

Implications of Stratospheric Ozone Variability For Climate Change Over Some Selected Stations In Northern Nigeria.

*Ojoye, S, ²Sulyman, A.O, ¹Odekunle, M.O & ¹Adenle, A.A.

¹Department of Geography

²Department of Urban and Regional Planning

Federal University of Technology

Minna, Niger State, Nigeria

*Corresponding Author: dejoyo@futminna.edu.ng

ABSTRACT

The sun is the major source of energy that drives the entire atmospheric processes. The insolation from the sun is responsible for the wind pattern experienced on earth. The harmful part of the radiation from the sun is shielded from the earth by two layers namely; the stratospheric ozone and the tropospheric ozone. In this paper, a study of the statistical analysis of total ozone concentration as released by Earth Probe Total Ozone Mapping Spectrometer (EPTOMS Satellite) was used to get the total ozone variability in some selected stations in northern Nigeria. The annual coefficient of relative variability (ACRV) of ozone at these stations over a period of 72 months from January 2009 to December 2014 was carried out. The climate variables of average annual temperature and rainfall for this stations were obtained from the Nigerian Meteorological Agency (NIMET) office in Oshodi, Lagos. The climatological station used for the study include; Yelwa, Sokoto, Zamfara, Katsina, Kano, Dutse, Damaturu and Maiduguri. The results of the findings showed that there was a variation in the average value of stratospheric ozone between 4.2% and 6.8%. A strong positive correlation of 0.92 was observed between the ACRV of ozone and average annual temperature, which increased from 12°C at Kebbi to 25°C at the hot arid north of Maiduguri. Also a negative correlation of -0.32 was observed between the ACRV of ozone and the average annual precipitation over the region which varied from an average of 718.4mm to 1053.7mm. Maximum ozone inter-annual variability of between 6% and 10% occurred between December and March, coinciding with the dry Harmattan season, while the minimum of between 2% and 4% occurred between June and September coinciding with the raining season. The findings of this study reveals that the higher temperature characterize of the study area could be accounted for by the ACRV. This variability of ozone if properly monitored will assist in the prediction of rainfall and temperature variability as the thermal processes observed in the atmosphere is responsible for the convective activities. It will also serve as a good tool for the monitoring of climate variability in the zone.

Keywords: Stratospheric Ozone Variability, Climate Change, Stations, Northern Nigeria, Implications

Aims Research Journal Reference Format:

*Ojoye, S, ²Sulyman, A.O, ¹Odekunle, M.O & ¹Adenle, A.A. (2016): Implications of Stratospheric Ozone Variability For Climate Change Over Some Selected Stations In Northern Nigeria.. *Advances in Multidisciplinary Research Journal*. Vol. 2. No. 3, Pp 245-252 .

1. INTRODUCTION.

Air in the troposphere has relatively low ozone concentrations, except in highly polluted urban environments. Even polluted regions are relatively low when compared to stratospheric levels. As this "ozone clean" air moves slowly upward in the tropical stratosphere, ozone is being created by the slow photochemical production caused by the interaction of solar UV radiation and molecular oxygen. Ozone is created in this region because it is here that the Sun, positioned high overhead during the day all year long, is most intense. There is enough of the necessary sufficiently energetic UV light to split apart molecular oxygen, O₂, and form ozone. It typically takes more than 6 months for air at 16 km (near the tropical tropopause) to rise up to about 27 km.

Even though ozone production is small and slow in the lower tropical stratosphere, the slow lifting circulation allows enough time for ozone to build-up. This ozone has a higher density up to about 27 km. It is this that is commonly referred to as the "ozone layer". (Bojkov and Fioletov, 1995; Orsolini *et al.*, 1998). Ozone advection shows the effect of weather systems. Transport and wind motion in the stratosphere are interconnected with that of the troposphere. This is important in order to balance both the chemical processes and radiative flux in both regions. This overall way of moving ozone around in the atmosphere is referred to as transport process. It is different from photochemical processes that actually create and destroy ozone.

Transport merely redistributes ozone from place to place (Holton, 1992; Cordero and Forster 2006). There is a linkage between ozone depletion and climate change but ozone depletion is not known to be the major cause of climate change. Ozone in its formation performs two basic functions by absorbing the ultraviolet radiation which heats the earth surface from above and also absorbs the longwave infrared radiation that is emitted by the earth surface. Therefore, the changes in the earth ozone concentration will depend on the altitude. The major losses observed in ozone concentration is largely due to human activities which have a cooling effect on the earth's surface. (Sivasakthivel and Siva, 2011).

In the semi-arid mid-north, annual rainfall averages about 480 mm. The far northern portion of Nigeria is hot and arid and stretches into the Chad area with rainfall averaging about 400 mm and less than 250 mm in the Maiduguri and Damaturu areas. All this changes to the rainfall regime in this zone is attributable to the convective activities that takes place in the zone. This is a major reason why the study of the insolation at this zone is important. The duration of the dry season get prolonged as one moves farther north. The average temperature South of Latitude 10° is 38°C , and in the north of latitude 12° is 44°C , which has been attributed to the depletion of the ozone layer (Ojoye, 2012).

The climate system encompasses complex interactions between the different subsystems such as the oceans, the land surface, the ice coverage of land and oceans, thus incorporates many feedbacks. It has also been proven by Forster *et al.*, (1997) and Hansen *et al.*, (1997) that the stratosphere is a sensitive component of the climate system, which can affect the troposphere through coupling mechanisms and thereby triggers the climate of a place. According to the study of Sivasakthivel and Siva (2011), they observed that the redistribution of ozone in the atmosphere has some link with the weather pattern variation. It is pertinent to note that areas of high ozone depletion are characterized by high temperature. This study thereby assesses the total concentration of ozone in the stratosphere as a cause of the observed climate change in some selected parts of Northern Nigeria and in order to achieve this aim, the study examines the linear trend in temperature and rainfall over the study area and examined the relationship between ozone variability and climatic variability over the time under study.

In a comparison of future ozone predictions in 10 chemistry climate models (Stevenson *et al.*, 2006) the net tropospheric ozone response is determined by the balance between increases in water vapor decreasing the concentration of ozone and the increase in STE increasing the concentration of ozone. Climate models almost universally predict an increase in the exchange of mass from the stratosphere to troposphere associated with climate warming (Butchart *et al.*, 2006) with commensurate, although highly uncertain increases in the exchange of ozone between the stratosphere and troposphere (Collins *et al.*, 2003; Hegglin and Shepherd, 2009). Historic transient simulations have also indicated the stratospheric mass flux into the troposphere has increased during the latter part of the 20th century (Butchart *et al.*, 2006) suggesting increased STE should already be occurring. Hegglin and Shepherd (2009) suggest that the stratospheric flux of ozone has been increasing at a nearly constant rate in the NH of approximately 2 %/decade since 1970. By 2100, Hegglin and Shepherd (2009) predict this alone will have increased ozone throughout much of the troposphere by 30 % compared to 1970.

1.1 The Study Area

The Northern Nigerian lies between 7°N and 12°N of the equator and 4°E to 14°E of the greewich meridian which is known to be vulnerable to climatic and ecological anomalies such as flood, cyclones, drought and desertification. The anomaly had enormous socio-economic impacts in the region where pressure on available resources is on the increase amidst fluctuations of rainfall (Ojoye, 2012). Rainfall in the region is highly seasonal and variable in time and space, with 2 seasons, the wet and dry. The dry season is from October to April/May, while the highly variable seasonal rainfall is concentrated in a short wet season and runs from May to September.(Odjugo, 2010).

Annual rainfall in the region is marked by clear seasonal variation and by virtue of the geographical location; rainfall is the most critical element of climate. The effect of the higher and cumulative rainfall variability over this zone is presently not well understood but Ojoye, (2012) explained the fundamentals in terms of the atmospheric systems controlling the whole region. The temperature of the region is generally sufficient throughout the year to allow plant growth but the insufficient rainfall, its variability and the single short rainy season imposed serious limitations on the growth of viable vegetal cover. The region is rich in agricultural production, but the large inter annual variability of rainfall produces dry spells which lead to severe and widespread drought which imposes serious socio-economic constraints.

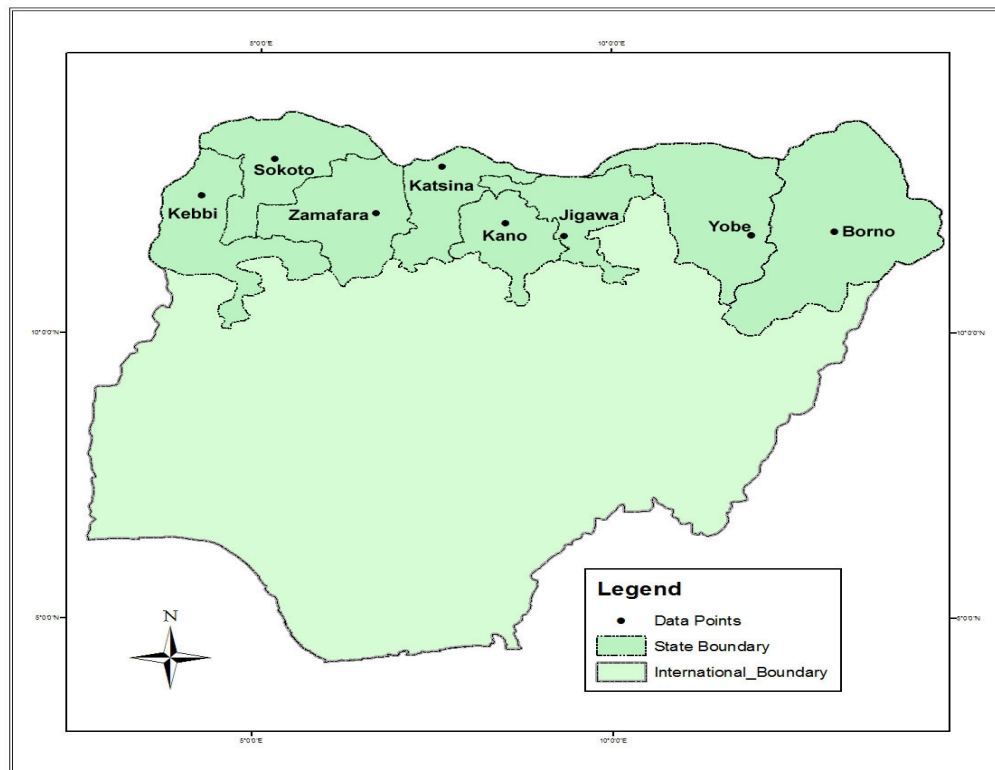


Figure 1: The study area showing the data collection points

The climate of the zone is dominated by the influence of three major meteorological features, namely; the Tropical Maritime (mT) air-mass, the Tropical Continental (cT) air-mass, and the equatorial easterlies. The first two air-masses (mT and cT) meet along a slanting surface called the inter-tropical discontinuity (ITD); the equatorial easterlies are rather erratic and relatively cool air masses from the east in the upper troposphere along the ITD. The movement of the ITD Northwards across the country between January and August, and its retreat from the Southern fringe of the Sahara desert, after August, causes much of Nigeria to experience seasonal rainfall (Ojoye, 2012).

Within the mT air mass is enclosed a number of rainfall producing system such as the disturbance lines (especially the easterly waves), squall lines and the two tropospheric jet streams. The magnitude of these systems was reported to be the contributing factor that influences the amount and seasonal distribution of rainfall over the region.

2. MATERIALS AND METHODS.

Total ozone data were collected from the NASA TOMS website for a period of six years (2009 to 2014). The average annual meteorological data of rainfall amount and temperature over eight stations in northern Nigeria were collected from Nigeria Meteorological Agency, Oshodi, Lagos State Nigeria. In order to study the long term trends in the three variables (Ozone, Rainfall and temperature) a linear regression analysis was used on the daily means.

The long term trend is given as

$$Y = a + bX + e \text{ ----- } 1.0$$

Y = Rainfall variation or Temperature variation

X= ozone variation

a and b are constants of regression.

In order to compute the annual coefficient of relative variation for the ozone values ,the standard deviation (SD) was deduced and the annual coefficient of relative variation (ACRV) was calculated thus:

$$ACRV = \frac{A(t) \times \sigma}{A(mean)} \times 100 \text{ (2)}$$

Where:

ACRV = Annual Coefficient of Relative variation.

A(t) = Annual total

A(mean) = Annual mean

σ = Standard Deviation.

The standardized anomaly index and the coefficient of relative variation were used to compare the relative variability of rainfall and temperature with the ozone value received at the time of study.

The linear multiple regression analysis was used to investigate the relationship between the climate variable and total ozone variability over the study area. The linear multiple regression equation is given as

$$Y = a + b_1X_1 + b_2 \text{(3)}$$

Where:

Y = ozone variability

X₁ and X₂ are climate variables.

3. RESULTS AND DISCUSSION

3.1 Spatial Variability of Climatic variables.

The trend analysis carried out on the temperature values reveals that the mean temperature during the dry season is on the decrease over the years under study while the rainfall keep increasing, an indication that for the six years under study, the northern part of Nigeria is getting wetter. This results corroborate the earlier findings of Odekunle, *et.al.*, (2008) , Dami, (2008) and Ojoye, (2012) when they found out that the rainfall received in the northern part of Nigeria after the drought episode of 1998 has been on the increase.

In order to investigate the relationship between climate and total ozone variability over Northern Nigeria, a linear multiple regression analysis carried out indicates that the observed variability in the temperature and rainfall over the area could be explained by the annual variability in the stratospheric ozone. The coefficient of multiple determination R^2 reported a 79% variation due to ozone variability in temperature and rainfall combined, a 54% variation on temperature alone and 1% variation on rainfall alone. This inferred that the rainfall received at the station is not connected to the ozone variation at the zone and an indication that the increasing trend in temperature of the area could be attributed to stratospheric ozone variability.

Table 1.0 shows the ACRV at the various stations used for the study. In the six years studied, minimum average ACRV value of 4.2% was observed at Kebbi, 6.0 % in Zamfara, 5.2% in Dutse, 6.7% in Kano, 6.1% in Katsina, 6.5% in Sokoto and 6.8 % at Maiduguri and Damaturu an indication that Maiduguri and Damaturu having the highest variation and Kebbi the lowest. This explains the reason why temperature is higher at this two locations above other locations used for the study. This may not be unconnected with the Sun's inclination and the aridity of the area.

The ACRV of ozone when correlated with average zonal temperature and rainfall revealed significant positive and negative trends respectively in the eight stations. The correlation coefficient of ACRV with temperature was 0.70 in Kebbi, 0.97 in Sokoto, 0.96 in Zamfara, 0.95 in Katsina, 0.92 in Kano, 0.90 in Jigawa and 0.98 in both Damaturu and Maiduguri. This yielded an average positive correlation of 0.92 (Table 2.0). The average zonal temperature increased from 38.4°C at Kebbi to about 45.2°C at Yobe (Table 1). This corroborate the findings of Azeem *et al.*, (2001) and Akinyemi, (2010) when they observed that variations observed in total ozone concentration are among other things, directly linked with photochemical coupling between ozone and temperature. The correlation coefficient of ACRV with rainfall as revealed by Table 2.0 was -0.34 for Kebbi, -0.26 for Sokoto, -0.37 for Zamfara, -0.42 for Katsina, -0.23 for Kano, -0.36 for Jigawa, -0.30 for Yobe and -0.33 for Maiduguri. This yielded a notable inverse relation between rainfall and the ozone average ACRV.

Table 1.: The average ACRV, Temperature and Rainfall in the selected stations in some parts of Northern Nigeria

| Stations | Average. ACVR | Average AnnualTemp(0C) | Average Annual Rainfall(mm) |
|----------|---------------|------------------------|-----------------------------|
| Kebbi | 4.2 | 38.4 | 839.3 |
| Sokoto | 6.5 | 41.3 | 953.9 |
| Zamfara | 6.0 | 41.8 | 934.9 |
| Katsina | 6.1 | 41.7 | 718.4 |
| Kano | 6.7 | 45.6 | 905.1 |
| Jigawa | 5.2 | 39.3 | 1053.7 |
| Yobe | 6.8 | 45.2 | 720.4 |
| Borno | 6.8 | 44.9 | 739.1 |

Table 2.: Correlation of ACRV and average annual rainfall and temperature

| Stations | ACVR Vs. Average AnnualTemp(0C) | ACVR Vs. Average Annual Rainfall(mm) |
|----------|---------------------------------|--------------------------------------|
| Kebbi | 0.70 | -0.34 |
| Sokoto | 0.97 | -0.26 |
| Zamfara | 0.96 | -0.37 |
| Katsina | 0.95 | -0.42 |
| Kano | 0.92 | -0.23 |
| Jigawa | 0.90 | -0.36 |
| Yobe | 0.98 | -0.30 |
| Borno | 0.98 | -0.33 |

3.2 Inter-annual variability of total column ozone

For further investigation of the relationship between total ozone distribution and the climatic variation over Northern Nigeria, seasonal percentage variability of monthly ozone concentration over the period of seventy-two months(January, 2009 to December, 2014) was computed for the eight stations. Figure 2. make the changes in the magnitudes of variability in ozone trend distinct and easy to identify. The figure shows there was an increase in the average ozone variability from December to March coinciding with the peak of harmattan period in the northern hemisphere when the planetary wave causes strong coupling of the stratosphere and the troposphere resulting in large year-to-year or inter-annual ozone variability.

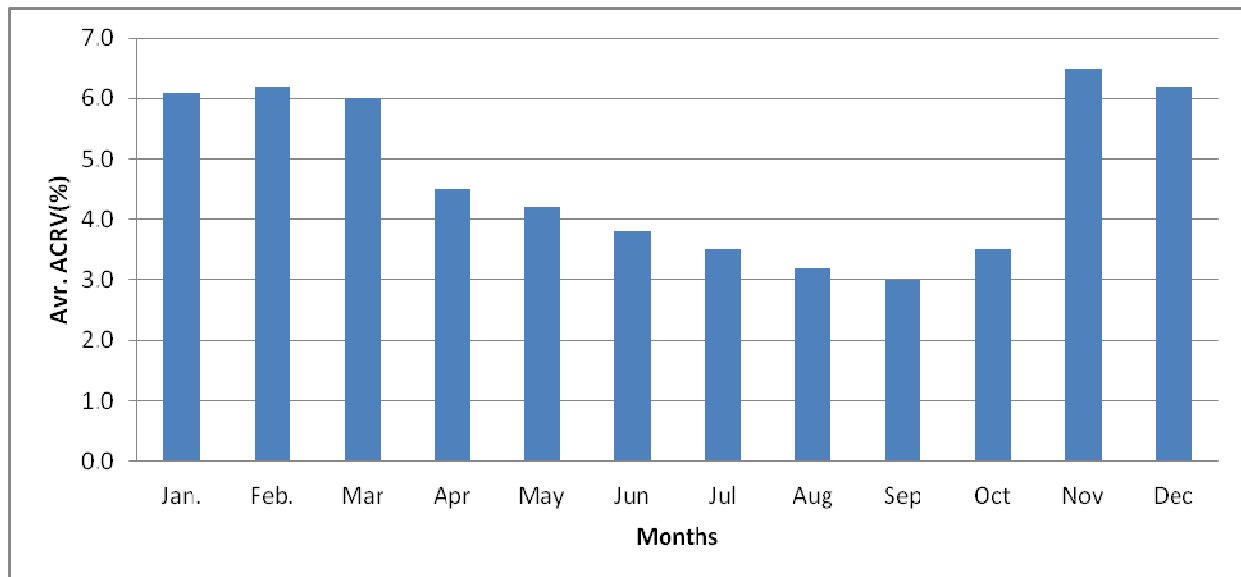


Figure 2: Inter-annual variability of ozone (2009-2014)

This results corroborated the findings of Fusco and Salby, (1999) and Akinyemi (2010) when inter-annual variability was compared for different stations over Africa. The observed maximum inter-annual fluctuations in ozone column from December to March may be associated with the variation in the strength of the local harmattan wind, a prevailing atmospheric dynamics over Northern Nigeria during that period.

The year-to-year variability in intensity of the planetary scale atmospheric dynamics is responsible for driving the harmattan wind and could be suggested to be responsible for the high inter-annual fluctuation in total ozone column observed between December and March. The period of maximum ozone concentration coincided with the period of minimum ozone variation which happened to be the peak of tropical over Northern Nigeria between June and September.

This observation could possibly be attributed to reduction in the strength of the extra tropical suction pump (ETSP) action responsible for the transportation of ozone from the tropical stratosphere into the mid and high latitudinal region. The ETSP is a phenomenon, whereby the extra-tropical stratosphere and mesosphere through relevant eddy effects act globally on the tropical stratosphere as a fluid-dynamical suction pump. Thus it may be inferred that there is interconnectivity between reduction in the strength of the ETSP and ozone distribution during the tropical rainfall season.

4. CONCLUSION

The average coefficient of relative variability (ACRV) in ozone was between ACRV computed for eight stations in northern Nigeria between it and climate variability. The mean annual rainfall and temperature was used as an index of climate variability between 2009 and 2014. The results revealed an average correlation of 0.92 between ACRV and average annual temperature, a result of which manifested in a high temperature received at the stations. The coefficient of determination R^2 computed for ACRV and temperature revealed that the ACRV explained 79% variation in temperature and a 1% variation in rainfall, an indication that the rainfall variability observed at the station cannot be attributed to the ACRV observed over the years under study in the zone. These observations suggest significant association between the radiative activities and total ozone redistribution over the region and the possibility of total ozone trend over Northern Nigeria being used as an indicator of climate variability over the zone.

REFERENCES

1. Akinyemi, M.L. (2010). Total ozone as a stratospheric indicator of climate variability over West Africa. *International Journal of the Physical Sciences*. 5(5), pp. 447-451
2. Allen J. (2004). Ozone and Climate Change. National Aeronautics and Space Administration (NASA), Earth Observatory Release.
3. Azeem S.M.I, Palo S.E, Wu D.L., Froidevaux L (2001). Observation of 2-day Wave in UARS MLS Temperature and Ozone Measurements, *Journal of Geophysics*. 28(16): 3147-3315.
4. Bojkov R.D, Fioletov V.E. (1995). Estimating the global ozone characteristics during the last 30years, *Journal of Geophysics*. 5 (100):16537-16551.
5. Butchart, N., Scaife, A. A., Bourqui, M., de Grandpre, J., Hare, S. H. E., Kettleborough, J., Langematz, U., Manzini, E., Sassi, F., and Shibata, K. (2006). Simulations of anthropogenic change in the strength of the Brewer–Dobson circulation, *Clim. Dynam.*, 27, 727–741,
6. Collins, W. D., Rasch, P. J., Boville, B. A., Hack, J. J., McCaa, J. R., Williamson, D. L., and Briegleb, B. P. (2006) The formulation and atmospheric simulation of the community atmosphere model version 3 (CAM3), *J. Climate*, 19, 2144–2161,
7. Cordero E.C, Forster P.M (2006). Stratospheric variability and trends in IPCC model simulations, *Journal of Atmospheric Chemistry* 6: 7657–7695.
8. Dami, A. (2008). A Predictive Study of Environmental Change in the Nigeria's section of the Chad Basin. *Unpublished PhD Thesis, Obafemi Awolowo University, Ile-Ife*.
9. Forster P.M, Freckleton R.S, Shine K.P (1997). On aspects of the concept of radiative forcing, *Climate Dynamics* 13: 547-560.
10. Fusco A.C, Salby M.L (1999). Interannual Variations of Total Ozone and Their Relationship to Variation of Planetary Wave Activity, *Journal of American Meteorological Society* pp. 1619-1629.
11. Hegglin, M. I. and Shepherd, T. G. (2009). Large climate-induced changes in ultraviolet index and stratosphere-to-troposphere ozone flux, *Nat. Geosci.*, 2, 687–691, 2009.
12. Hansen J.M, Sato M, & Ruedy. R. (1997). Radiative forcing and climate response, *Journal of Geophysics*. 102: 6831-6864
13. Holton J.R. (1992). An Introduction to Dynamic Meteorology. Academic Press, San Diego pp 511-554
14. Odekunle, O.T., Andrew, O., Aremu, O.S., (2008). Towards a Wetter Sudano-Sahelian Ecological Zone in the Twenty-First Century Nigeria. *Journal of weather and the environment*, March 2008, 63:3
15. Ojoye, S. (2012). Climate change and adaptation Strategies to water resources management in Sudano Sahelian Ecological Zone of Nigeria. An unpublished PhD thesis, Department of Geography, University of Ilorin, Ilorin, Nigeria.
16. Orsolini Y.J, Stephenson D.B, Doblus-Reyes F.J (1998). Storm track signature in total ozone during northern hemisphere winter. *Journal of Geophysics*. 25: 2413–2416.
17. Sivasakthivel.T and Siva K.K. (2011). Ozone layer depletion and its effect: A review. *International Journal of Environmental Science and Development* 2(1): 35-36