Australian Journal of Basic and Applied Sciences, 1(4): 497-505, 2007
ISSN 1991-8178

The Influence of Some Atmospheric Phenomena on Total Ozone Concentration over the Tropics

M. L. Akinyemi

Department of Physics, Covenant University, Ota, Nigeria.

Abstract: The influence of some atmospheric phenomena such as the Quassi Biennial Oscillation, the El Nino Southern Oscillation (ENSO) and the extratropical suction pump action on total ozone concentration over the region spreading from latitude 30° south to 30° north were studied using satellite data from 1997 to 2002. These phenomena were observed to contribute significantly to the variability of ozone concentration over the region. The region was divided into twelve latitudinal zones of 5° each. The equatorial zones 5^0S-5^0N recorded high percent variability above 6.5% in at least nine months of the year. This may be attributed to the extra-tropical suction pump action been strongest over the two zones closest to the equator. Zone 30^0S-25^0S recorded a high stability in ozone concentration in March in the six years studied with average variability of 0.7%. The six northern zones recorded higher values of annual coefficient of relative variation (ACRV) of ozone than their southern counterparts in the six years studied with average value of 5.0% and 3.0% respectively. There was a peculiarity in the ozone concentration in 1998, which was a year of El Nino Southern Oscillation (ENSO) occurrence. The ACRV of ozone concentration almost doubled the average zonal values especially at the southern tropics. At zones 5^0S - 15^0S, the average ACRV in 1998 was 4.3% while the average ACRV for the other five years studied was 2%. In the northern tropics, the values of ozone concentration at zones 0^0-15^0 north were very close with a correlation of 0.99, between September to December of the years 1997, 1999 and 2002, while there were noticeable degrees of disparities in the other periods studied. This was attributed to the effect of quasi-biennial oscillation (QBO) at the region in these periods.

Keywords: Ozone variation, quasi-biennial oscillation (QBO), ENSO's effects, the extra-tropical suction pump.

INTRODUCTION

Atmospheric dynamics is known to be a major factor in the variability of stratospheric ozone distribution over the tropics from year to year. It is widely appreciated that the dynamics of the stratosphere is interrelated to a good extent with that of the troposphere (Randel, 1988; Holton *et al.,* 1995). Thus transport and wind motion in the stratosphere are interconnected with that of the troposphere and thus play crucial roles in ozone distribution over the tropic. Besides the atmospheric dynamics, altitudinal locations were also found to contribute significantly to the variability of stratospheric ozone distribution over the tropics. In Akinyemi and Oladiran (2007), Lagos and Dakar, two West African cities at altitudes 10m and 35m respectively above sea level recorded annual seasonal oscillation periods of ozone concentration with values varying between 295 and 375 days. While those of Kinshasa/Brazzaville and Nampula located at altitudes 314m and 440m above sea level respectively in the southern tropical Africa were biannual and varied between 120 and 200 days. This is also in conformity with the studies of Chipperfield *et al*., (1994b) which reported increase in seasonal variations of ozone concentration at locations within the tropical reservoirs with altitudes.

One of the key factors that influence the strength of atmospheric dynamics over the tropics is the extra-tropical suction pump. The extra-tropical suction pump, through wave driven circulations causes large-scale upward transfer of air mass from the tropics into the mid and high latitudinal regions. In a situation where Coriolis forces dominate over the inertial or viscous forces, sloping convection is an effective way of transferring heat energy. This gives the inference that the sources and sinks of atmospheric radiation is the same as that of stratospheric ozone (Holton, 1992).

Corresponding Author: M.L. Akinyemi, Department of Physics, Covenant University, Ota, Nigeria.
E-mail: marvel.akinyemi@gmail.com

A wave induced phenomenon has been observed to dominate the atmospheric circulation especially in the stratosphere and mesosphere and previous studies have established the fact that the tropical upwelling is primarily controlled by the extratropical suction pump action on the tropical stratosphere (Holton *et al.*, 1995; WMO, 1998). The main transport occurring at latitudes near the equator are meridional circulations. A situation where these meridional circulations are driven by breaking and dissipating Rossby waves and gravity waves was termed "extra tropical suction pump" by Holton *et al.,* (1995).

Another strong influencer of the distribution of atmospheric ozone over the tropics is the QBO. The QBO is the phenomenon in which tropical winds in the lower stratosphere switch from easterly to westerly within a space of two years. Thus the QBO plays a dominant role in the inter-annual variability of tropical lower stratospheric temperature, which is directly linked with ozone concentration and distribution (Dunkerton, 1997; WMO, 1998). QBO is driven by wave momentum transport propagating vertically from below. These waves are found to consist mainly in a single westerly Kelvin wave during the descending westerly phase of the QBO and in a single easterly gravity-Rossby wave during the descending easterly phase (Holton and Lindzen, 1972). Rossby (planetary) waves are important for synoptic and planetary scale meteorology (WMO, 1998).

Another atmospheric phenomenon of importance in the variability of ozone concentration over the tropics is the El-Nino Southern Oscillation (ENSO). ENSO is an anomalous large scale ocean-atmosphere system which starts from the southern Pacific Ocean and is propagated by the Atlantic Ocean towards Africa. The system is usually associated with strong fluctuations in ocean currents and surface temperatures, which causes large scale abnormal atmospheric and environmental conditions which also affects the distribution of ozone over the tropics. ENSO is a major example of the interconnectivity between ocean currents and atmospheric conditions.

Justification of the Study:

Although some studies on the tropical ozone and its distribution and variation have been carried out (Randel and Cobb 1994; Shiotani 1992; Shiotani and Hasebe 1994, Akinyemi and Oladiran 2003; Akinyemi and Oladiran 2007), amongst many, there is still need for more detailed study on the influence of some atmospheric phenomena as it relates to total ozone concentration over the tropics. In Akinyemi and Oladiran (2007), the influence of the QBO on total ozone concentration at Lagos Nigeria, was observed to be stronger than that of Dakar Senegal though both station are located within the West African zone. The annual mean values of ozone concentration at Lagos were 10DU higher than those of Dakar in the years of QBO occurrences. While the difference in the years of non- QBO were marginal with an average value of ±1.4DU. Thus it is apparent that the spatial variability of total ozone concentration could be significant even within the same tropical zone. This study establishes other vital factors that affect total ozone concentration

MATERIALS AND METHODS

Ozone variations are controlled largely by atmospheric motion. Consequently there exist strong interactions between total ozone concentration and prevalent atmospheric dynamics on the seasonal-to-inter annual time scales. The data of ozone concentration for latitudes 30º south to 30º north as measured by satellite EPTOMS (Earth Probe Total Ozone Mapping Spectrometer) of NASA Goddard Institute for Space Study USA, from 1997 to 2002 were used in this study.

The annual coefficient of relative variation (ACRV) of ozone for each of the tropical zones was calculated for the six years studied as follows:

$$CRV = \frac{100 \times StandardDeviation}{Mean}$$

$$AnnualCRV = \frac{100 \times AnnualStandardDeviafon}{AnnualMean} \quad (1)$$

Total ozone percent variability at each zone for each month of the year was deduced as follows:

$$A(i) = \frac{R(i)}{Q(i)} \times 100 \quad (2)$$

Where,

- i = Months of the year (1, 2, … 12),

- $A(i)$ = Percent Variability of total ozone concentration for month (i),
- $R(i)$ = Range of total ozone concentration for month (i) in the six years studied,
- $Q(i)$ = Average Ozone concentration

RESULTS AND DISCUSSIONS

The percentage variability of ozone concentration in the twelve zones was studied for each month of the year as indicated in Figures 1 and 2. Figure 1 depicts the duration and extent of the total ozone's percent variability, while Figure 2 portrays the strength and intensity of the atmospheric dynamics over the different locations. It was observed that ozone concentrations at the equatorial zones 0°-5°S and 0°-5°N consistently recorded high percent variability values that were above 6.5% in nine out of the twelve months of the year (Figures 1). This may be attributed to the extra-tropical suction pump action being strongest over the two zones closest to the equator. According to Holton *et al.,* 1995, the extra-tropical suction pump, through wave driven circulations causes large-scale upward transfer of air mass from the tropics into the mid and high latitudinal regions. Thus the extratropical stratosphere and mesosphere act upon the tropical stratosphere on a continuous basis as a kind of global scale fluid-dynamical suction pump. (Dickson, 1968; Holton *et al.,* 1995). Previous researches using other analytical approaches, have confirmed the influence of atmospheric dynamics as a major factor in the variability of stratospheric ozone distribution over the tropics from year to year (Randel, 1988; Holton *et al.,* 1995).

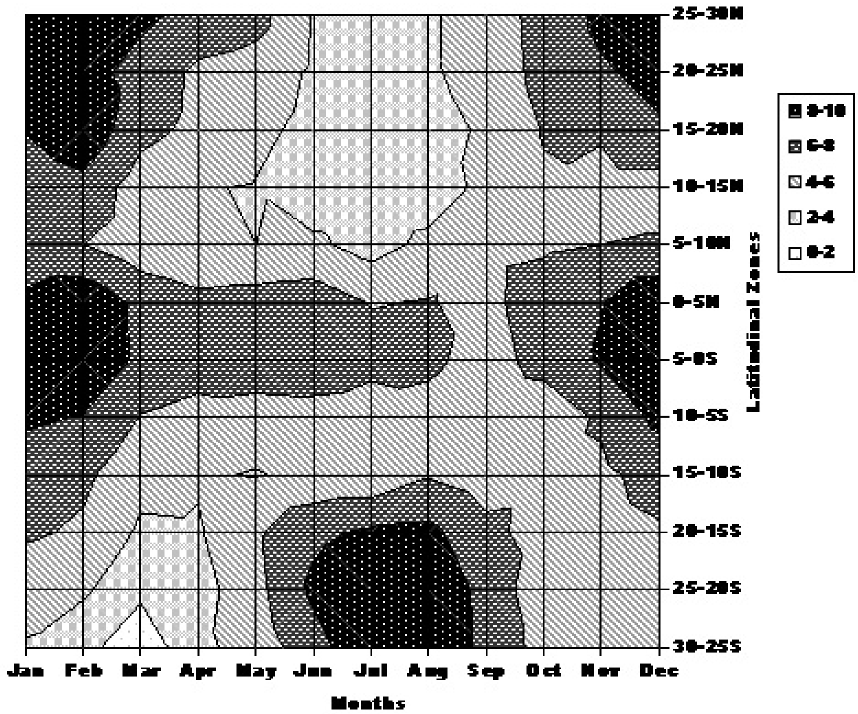


Fig. 1: Duration of Average Percent Variability of ozone from Latitudes 30N to 30S

Zone 5°N-10°N was observed to record no variability value above 6.5% in all the twelve months of the years studied (Figures 1). Also from this zone northwards the number of months with high percent variability values above 6.5% increased as one moved farther away from the equator. It was observed that zone 10°N-15°N recorded two months (January – February); zone 15°N-20°N recorded four months (December to March); zone 20°N-25°N recorded six months (October to March) and zone 25°N-30°N recorded eight months (October to May). Relating these observations to weather patterns, it is well appreciated that the duration of the dry season gets prolonged as one move farther north particularly in the West African region.

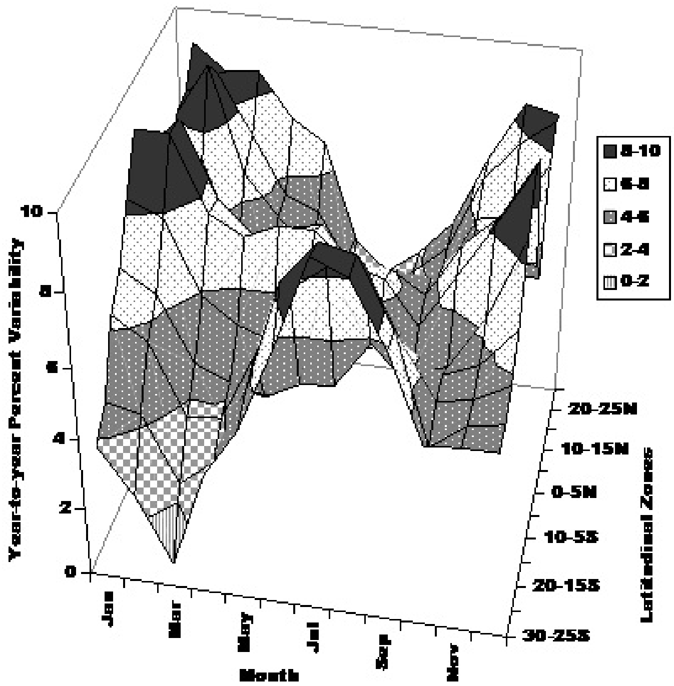


Fig. 2: The Strength of Atmospheric Dynamics at latitudes 30S to 30N as revealed by Average Percent Variability of Ozone

Unlike zone 5°N-10°N, which recorded a noticeable departure from what was observed at zone 0°-5°N, the zone 5°S-10°S had similar trend with that of zone 0°-5°S. The average percent variability of above 6.5% was observed for three consecutive months, between December and February. The last three southern tropical zones, 15°S-20°S 20°S-25°S and 25°S-30°S recorded percent variability of above 6.5% from month of June to September (Figure 1). Prevalent atmospheric dynamics over the different zones is believed to be responsible mostly for these observations.

A high stability in ozone concentration at zone 30°S-25°S with variability of 0.7% in the six years studied was observed in March (Figures 1 and 2). The monthly ozone concentration value at the zone in March was observed to be relatively stable with a maximum value of 265.4DU and a minimum of 263.5 giving a range of 1.8DU and a percent variability of 0.7%. The reason for this strong stability in ozone concentration in the zone in March for the six years studied may be attributed to minimal atmospheric dynamics occurrences over the zone in this particular month (Figures 1 and 2).

The annual coefficient of relative variation (ACRV) of ozone for each of the tropical zones from latitudes 30°S-30°N was calculated for the six years studied. A gradual decrease in ACRV of ozone from an average value of 5.3% at both extreme ends of the tropics (30° north and south) as one move towards the equator, to a minimum average value of 2.0% at zones 15°S to 5°S was observed (Figure 3a). This trend was clearly observed in all the six years of study except in 1998 when the decrease was not as prominent as the other years (Figure 3a).

The average ACRV for the other years studied, 1998 exclusive, was calculated for the twelve zones. Zone 20°N -25°N recorded the highest average ACRV of 5.9% in all the twelve zones, while zone 10°S-15°S recorded the minimum average ACRV of 1.9%. The six northern zones recorded higher values of ACRV than their southern counterparts. The values of the ACRV for zones 25°N-30°N, 20°N-25°N, 15°N-20°N, 10°N-15°N, 5°N-10°N and 0°N-5°N were 5.7, 5.9, 5.6, 5.1, 4.3 and 3.5 percent respectively, while their corresponding southern zones had ACRV values of 4.8, 3.7, 2.8, 2.1, 1.9 and 2.8 percent respectively. The departure of 1998 ACRV of ozone concentration from this trend especially in the southern zones is shown in Figure 3a. At zones 10°S-15°S and 5°S-10°S, the average ACRV in 1998 was 4.3% while the average ACRV for the remaining five years was 2.0% for the same zones. The departure of 1998 ACRV of ozone concentration from the average of the remaining years studied was attributed to the occurrence of the El Nino Southern Oscillation in that year. Thus, through the instrumentality of ACRV though a simple statistical tool, the influence of the ENSO on ozone concentration over the tropics was clearly displayed.

Figure 3(b) shows the regional coefficient of relative variation (RCRV) of total ozone concentration for the six years studied on monthly basis for both the southern and northern tropical regions. The tropics comprises of two regions, the southern and northern tropics which were subdivided into six zones of 5-degree latitude each.

The northern tropic recorded higher levels of RCRV in the first half of the year (January to June) than the southern tropic (Figure 3b). Midway between June and July, the trend was reversed with the southern tropic recording higher levels of RCRV than the northern tropic in the second half of the year. Maximum RCRV for the northern tropic occurred in April and the minimum in September with values of 4.7% and 1.7% respectively. Likewise, the southern tropic had its maximum RCRV in October and the minimum in March with values of 4.6% and 1.9% respectively. This observation is in conformity with the weather seasonal patterns of the northern and southern hemisphere.

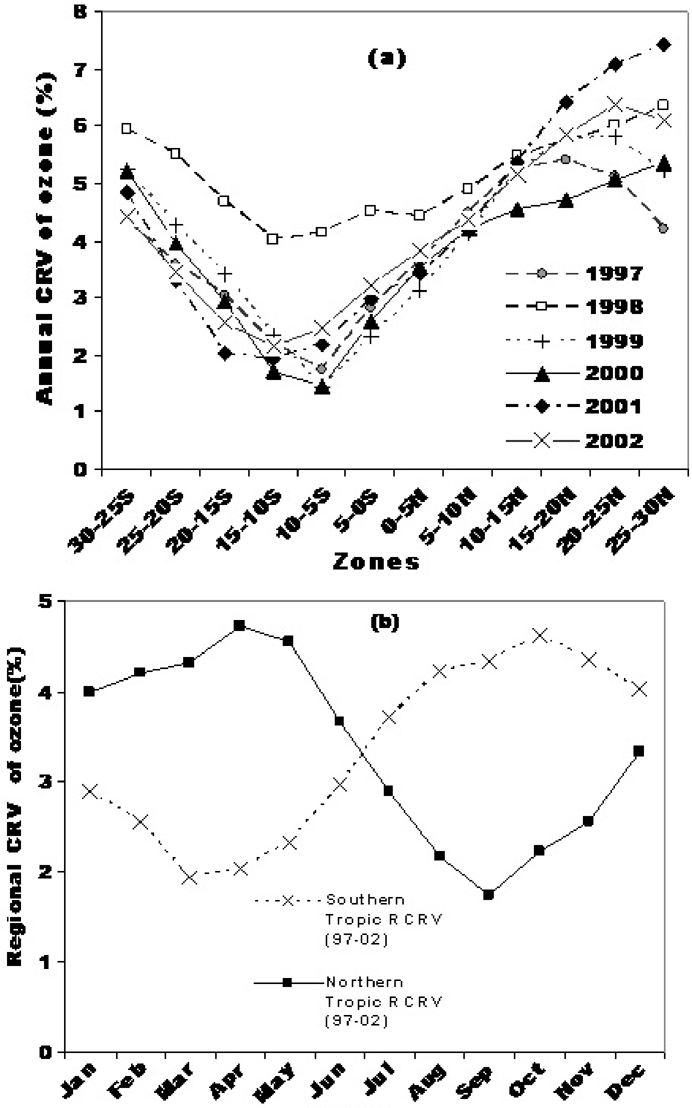
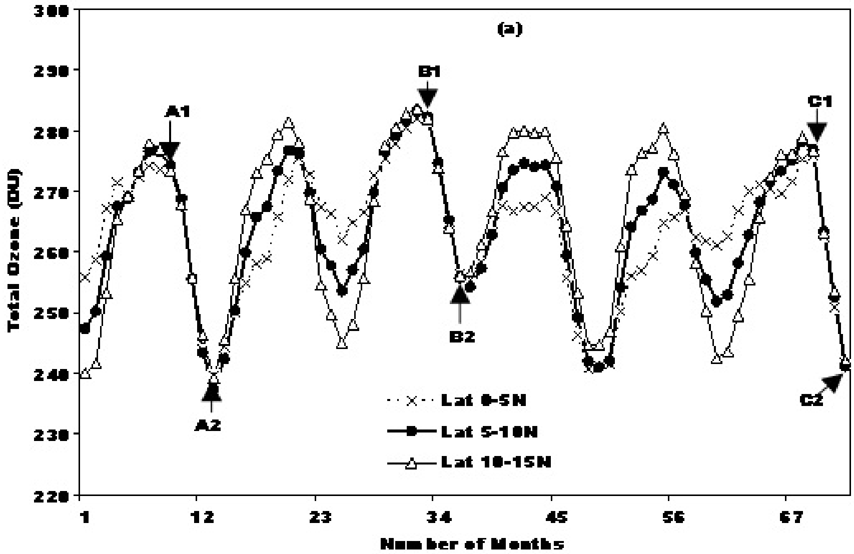
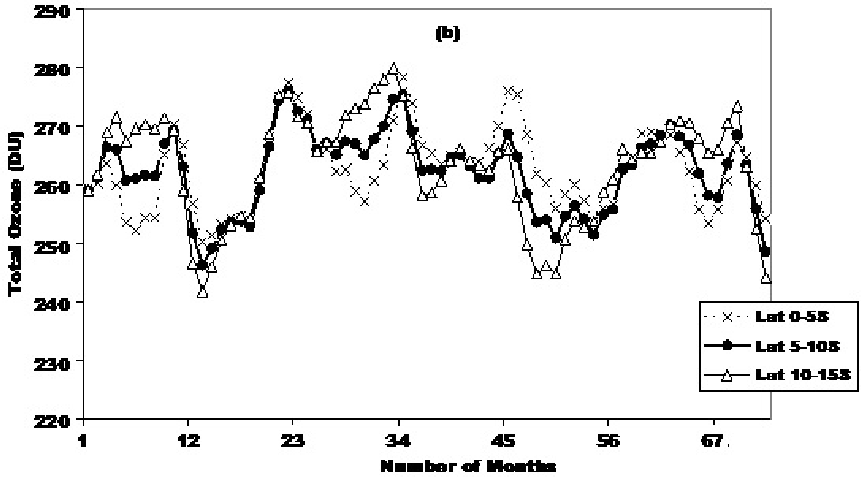


Fig. 3a,b: The annual CRV of ozone in the different tropical zones and the seasonality of ozone over the tropical region respectively (1997-2002).

It was observed that the average monthly values of ozone concentrations were almost the same at the three zones within latitudes 0°-15° north at a certain period within the six years studied. This characteristic which can be attributed to the QBO effects, occurred between September 1997 (A1) and January 1998 (A2) with the three zones recording very close values and a high correlation coefficient of 0.99 (Figure 4a). Similar observations were made between September (B1) and December (B2) 1999, and also between September (C1) and December (C2) 2002 (Figure 4a). Whereas the other data showed some degrees of disparities from one another depending on the time of the year, those periods that fell between A1-A2, B1-B2, and C1-C2 respectively, were closely related as can be observed in Figure 4a.



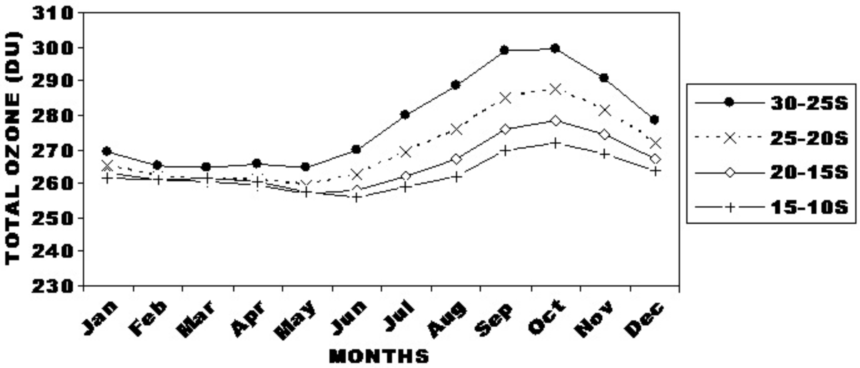


Figures 4(a-b): Some Characteristics of Ozone Concentration at latitudes 0-15° north and south.

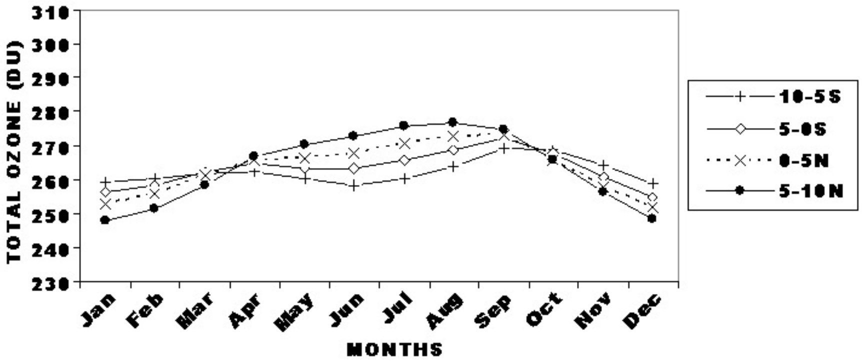
From Figure 4(a), the time-gap between A1-A2 occurrence and B1-B2 occurrence was two years. While C1-C2 occurrence was separated from B1-B2 by time-gap of three years. These observations could therefore be linked with the notable occurrence of quasi-biennial oscillation (QBO). The QBO is a regular feature of the tropical stratosphere. Convective activity and other forcing in the tropics generate a variety of atmospheric waves, some of which propagate vertically from the troposphere into the stratosphere (similar to a wave propagating onto a beach). The QBO causes the reversal of wind in the tropics from easterly to westerly and back to easterly again approximately every two years (Dunkerton, 1997; Hansebe, 1994; Holton, 1972).

It was observed that in the years of QBO occurrences, the values of ozone concentration at the three zones closest to the equator northward are very close. It could also be deduced from Figure 4(a) that the QBO duration over the northern tropics was approximately four months and that the period of separation between one QBO occurrence to the other ranged between 2 and 3 years for the period studied which is in accordance with many previous researches (Holton and Lindzen, 1972; Plumb and Bell, 1982; Hollandsworth *et al.*, 1995). Figure 4(b) shows that the influence of the QBO on mean ozone variation in the southern tropics is not as prominent as that of the northern tropics, as a definite pattern could not be ascertained.

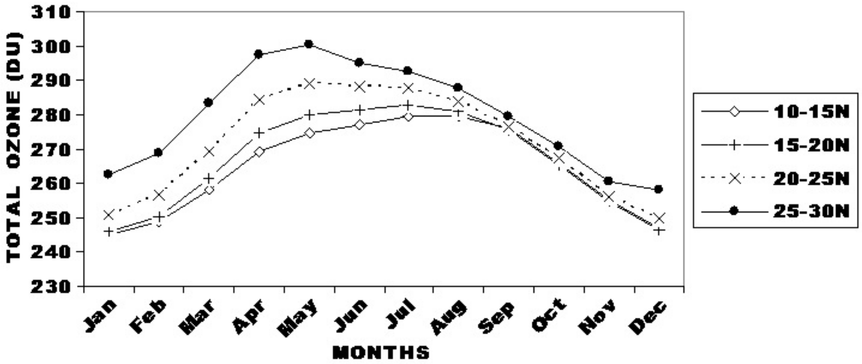
Figures 5(a-c) showed the seasonal variability of ozone for the twelve months of the year and at the twelve zones studied for the period 1997 to 2002. Each of the zones at latitudes 10^0S-30^0S and 10^0N-30^0N (Figures 5a and c) recorded single seasonal oscillation per annum. Also from the two figures there was noticeable increase in seasonal ranges and annual mean of ozone concentration as one moved farther away from the equator. Ozone advection shows the effect of weather systems. This overall way of moving ozone around in the atmosphere is referred to as a transport process and differs from photochemical processes that actually create and destroy ozone. Transport merely redistributes ozone from place to place (Holton, 1992; Cordero *et al*., 2003).



(a)



(b)



(c)

Fig. 5a,b,c): Seasonal Variation of Ozone in the Tropics.

For the southern tropics 10^0S-30^0S seasonal ranges varied between 16.7DU and 34.8DU and for the northern tropics 10^0N-30^0N, it varied between 34.7DU and 42DU. While the annual means varied between 262.7DU and 278DU, 264.6DU and 279.6DU respectively. Seasonal ranges were more pronounced in the northern tropics than in the south. For zones 10^0S-30^0S (Figure 5a) well-defined seasonal maxima occurred around September/October while the seasonal minima were not well defined, but a long stretch from February to June. For zones 10^0N-30^0N (Figure 5c), seasonal maxima varied between April to August, and seasonal minima between December and January.

The two south zones closest to the equator latitudes 0^0S-10^0S (Figure 5b) had biannual seasonal oscillation, which had its peak in April and September with seasonal ranges of 9DU and 17DU for zone 0^0S-5^0S, 4.5DU and 11.1DU for zone 5^0S-10^0S. The two northern zones 0^0N-10^0N each recorded single seasonal oscillation per annum and seasonal ranges of 20DU and 29DU respectively. So in all for the northern tropical zones, seasonal ranges varied between 20DU and 42DU.

Conclusion:

A high percent variability value of ozone concentrations in nine out of the twelve months of the year was observed at the equatorial zones 0°-5°S and 0°-5°N. This was attributed partly to the extra-tropical suction pump action being strongest over the two zones closest to the equator and a sign of strong atmospheric dynamics over the zones. Previous researches have confirmed the influence of atmospheric dynamics on the variability of stratospheric ozone distribution over the tropics from year to year (Randel, 1988; Holton *et al.,* 1995). The dynamics of the stratosphere is interwoven to a good extent with that of the troposphere and these play crucial roles in ozone distribution over the tropic.

On the other hand, zone 5°N-10°N did not record variability value of above 6.5% in any of the twelve months of the years studied. Also from this zone northwards the number of months with high percent variability values above 6.5% increased as one moved farther away from the equator which was observed to have a strong positive correlation with weather system generally in the zone, especially within the West African region.

A strong stability in ozone concentration at zone 30°S-25°S was observed, with variability of 0.7% in the month of March of the six years studied. The monthly ozone concentration value at the zone in March was observed to be relatively stable with a range of 1.8DU. The reason for this strong stability in ozone concentration in the zone for the six years studied may be attributed to minimal atmospheric dynamics occurrences over the zone in March. The strong stability observed at zone 30°S-25°S in March when compared to the high variability at zones 0°-5°S and 0°-5°N proved the significant differences in spatial variability of atmospheric dynamics on ozone concentration within the tropics. This further showed why the variation of ozone concentration over the tropics cannot be over generalized.

The six zones in the northern tropics 0°N to 30°N recorded single seasonal oscillation per annum with seasonal ranges varying between 20DU and 42DU. Similar observations were made at the zones within latitudes 10°S to 30°S with their seasonal ranges varying between 16.7DU and 34.8DU.

The ACRV of ozone decreased from both extreme ends of the tropics (30° north and south) as one moves towards the equator from an average value of 5.5% to a minimum average of 2.0% which occurred at zones 15°S-5°S. The northern zones recorded higher values of ACRV of ozone than their southern counterparts in the six years studied with average value of 5.0% and 3.0% respectively.

In general, global occurrence such as the ENSO of 1998 was found to have significant impact on the ozone concentration over the studied area. At zones 5^0S - 15^0S, the average ACRV in 1998 was 4.3% while the average ACRV for the other five years studied was 2%. This sharp difference revealed the impact of the ENSO occurrence in 1998 at the zones. The impact was more pronounced over the southern tropics than the north. This is to be expected since ENSO starts from the southern Pacific Ocean and is propagated by the Atlantic towards the south of Africa and eventually to the north of Africa (Shiotani, 1992). The observed difference on the impact of ENSO over the southern and northern topics was another pointer to the significance in spatial variability of atmospheric phenomena on tropical ozone concentration.

This is in line with (Akinyemi 2005) which showed that ozone concentration over two southern tropical stations Kinshasa/Brazzaville and Nampula revealed the significant impact of the 1998 El Nino occurrence over the stations. For instance Kinshasa/Brazzaville had a record CRV of 5.1% in 1998 compared to the other five years with an average CRV of 2.7% only. Similarly, Nampula also recorded its highest CRV of the same value of 5.1% as Kinshasa/Brazzaville in 1998. Akinyemi (2005) also observed a strong positive correlation between the temperature trends and ozone concentration over the two stations. A comparison of the ACRV with the annual temperature indicated that the maximum annual temperature for the six years studied in the two stations occurred in 1998 with a similar trend as revealed by ozone concentration, spreading as far as latitudes 10°N.

REFERENCES

Akinyemi, M.L. and E.O. Oladiran, 2003. Stratospheric Ozone Trends over the Tropics. ASSET Series B, 2(2): 63-72.

Akinyemi, M.L., 2005. The Variation of Total Ozone Concentration over Tropical Africa. PhD Thesis, University of Ibadan, Nigeria.

Akinyemi, M.L. and E.O. Oladiran, 2007. Temporal and Spatial Variability of Ozone Concentration over Four African Stations. ANSI J. App. Sci., 7(6): 913-917.

Chipperfield, M.P., L.J. Gray, J.S. Kinnersley and J. Zawodyn, 1994b. A Two- Dimensional Model Study of the QBO Signal in SAGE II NO_2 and O_2. Geophy. Res. Lett., 21: 589-592.

Cordero, E., P.A. Newman, C. Weaver and E. Fleming, 2003. Stratospheric Dynamics and the Transport of Ozone and Other Trace Gases. http://hyperion.gsfc.nasa.gov/ code 916 recovered on 18/6/2004

Dunkerton, T.J., 1997. The Role of Gravity Waves in the Quasi-Biennial Oscillation. J.Geophy. Res., 102: 26053-26070.

Hasebe, F., 1994. Quassi Biennial Oscillation of Ozone Diabatic Circulation in the Equatorial Stratosphere. J. Atmos. Sci., 51: 729-745.

Hollandsworth, S.M., K.P. Bowman and R.D. McPeters, 1995. Observational study of the quasi-biennial oscillation in ozone. J. Geophys. Res., 100: 7347-7361.

Holton, J.R. and R. Lindzen, 1972. An updated theory for the quasi-biennial cycle of the tropical stratosphere. J. Atmos. Sci., 29: 1076.

Holton, J.R., 1992. An Introduction to Dynamic Meteorology. Academic Press, San Diego, pp: 511-554.

Holton, J.R., P.H. Haynes, M.E. McyInty, A.R. Douglas R.B. Rood and L. Pfister, 1995. Stratosphere Troposphere Exchange. Review of Geophy., 33(4): 403-439.

Plumb, R.A. and R.C. Bell, 1982. A model of the quasi-biennial oscillation on an equatorial beta-plane. Quart. J. Roy. Meteor. Soc., 108: 335-352.

Randel, W.J., 1988. The seasonal evolution of planetary waves in the southern hemisphere stratosphere and troposphere. Quart. J. Roy. Meteor. Soc., 114: 1385-1409.

Shiotani, M., 1992. Annual quasi-biennial, and El Nino-Southern Oscillation (ENSO) time-scale variations in equatorial ozone. J. Geophys. Res., 97: 7625-7633.

World Meteorological Organization, (WMO), 1998. Scientific Assessment of Ozone Depletion, Global Ozone Research and Monitoring Project Report No., 44, Les Diablerets, Switzerland.