Assessing the influence of intertropical 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 have influence several atmospheric processes 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 African region as a case study. The study used wind, ozone, and dewpoint temperature data for the period between 1980 and 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 have a higher concentration of TCO than the southern region of the ITD between April and September. However, ITD influence was more visible during the wet months 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 to 18° N, 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° N 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 40 years was also analysed to observe the monthly deviation along the ITD region 40 years, and the spatial distribution of TCO was analysed from January to December. It is of note that during the cause of this study, low-ozone values of 220DU are not found in the study region. The highest and the lowest value of TCO is 295 DU and 227 DU, respectively, with an average range of 68DU.

Keywords Total column ozone · Intertropical discontinuity · Mann–Kendall · West Africa

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 overemphasized. 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 Odadiran, 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, Barnes et al. 2019). 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 (Dueñas 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 Fioletov 1995; Orsolini et al. 1998; Akinyemi 2010).

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 reduce 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 intertropical 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 10° 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 210 N (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 multiday 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.

**Data and methods**

### Description of the area of study

This research focuses on the West Africa subcontinent, which is formed from the Africa continent. As indicated in Fig. 1, the area spans latitudes 0° S to 25° N and longitudes 20° W to 20° E. The climatology of the West African region is governed by the intertropical discontinuity’s latitudinal movement (which is a north–south movement), and the three main climatic zones are the following: Guinea coast (4–8° N), Savannah (8–11° N) and Sahel (11–16° N) according to the classifications defined in Omotosho and Abiodun (2007) and Akinsanola et al. (2015). The Guinea coast is the southernmost point of the Atlantic Ocean, and it has a subhumid climate with annual rainfall ranging between 1250 and 5000 mm. This is the realm of deciduous or semi-deciduous forest that is moist and dry throughout the year.

The Savannah zone is a semi-arid region with annual rainfall ranging from 750 to 1250 mm. 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 750 mm. The average annual temperature is usually over 18 °C. The mean annual temperature in areas within 10° 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 and 35 °C (Food and Agriculture Organization, 2001).

### Data acquisition and analysis

Three datasets were utilized in this study: total column ozone, zonal wind and dewpoint 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 were 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 and December 2019 at 25 km × 25 km resolution.

In order to delineate the position of 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 spatiotemporal variation of total column ozone. This was carried out in order to determine the spatial distribution and temporal variation along the intertropical discontinuity.

The long-term variation of total column ozone is represented by a simple linear regression trend model given as follows:

\[ Y = bt + c \]  

where
- ‘b’ is the slope coefficient of the linear regression line.
- ‘t’ is the time in months (1 to n months).
- ‘c’ is the intercept.

And Y is the monthly mean of total column ozone.

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

\[ \text{Trend} (\% \text{DU per decade}) = \frac{b \times 12 \times 10}{\text{AvGTCO}} \times 100 \]  

where
- ‘b’ is the coefficient of the slope
- And ‘Avg TCO’ is the average value of TCO for the study period

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

\[ \text{ACRV} = \frac{\text{ANNUAL SD}}{\text{ANNUAL MEAN}} \times 100 \]  

where SD = standard deviation.

Ozone monthly time-series data was also standardized in the range of −3 and 3 to assess ozone anomaly. The standardized anomaly, Z, is calculated as follows:

\[ Z = \frac{x - \bar{x}}{Sx} \]  

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 follows:

\[ K = \sum_{i=1}^{n} \sum_{j=1}^{i-1} \text{sign} (x_i - x_j) \]
where $x_i$ and $x_j$ are the value of the sequential generic data, $n$ is the data total length, while sign $(x_i-x_j)$ can be defined as follows:

$$
\text{Sign}(x_i - x_j) = \begin{cases} 
1, & \text{if } (x_i - x_j) > 0 \\
0, & \text{if } (x_i - x_j) = 0 \\
-1, & \text{if } (x_i - x_j) < 0 
\end{cases}
$$

(6)

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

$$
E(S) = \frac{n(n - 1)(2n + 5) - \sum t(t - 1)(2t + 5)}{n(n-1)(2n+5)}
$$

(8)

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:

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

(9)

When a dataset of $n$ variable 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**

The zonal and meridional wind data were downloaded at a standard height of 10 m above the ground level (Table 1).

**Results and discussion**

The intertropical discontinuity over the land is a low-pressure system generated when the northeast and southwest trade winds meet near the Earth’s equator in West Africa. It is vital to remember that the ITD is a zone rather than a demarcation line; nevertheless, the intertropical front (ITF), which is the same as the ITD’s northmost boundary, is defined as a line. ITD 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).

Figure 3 shows the monthly mean position of ITD for a period of 10 years (2010–2019), while Fig. 2 shows the seasonal position of ITD for a period between 1980 and 2019. ITD can be observed to be between 2 and 22° N for the monthly position and between 2 and 20° N for the seasonal position. The surface wind convergence and dewpoint temperature of 15 °C were 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 air masses (Odekunle 2010; Lélé and Lamb 2010; Oluleye and Jimoh, 2017). The northernmost position is seen to be at the northern boundary of West Africa at 22° N. The black continuous line shows the position of ITD at each month over the region, as illustrated in Figs. 2 and 3.

Wind direction and dewpoint temperature for each month were 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 and August (JJA) with its northernmost position at 20° N, while it extended from 10° N. While the season with the least variation was observed at MAM (March, April, May) which span between 6 and 14° 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 to SON, while dry season ranges from MAM to DJF. These dry months have the lowest propagation of ITD, while significant observation was recorded during the wet months as in JJA and SON (Fig. 4).

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).

| Data source, type and description | Spatial resolution | Temporal resolution | Sources | Units |
|---------------------------------|-------------------|--------------------|---------|-------|
| Total column ozone             | 0.25×0.25         | Monthly            | Giovanni and Era-Interim | Du |
| Dewpoint temperature           | 0.25×0.25         | Monthly            | ERA-Interim       | Kelvin |
| Uwind, Vwind                   | 0.25×0.25         | Monthly            | ERA-Interim       | m/s |
Figure 5 depicts TCO range to be between 227 and 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 Figs. 2 and 3. From Fig. 4, ITD position over West Africa in the dry months shows that regions south of the ITD which are 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 depicted between latitude 8–14° 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 Fig. 5. In DJF, north easterly wind dominates most of West African 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 to 2° 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° N, 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° N; 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.
Fig. 3 Monthly mean position of ITD from January to December
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 is dominant which is also regarded as the rain peak over West Africa.

As the moist southwesterly wind stabilizes over the region in JJA when ITD is reaching its northernmost position as observed in Figs. 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, it also marks the beginning of ozone decrement which wind up in returning to January situation as the dry northeasterly 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 the 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 its lower concentration, while south of ITD has the highest concentration of TCO. The pattern 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 shares the same regional characteristics as West Africa as it is also a tropical region; he however attributed these changes to some other meteorological variables. A model study by Haigh (1994)

Fig. 4 Monthly distribution of total column ozone over the West African region, for a period between 1980 and 2019
revealed that a 1% increase in ultraviolet (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 agree with a study by Nishanth et al. (2021), where he also observed a 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 southwest monsoon over the delineated locations.

**TCO variation across latitudes**

TCO trend over the Guinea coast established a relationship between ITD and ozone as shown in Fig. 6. The Guinea coast is a region of maximum precipitation, when compared to the Savannah and Sahel; it lies between 4 and 8° N. The maximum concentration of TCO occurred in August while in July, August and 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 and large wind speed and lower atmospheric temperature which are the features of wet season in the Guinea coast.

During the months of January, February, March and December, which have notably the lowest concentration of TCO, this may also be linked to atmospheric phenomenon associated with the dry period which includes more sunshine hours, high temperature, low humidity and 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 African region. Generally, high concentration was observed between June and September, with concentration between 270 and 282 DU, which can be attributed to increased monsoon rainfall, while low concentration was observed between January and 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 Fig. 6; the study of the trend between latitude 4 and 8° N revealed the variability between the latitudes. As they all increase steadily between January and March, interchanging positions at April, it is observed that concentration at 8° N is now higher than TCO concentration at 4° N. 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.

Figure 7 further describes TCO variation across latitude as observed over the Savannah region. Savannah region is situated between latitude 8–11° N; it has lesser precipitation when compared to the Guinea coast. Maximum concentration is also at July with a TCO concentration of 280 DU at 11° N as compared to Guinea coast which peaked at August and a TCO peak of 282 DU. Over the Savannah region, June, July, August and September have the highest concentration with a difference of less than 5 DU as compared to the Guinea coast which has a difference of about 10 DU, while DJF still maintained the lowest concentration over the region.

This region exhibits a significant difference from the Guinea coast as has observed in January, latitude 8° N 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 to 8° N throughout TCO peak at July as opposed August of the previous zone. Then at August, the latitudinal position concentration is maintained until October which 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 and February progressively until it peaked at July when compared to Guinea coast (Fig. 8).

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 the same with the Savannah region. However, latitudinal positions are maintained until August, which over Sahel region signifies the beginning of the dry season. This also correlated with the position of ITD as observed in Fig. 4; over the months and across latitudinal regions, it shows that June, July, August and September are months were ITD position is northernmost.

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. This 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.

Figure 10 shows annual and mean trend of TCO over the Savannah region, which is located between latitude 8–11° N. The trend is similar to the trend over the Guinea coast but of lower TCO concentration, with a minimum of 240 DU and a maximum concentration of 289 DU, with a difference of 49 DU, from the minimum concentration in January/December to the maximum concentration in July/august and also a mean minimum value of 250 DU and mean maximum

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**Fig. 9** Annual trend of TCO over the Guinea region

![Graph A](image)

**Fig. 10** Annual trend of TCO over the Savannah region

![Graph B](image)
The concentration of TCO was observed to be 280 DU with a mean difference of 30 DU. The lowest concentration of TCO was observed at February 2010, while the highest concentration was observed at June 2013.

Figure 11 shows annual and mean trend of TCO over the Sahelian region, which is located between latitude 12–16° N. The trend is similar to the trend over both the Guinea coast and the Savannah region, having also the same lower TCO concentration with the Savannah region, with a minimum of 240 DU and a maximum concentration of 290 DU, with a difference of 50 DU, also with a minimum concentration in January/December to the maximum concentration in July/August and also a mean value of 250 DU and maximum concentration of 282 DU, with a mean difference of 30 DU.

Figure 12, 13, 14 and 15 shows the regression trend at each latitude from 20N-4N. This is also summarized in Table 2. From 20 to 4° N, an increase in the variation of TCO is observed as the slope of the trend is positive, with the exception of 18° N and 19° N which shows a negative trend/year. Throughout higher latitude, TCO seems to have its maximum concentration to be at 2013 from 20 to 12° N, while from 11° 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 interannual variability of TCO concentration was also observed which can be attributed to variation in tropopause height, air circulation.
Fig. 13 Variation from 8 to 15° N

Fig. 14 Variation from 16 to 19° N
changes, changes in anthropogenic concentration and other atmospheric factors.

**Latitudinal variation with regression trend from 1980 to 2019**

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 a magnitude of change to be between 0.1 and 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 Fig. 16 over the West African region. In December, January, February and March, between latitude 20 to 25° N, the level of significant is negligible, and the trend over the area is also significantly low. While between latitude 4–20° N, the trend is most positive over the region in these months. ITD position between these months is between 4 and 12° N. Over these months, the low significance level observed may be attributed to the outlying position of ITD. The tarrying months are 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 and 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 and 20° N of the equator. The literature review has provided an insight
Fig. 16  Trend in total column ozone over West Africa from 1980 to 2019; region with black dots depict where the trend is significant at 95% confidence level
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 than the wet months. However, lower concentration is also observed in the dry months as opposed the wet months of JJA over the study region.

Findings from this study shows that TCO distributions vary over time and space, but there appears to be a significant 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° N, which is the Savannah region. It is also noted that throughout this study, low ozone values which is designated by concentration less than or equal to 220 DU was not recorded. The highest and lowest concentration was 295 DU and 227.60 DU, respectively, which gives a difference of about 67 DU.

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Author contribution AA and AO both participated in the interpretation, data analysis and the review of the manuscript.

Data availability All data used in this publication can be accessed via https://giovanni.gsfc.nasa.gov/giovanni/#service=TmAvMp&start time=1980-01-01T00:00:00Z&endtime=2019-12-31T23:59:59Z& data=M2IMNXASM_5_12_4_TO3 and via https://cds.climate.copernicus.eu/cdsapp#!/dataset/reaanalysis-era5-single-levels-monthly-means?tab=form.

Declarations

Ethics approval Not applicable
Consent to participate Not applicable
Consent for publication Yes
Conflict of interest The authors declare no competing interests.

References

Akiniyemi ML (2010) Total ozone as a stratospheric indicator of climate variability over West Africa. Int J Phys Sci 5(5):447–451
Barnes PW, Williamson CE, Lucas RM et al (2019) Ozone depletion, ultraviolet radiation, climate change and prospects for a sustainable future. Nat Sustain 2:569–579. https://doi.org/10.1038/s41893-019-0314-2
Bojkov RD, Fioletov VE (1995) Estimating the global ozone characteristics during the last 30 years. J Geophys Res 100:16537–16551
Combrink J, Diab RD, Sokolic F, Brunke EG (1995) Relationship between surface, free tropospheric and total column ozone in two contrasting areas in South Africa. Atmos Environ 29:685–691
Dueñas C, Fernández MC, Cañete S, Carretero J, Liger E 2004 Analyses of ozone in urban and rural sites in Málaga (Spain). Chemosphere 56 (6) 631–639, ISSN 0045–6535, https://doi.org/10.1016/j.chemosphere.2004.04.013, https://www.sciencedirect.com/science/article/pii/S0045653504002814
Ilori OW, Ajayi VO (2020) Change detection and trend analysis of future temperature and rainfall over West Africa. Earth Syst Environ 4(3):493–512. https://doi.org/10.1007/s41748-020-00174-6
Kalita G, Pathak B, Bhuyan PK, Bhuyan K (2011) Impact of zonal wind on latitudinal variation of total columnar ozone over the Indian Peninsula. Int J Remote Sens 32:9509–9520. https://doi.org/10.1080/01431161.2011.564221
Kendall (1975) Rank Correlation Methods, 4th edn. Charles Griffin, San Francisco, CA, p 8
Khan N et al (2020) Spatiotemporal changes in precipitation extremes in the arid province of Pakistan with removal of the influence of natural climate variability. Theor Appl Climatol 142 (3–4):1447–1462. https://doi.org/10.1007/s00704-020-03389-9
Lélé MI, Lamb PJ (2010) Variability of the intertropical front (ITF) and rainfall over the West African Sudan-Sahel zone. J Clim 23(14):3944–4004
Nishanth T, Praseed KM, Satheesh Kumar MK, Valsaraj KT (2014) Influence of ozone precursors and PM10 on the variation of surface O3 over Kannur, India. Atmos Res 138:112–124. https://doi.org/10.1016/j.atmosres.2013.10.022
Oluleye A, Okogbue EC (2013) Analysis of temporal and spatial variability of total column ozone over West Africa using daily TOMS measurements. Atmos Pollut Res 4:387–397

https://
Omotosho JA, Abiodun BJ (2007) A numerical study of moisture build-up and rainfall over West Africa. Meteorol Appl 14(3):209–225
Orsolini YJ, Stephenson DB, Doblas-Reyes FJ (1998) Storm track signature in total ozone during northern hemisphere winter. Geophys Res Lett 25:2413–2416

Sultan B, Janicot S (2003) The West African monsoon dynamics. Part II: the “preonset” and “onset” of the summer monsoon. J Clim 16:3389–3406

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