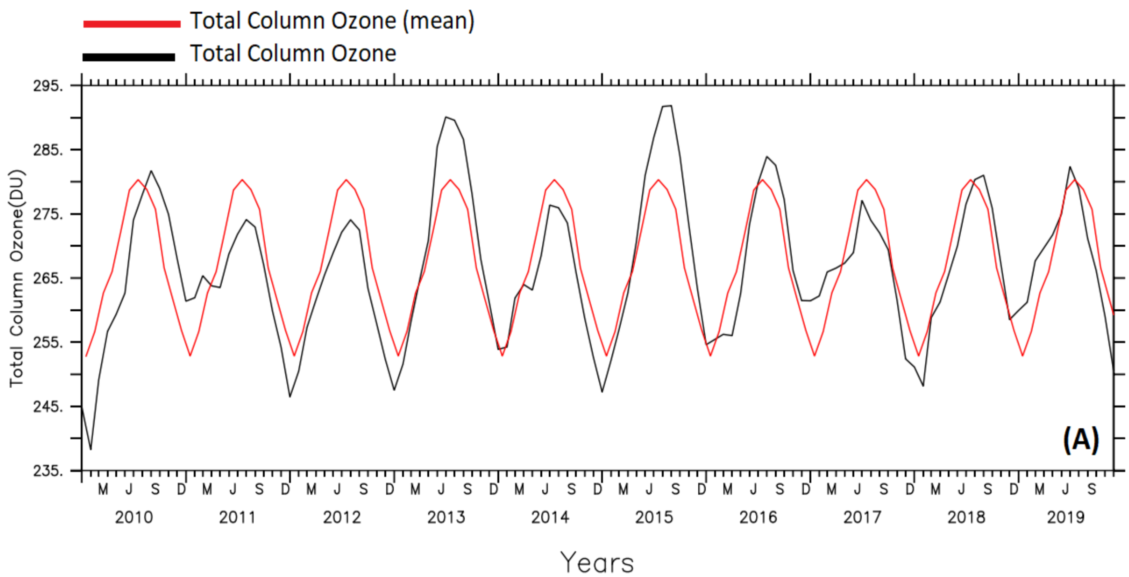


Fig. 9 Annual Trend of TCO Over the Guinea Region

Figure 9 shows the annual and mean trend of TCO over the guinea coast. The guinea coast region which has the presence of ITD almost throughout the year is observed to have a significant minimum value in the month of February in 2010 and maximum at August in 2015. While the mean range is between 253 and 280 DU over the Guinea coast. The minimum and maximum value for TCO in this region is 238 and 292 respectively. The trend also indicates a pattern along which ITD propagates. From January/December to July/august, there seems to be a significant progressive increment in the value of TCO across the study period and a decrease in the concentration from July/August to December/January. These establishes a relationship between ITD movements across the months and Total column ozone concentration along the region. the lowest concentration of TCO was observed at February 2010 while the highest concentration was observed at July/August 2015.

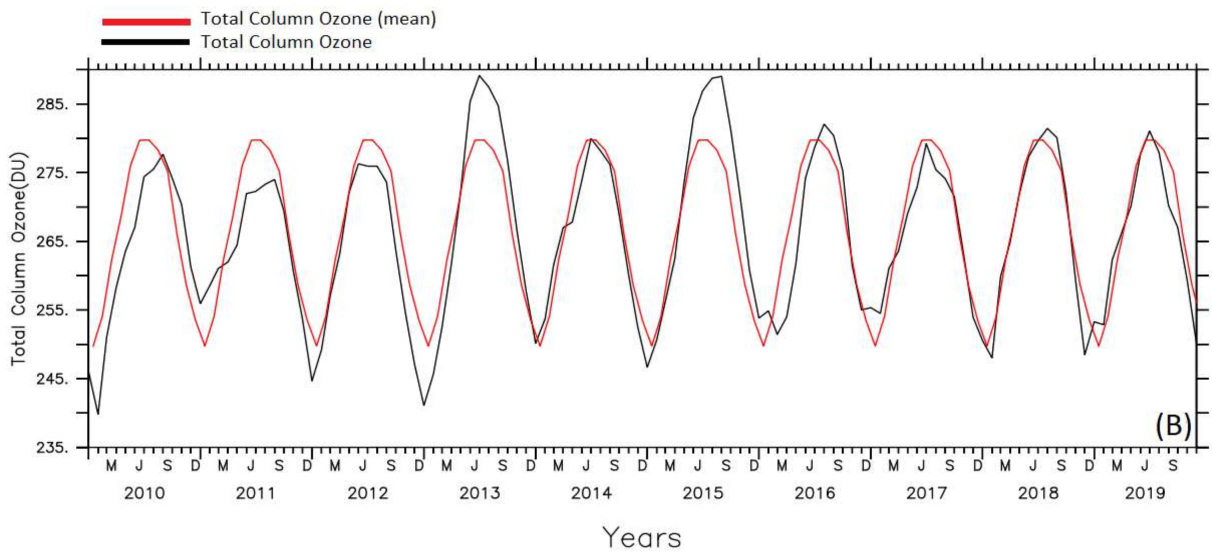


Fig. 10 Annual Trend of TCO over the savannah region

Figure 10 shows annual and mean trend of TCO over the savannah region. Which is located between latitude 8-11^{0}N. the trend is similar to the trend over the Guinea coast but of lower TCO concentration, with a minimum of 240DU and a maximum concentration of 289DU, with a difference of 49DU, from the minimum concentration in January/December to the maximum concentration in July/august and also a mean minimum value of 250DU and mean maximum concentration of 280DU, with a mean difference of 30DU. the lowest concentration of TCO was observed at February 2010 while the highest concentration was observed at June 2013.

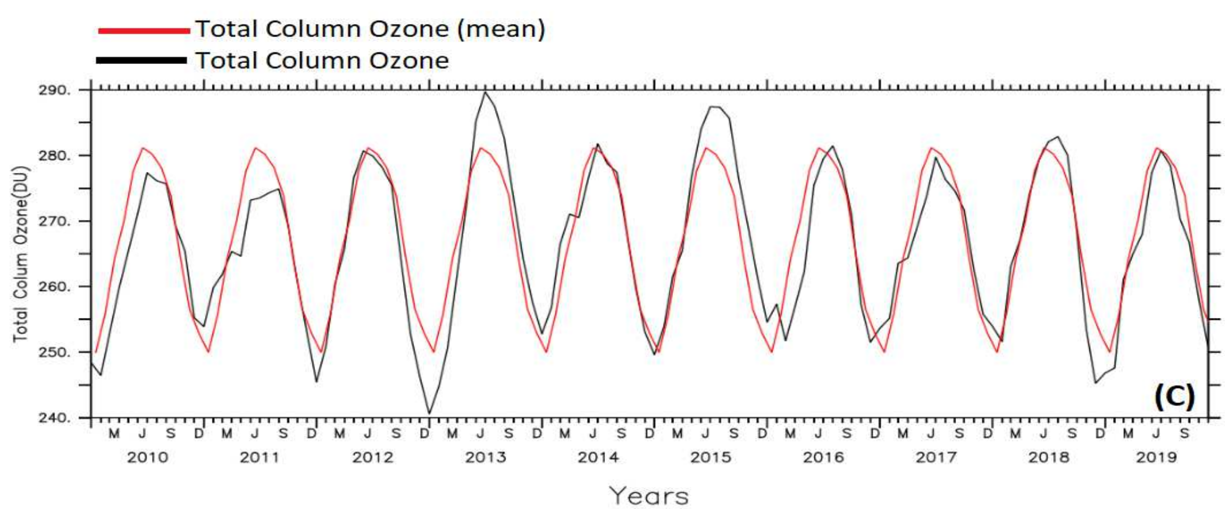


Fig. 11 Annual Trend of TCO over the Sahel region

Figure 11 shows annual and mean trend of TCO over the Sahelian region, which is located between latitude 12-16^{0}N. the trend is similar to the trend over both the Guinea coast and the savanna region, having also the same lower TCO concentration with the savannah region, with a minimum of 240DU and a maximum concentration of 290DU, with a difference of 50DU, also with a minimum concentration in January/December to the maximum concentration in July/August and also a mean value of 250DU and maximum concentration of 282DU, with a mean difference of 30DU. The major difference observed between savanna and Sahel region is the shift in months of lower concentration of ozone. It occurs over the savanna region majorly in November/December, while over the Sahelian region, lowest occurrence was observed in December/January. The lowest concentration of TCO was observed at December 2012 while the highest concentration was observed at June 2013.

In the year 2013 and 2015, in the month of June/July respectively, there is observed to be a significant increase in concentration of TCO, which may be attributed to factors other than the influence of ITD, similar observation was also made in the Guinea coast and savannah region.

Figure 12-14 shows the regression trend at each latitude from 20^{0}N-4^{0}N. From 20^{0}N-4^{0}N, an increase in the variation of TCO is observed as the slope of the trend is positive. With the exception of 18^{0}N and 19^{0}N which shows a negative trend/year. Throughout higher latitude, TCO seems to have it maximum concentration to be at 2013 from 20^{0}N-12^{0}N while from 11^{0}N the maximum concentration also extends to 2014 making it a dual peak this is reflected as the coefficient of the slope at this region increases. Similar observation was made by Nishanth et al., 2021 which he attributed to latitudinal variation he also noted that changes in wind pattern influence changes in spatial and Temporal distribution of TCO. Large inter annual variability of TCO concentration was also observed which is can be attributed to variation in tropopause height, air circulation changes, changes in anthropogenic concentration and other atmospheric factors.

Latitudinal variation with regression trend from 1980-2019

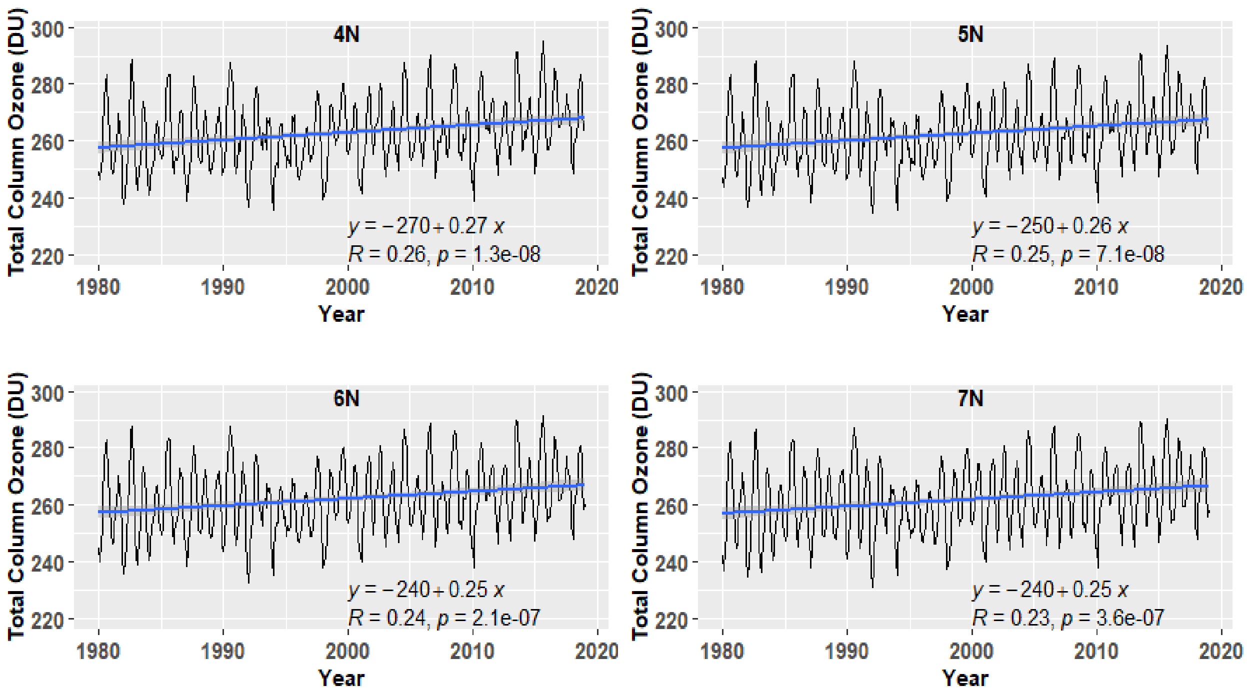
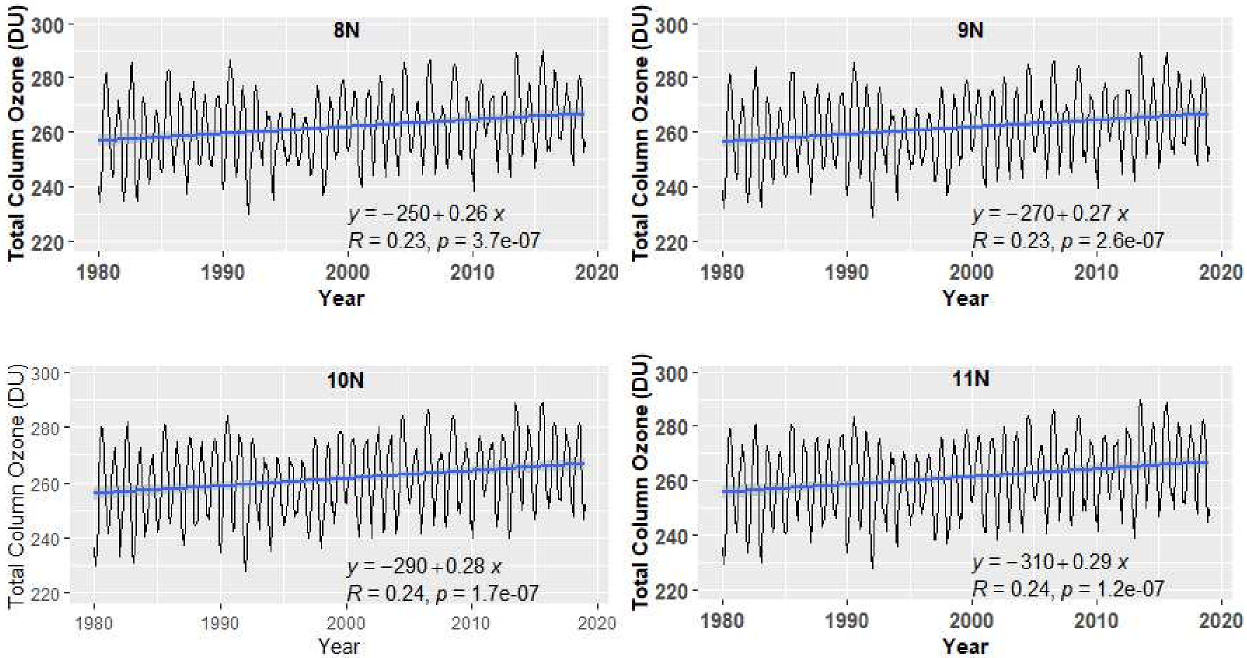


Fig. 12 Variation from 4-7^{0}N



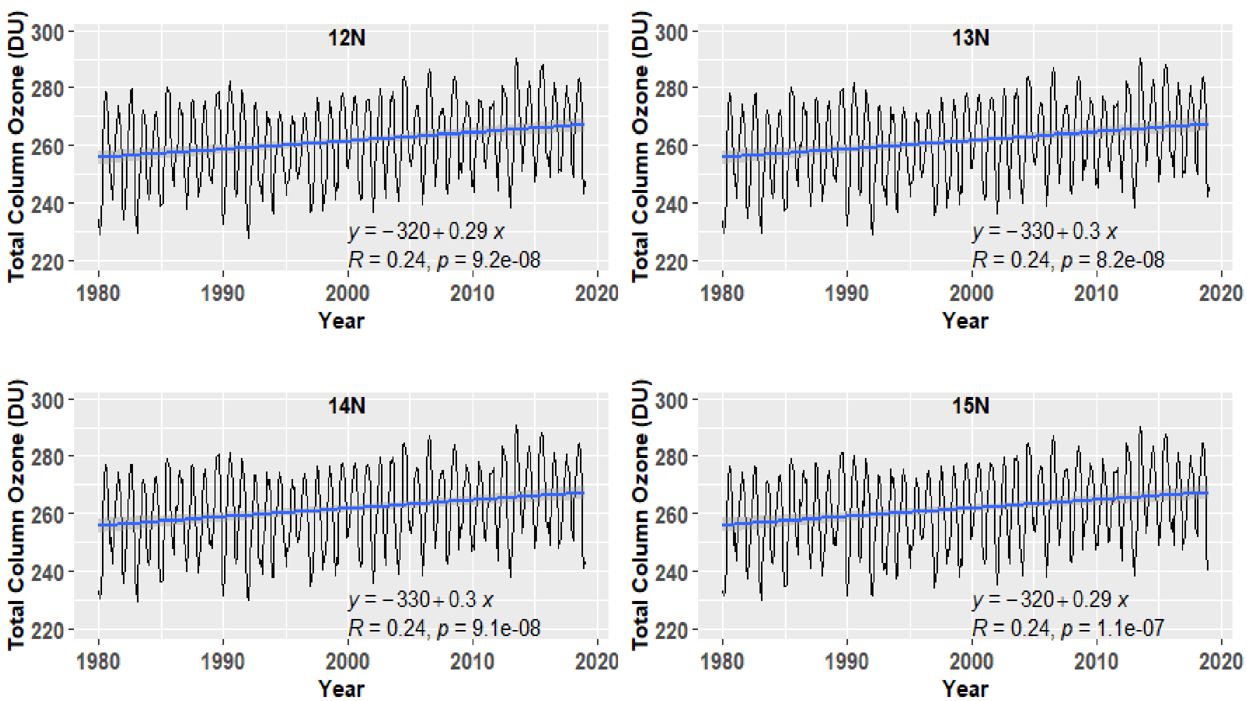


Fig. 13 Variation from 8-15^{0}N

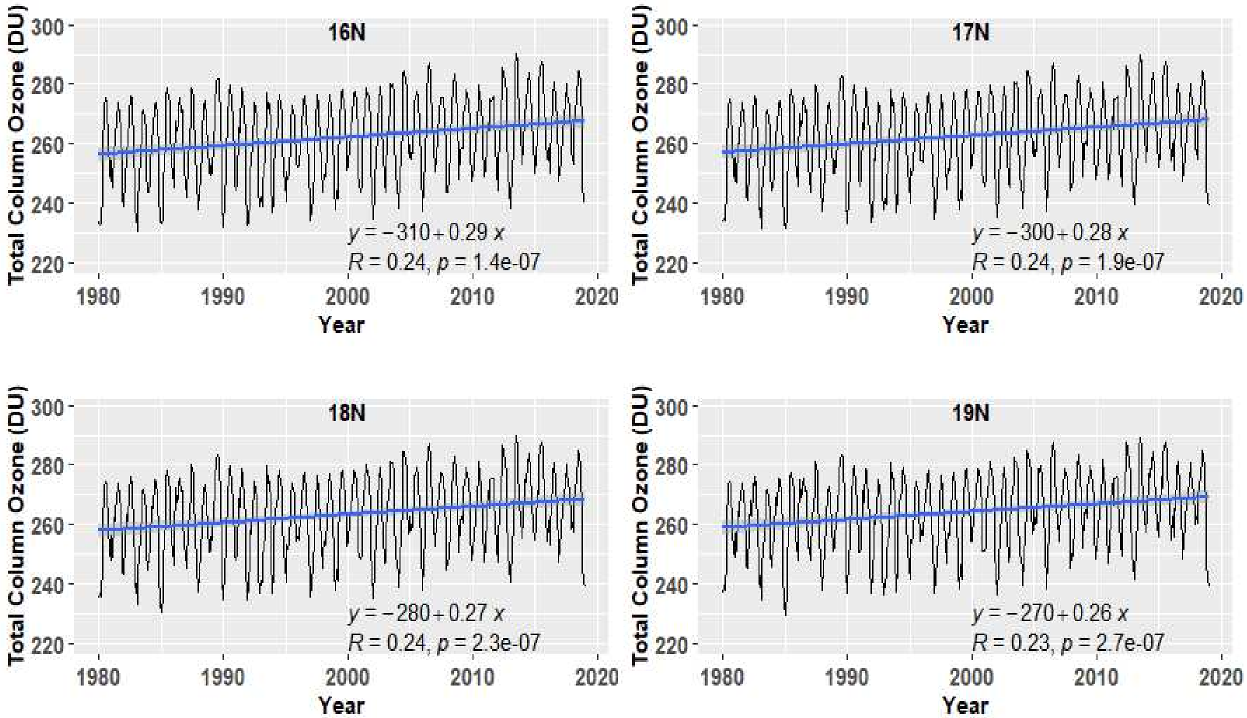


Fig. 14 Variation from 16-19^{0}N

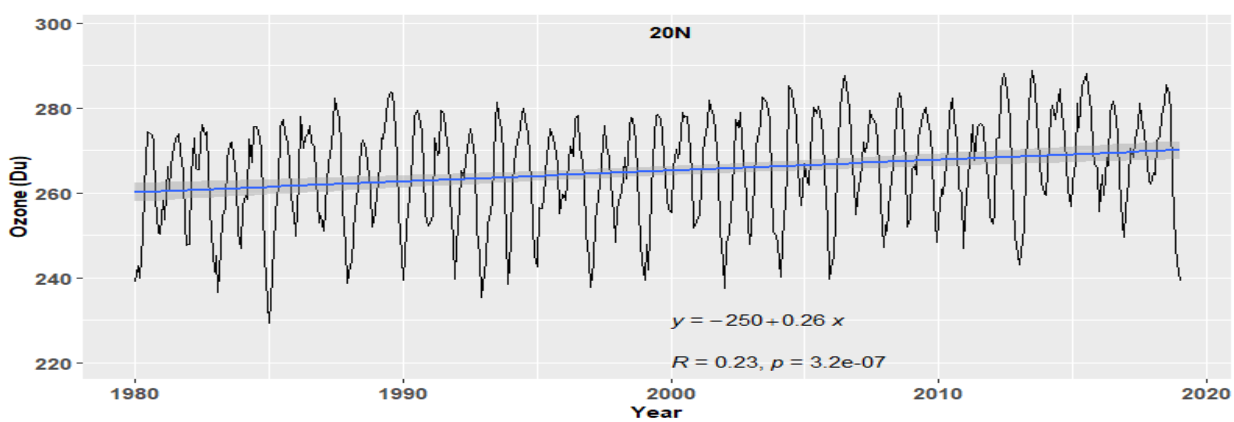


Fig. 15 Variation at 20^{0}N

Table 2: Statistical Summary

Latitude	Mean	Minimum	Maximum	Standard Deviation	TREND/YR	ACRV	Regression Coefficient
20^0N	**265.20**	**229.30**	**289.00**	**12.39**	**0.20**	**4.28**	**0.227**
19^0N	**264.11**	**229.50**	**289.30**	**12.70**	**-0.98**	**4.41**	**0.228**
18^0N	**263.13**	**230.30**	**289.60**	**13.03**	**-0.99**	**4.55**	**0.227**
17^0N	**262.51**	**231.60**	**290.00**	**13.30**	**0.41**	**4.67**	**0.227**
16^0N	**261.98**	**230.60**	**290.20**	**13.50**	**3.07**	**4.77**	**0.231**
15^0N	**261.69**	**229.90**	**290.40**	**13.62**	**0.63**	**4.83**	**0.233**
14^0N	**261.58**	**229.40**	**290.60**	**13.65**	**0.99**	**4.84**	**0.239**
13^0N	**261.54**	**228.70**	**290.50**	**13.61**	**1.26**	**4.79**	**0.238**
12^0N	**261.42**	**227.90**	**290.10**	**13.49**	**1.48**	**4.75**	**0.237**
11^0N	**261.35**	**227.60**	**289.70**	**13.30**	**1.63**	**4.63**	**0.235**
10^0N	**261.74**	**228.00**	**289.20**	**13.03**	**1.81**	**4.51**	**0.240**
9^0N	**261.92**	**228.90**	**289.20**	**12.72**	**1.94**	**4.37**	**0.232**
8^0N	**261.96**	**229.90**	**289.70**	**12.40**	**11.71**	**4.24**	**0.231**
7^0N	**262.22**	**230.90**	**290.40**	**12.11**	**2.21**	**4.17**	**0.232**
6^0N	**262.58**	**232.50**	**291.60**	**11.88**	**2.39**	**4.14**	**0.238**
5^0N	**262.89**	**234.50**	**293.30**	**11.74**	**2.47**	**4.15**	**0.248**
4^0N	**262.92**	**235.90**	**295.00**	**11.65**	**2.60**	**4.18**	**0.261**

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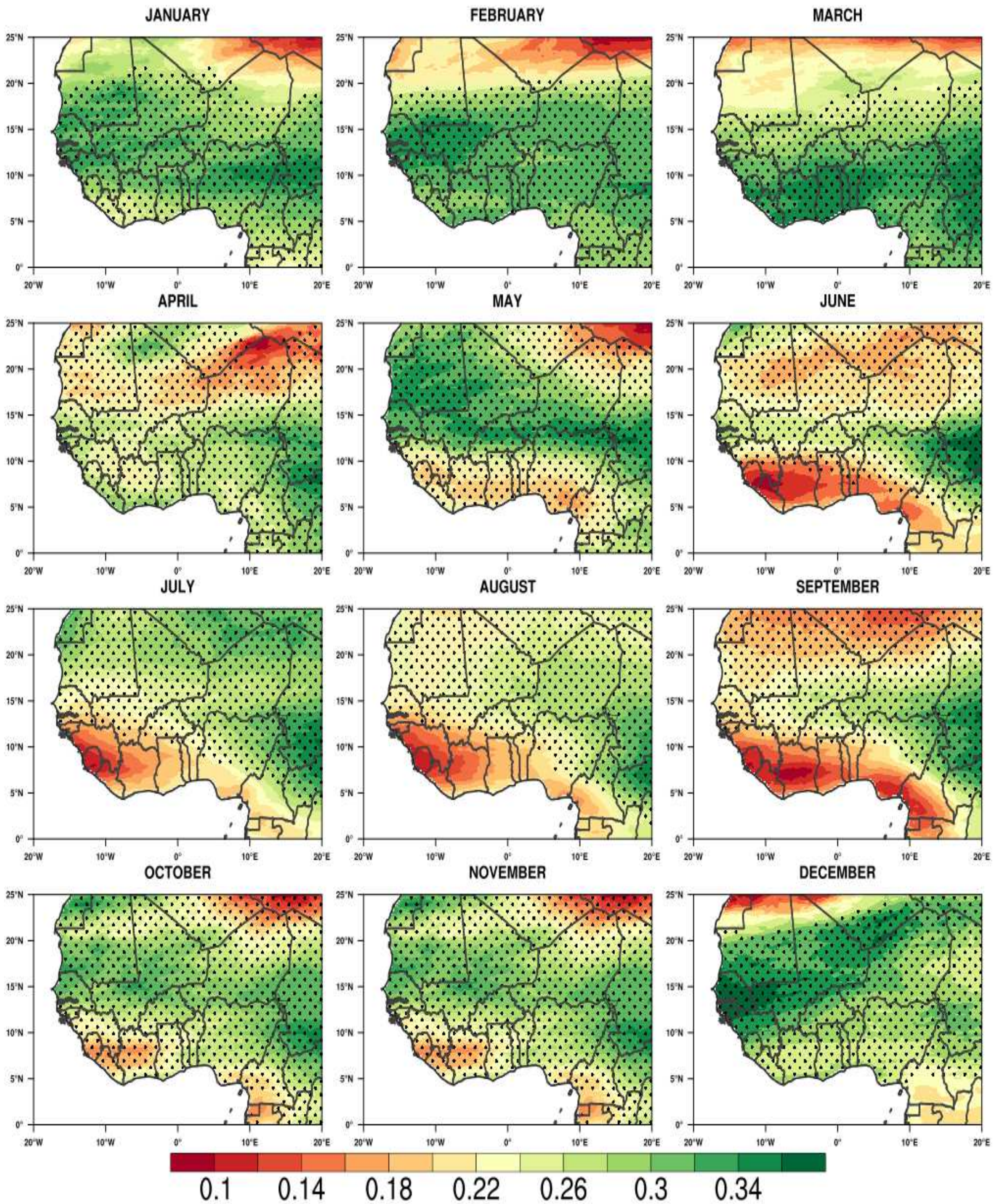

Fig. 16 Trend of Total column ozone over West Africa from 1980-2019; Region with black dots depict where the trend is significant at 95% confidence level.

The result of the Mann-Kendall (MK) trend analysis described by Mann (1945) and Kendall (1975) was performed at 95% confidence level for the months over the study region. The result shows that, there is an increasing trend over the months in the study area. With magnitude of change to be between 0.1 to 0.34. High magnitude was observed during the dry months and considerably low during the wet months. High level of significance was observed in all the months, with the highest in November, which marks the end of the wet season and the lowest in march. as observed in figure. 16 over the West Africa region. In December, January, February and March, between latitude 20 to 25^0N, the level of significant is negligible and the trend over the area is also significantly low. While between latitude 4-20^0N, the trend is most positive over the region in these months. ITD position between these months is between 4-12^0N. over these months the low significance level observed maybe attributed to the outlying position of ITD. The tarrying months is in synchronization with the position of ITD over the region.

CONCLUSION

This study has examined and helped in understanding the influence of ITD on total column ozone over the period between 1980–2019, over West Africa using satellite data. Both geospatial and correlation analyses were performed to show variations in total column ozone and the influences of ITD over TCO in the period of study. In this study, ITD is delineated to propagate between 4-20^0N of the equator. The literature review has provided an insight to the characterization, propagation and significant of ITD over West Africa based on scientific literatures**.**

This study, on the other hand, has provided an update on the trend and connection between these two distinct variables across the West African subcontinent. According to Oluleye and Okogbue (2013), there are additional variables that regulate ozone concentration, with bush burning being the most important. Bush burning is primarily responsible for the generation of photochemically reactive gases such as NO, CO, and hydrocarbons, which combine to create ozone. The assumption is that the dry season is best for ozone generation since there is apparently a lot of biomasses burning going on during this period.

This is not the situation over West Africa, which has the lowest ozone concentration during the dry season. The footprints of the burnings were found to have a minor impact on the overall temporal and spatial distribution of total column ozone. Oluleye and Okogbue (2013) attributed this to the fact that lower atmospheric ozone is primarily controlled by bush burning, while ozone in the upper atmosphere is independent of fluctuating lower atmospheric ozone concentrations, according to Combrink et al. (1995). As a result, the total ozone distribution aligns in the direction of the upper atmospheric ozone control mechanism, which happens to be the ITD over West Africa. The influence of ITD over west Africa is more renowned during the dry months most especially in DJF that the wet months. However, lower concentration is also observed in the dry months as opposed the wet months of JJA over the study region. The major finding of this study is that TCO distributions vary over time and space, but there appears to be a significance variation in the concentration of TCO along the ITD zone. Furthermore, the relationship between ITD and TCO varies across latitudes but appears to be more significant between latitude 10-14^{O}N, which is the savannah region. it's also noted that throughout this study, ozone hole which is designated by concentration less than or equal to 220DU was not recorded. The highest and lowest concentration was 295DU and 227.60DU respectively which gives a difference of about 67DU.

Ethical Approval

Not Applicable

Consent for publication

Not applicable

Consent to Participate

Not Applicable

Competing Interest

Authors have declared that there is no competing interest in this research.

Authors Contribution

Ayomide Arowolo and Ayodeji Oluleye both participated to the interpretation, data analysis and the review of the manuscript.

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Data availability

The datasets analysed during the current study are available at Giovanni at https: //giovanni .gsfc.nasa.gov/ giovanni/ and Era5 https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels-monthly-means?tab=form

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