International Journal of the Physical Sciences Vol. 5(5), pp. 447-451, May 2010
Available online at http://www.academicjournals.org/IJPS
ISSN 1992 - 1950

Full Length Research Paper

Total ozone as a stratospheric indicator of climate variability over West Africa

M. L. Akinyemi

Department of Physics, Covenant University, Ota, Ogun State, Nigeria. E-mail: marvel.akinyemi@gmail.com.

Accepted 30 March, 2010

In this paper, a study of the statistical analysis of total ozone concentration as released by satellite EPTOMS was used to show that annual coefficient of relative variability (ACRV) of ozone in West Africa over a period of 48 months increased gradually from 3.5% at latitudinal zone 0-5°N to 6.1% at zone 20-25°N. A strong positive correlation of 0.99 was observed between the ACRV of ozone and average annual temperature, which increased from 25°C at the Atlantic coastal area of West Africa to 34°C at the hot arid north of the region. Also a negative correlation of -0.99 was observed between the ACRV of ozone and the average annual precipitation over the region which varied from an average of 3000 mm along the Atlantic coast to 127 mm in the hot arid north. Maximum ozone inter-annual variability of between 6 and 10% occurred between December and February, coinciding with the dry Harmattan season, while the minimum of between 2 and 4% occurred between June and August coinciding with the raining season.

Key words: Ozone redistribution, photochemical coupling, climate indicator.

INTRODUCTION

Ozone is produced mainly through photochemical reactions, but it can also be formed when silent electric discharge passes through oxygen. As a result it can be produced in minute quantities during electric storms. Ozone has been found to be one of the most important radiative gases in the stratosphere and the upper troposphere, as it is not only able to absorb the incoming solar ultraviolet radiation, but also part of the visible radiation as well as re-emit and absorb the outgoing terrestrial infrared (IR) radiation, consequently, changes in ozone concentrations affect climate, with the effect depending on the altitudes where the changes occur (Bojkov and Fioeltov, 1995; Orsolini et al., 1998).

The primary source of variability in the lower atmosphere is transport processes. As a result, ozone in the lower stratosphere acts as a tracer of atmospheric motions. The motion of ozone is directly associated with the dynamics of motion in the atmosphere. 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).

For instance, above a tropospheric high-pressure system, rising air is brought into the stratospheric column at the tropopause and is removed from the column at higher altitudes. Since ozone-mixing ratio in the lower stratosphere increases with increasing altitude, the air brought into this column has less ozone than the air being removed. This results in decrease of ozone in the column. As this high-pressure system moves, it carries the low ozone column along with it. This explains why high-pressure systems are associated with decreased stratospheric ozone amounts. The effects of a low-pressure system are opposite; it results in increase in the ozone amounts (Cordero and Forster, 2006).

Abbreviations: ACRV, Annual coefficient of relative variability; **ETSP,** extra tropical suction pump.

WEST AFRICA'S CLIMATIC ZONES

Figure 1 shows the major climatic zone of West Africa, which stretches across five latitudinal zones of 5° each,

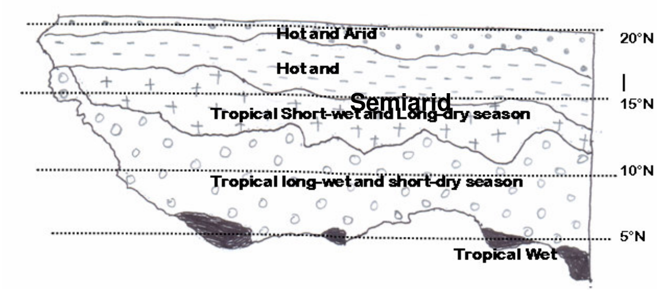

Figure 1. A sketch of West Africa showing the climatic zones.

namely zones 0 - 5°N, 5 - 10°N, 10 - 15°N, 15 - 20°N and 20 - 25°N. West Africa has a tropical climate, humid in the south and gets increasingly dry to the north. In the coastal region, the average annual rainfall is about 4,000 mm (about 160 in). On some exposed slopes of West Africa Mountain and the other peaks of the West African region, rainfall is almost constant and in some places can reach 10,000 mm (400 in) a year. In the semi-arid mid-north, annual rainfall averages about 380 mm (about 15 in). The far northern portion of West Africa is hot and arid and stretches into the Sahara desert with rainfall averaging about 250 mm (about 10 in) and less than 127 mm (5 in) in the Sahara desert region of the farthest north. The duration of the dry season get prolonged as one moves farther north. The average temperature in the south is 25°C, on the plateau it is 21°C and in the north it is 34°C (Guiling and Elfatm, 2000).

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. The traditional view in climatology has been that the stratosphere can only play limited role in climate change. However, there has been increasing evidence in recent years that the stratosphere is a sensitive component of the climate system, which can affect the troposphere through coupling mechanisms. (Forster et al., 1997; Hansen et al., 1997). The other mechanism by which the stratosphere influence the tropospheric climate takes into account the basic dynamical fact that tropospherically forced waves propagate upwards, while zonal mean anomalies propagate down. The stratosphere affects the "upper boundary condition" of the troposphere by influencing the characteristics of tropospheric wave's propagation. Thus observation of the redistribution of ozone in the atmosphere has some link with the weather pattern variation.

ACQUISITION AND ANALYSIS OF DATA

TOMS total ozone data were collected from the NASA TOMS website and the period 1999 to 2002 were considered. The average annual meteorological data over West Africa which included rainfall and temperature were deduced from article based on data from Global Climate Observatory System (GCOS) (Alexander et al., 2006). In order to study the long term trends, a linear regression analysis was used on the daily means. The standard deviation (SD) was deduced. The annual coefficient of relative variation (ACRV) was calculated thus:

$$\text{Annual CRV} = \frac{100 \times AnnualS.D}{AnnualMean}$$

CRV is statistical parameter for comparing relative variability of two or more variants whose means are dissimilar. The inter-annual fluctuation was deduced by dividing the ACRV range for each zone by the maximum ACRV value observed.

Spatial variability of total ozone concentration

In order to investigate the relationship between climate and total ozone variability over West Africa on latitudinal scale, the annual coefficient of relative variation (ACRV) of total ozone distribution for the period 1999 - 2002 was calculated and plotted as shown in Figure 2. The figure reveals significant increase in ACRV with latitudinal zones. In the four years studied, ozone ACRV value of between 3.1 and 7.1% was observed. Minimum average ACRV value of 3.5% was observed at zone 0 - 5°N and maximum average ACRV value of 6.1% at zone 20 - 25°N. Minimum inter-annual fluctuation of 0.075 in ozone ACRV occurred at zone 5 - 10°N, while maximum fluctuation of 0.29 occurred at zone 20 - 25°N (Figure 2).

Equations of linear trend of ACRV of ozone with latitude for each of the four years studied were as follow:

$$\Psi_{(1999)} = 0.7\omega_{(1999)} + 2.7$$

$$\Psi_{(2000)} = 0.35\omega_{(2000)} + 3.4$$

$$\Psi_{(2001)} = \omega_{(2001)} + 2.4$$

$$\Psi_{(2002)} = 0.7\omega_{(2002)} + 3.1$$

Where Ψ is the average ACRVs and ω represent the latitudinal zones. The plot of the average ACRV of ozone for the four years with latitude yielded an exact linear trend of same value as 1999.

$$\Psi_{(average)} = 0.7\omega + 2.7$$

The ACRV of ozone when correlated with average zonal temperature and rainfall revealed significant positive and negative trends respectively in the five zones. Tables 1 and 2 compared the ozone's ACRV against the corresponding temperature and rainfall values. The correlation coefficient of ACRV with temperature

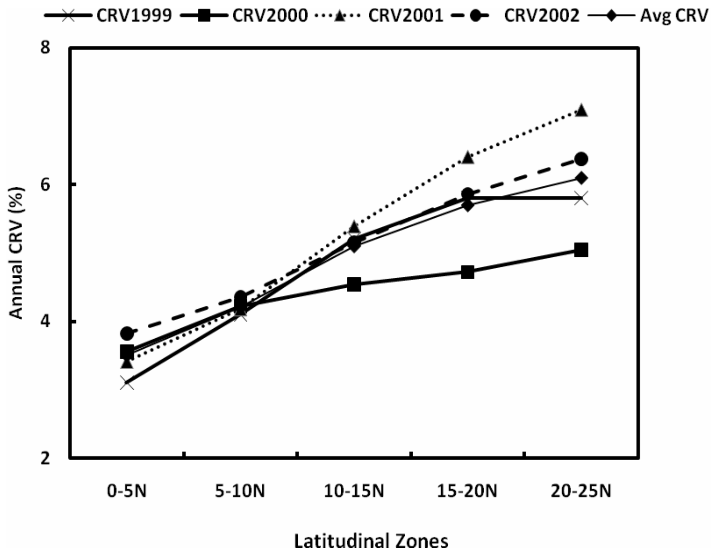

Figure 2. Annual coefficient of relative variation (ACRV) of ozone over West Africa.

was 0.97 in 1999 and 0.99 in the remaining three years. This yielded a perfect positive correlation of 0.99. The average zonal temperature increased from 25°C at the equatoriall zone 0 - 5°N, to about 34°C at zone 20 - 25°N (Table 1). This is in accordance with previous researches that variations observed in total ozone concentration are among other things, directly linked with photochemical coupling between ozone and temperature (Azeem et al., 2001). This pure photochemical perturbation without much recall to atmospheric dynamics has been used to model the response of ozone to observed temperature variation.

The correlation coefficient of ACRV with rainfall was -0.99, -0.97, -0.98, -0.98 in the four years studied respectively. This yielded a notable inverse relation between precipitation and the ozone average ACRV, which is a strong negative correlation of -0.99. The average precipitation of 3000 mm at the equatorial zone 0 - 5°N which reduced drastically to about 127 mm at zone 20 - 25°N (Table 1), was used for the correlation.

Inter-annual variability of total column ozone

For further investigation of the relationship between total ozone distribution and the climatic variation over West Africa, seasonal percentage variability of monthly ozone concentration over the period of forty-eight months studied was computed for each zone. The graphs of these computations plotted in Figure 3, make the anomalous changes in the magnitudes of variability in ozone trend distinct and easy to identify. The figure shows that the equatorial zone of 0 - 5°N recorded inter-annual fluctuation of above 5% all year round. This may be related to the all year round atmospheric dynamics in the equatorial zone generated by temperature gradients which result in continuous atmospheric circulation. In the five West African zones studied, maximum ozone inter-annual variability of between 6 and 10% occurred between December and February, coinciding with the dry Harmattan season, while the minimum of between 2 and 4% occurred between June and August coinciding with the raining season. December to February coincided with the peak winter 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 (Fusco and Salby, 1999). Inter-annual variability compared the valueof ozone in a particular month for the years studied. The observed maximum inter-annual fluctuations in ozone column from December to February may be associated with the variation in the strength of the local Harmattan wind, a prevailing atmospheric dynamics over West Africa during that period. The dry cold Harmattan wind is a polar-continental air mass that originates from the high northern latitude towards Africa. The wind carries along with it a lot of dust from the Sahara desert and flows over West Africa towards the Atlantic Ocean. The year-to-year variability in intensity of the planetry scale atmospheric dynamics responsible for driving the Harmattan wind could be suggested to be responsible for the high inter-annual fluctuation in total ozone column observed between December and February.

RESULTS AND DISCUSSION

For the five West African zones studied, average monthly maximum ozone concentration of 286 DU was observed between July and August which coincided with the peak period of tropical summer rainfall over the West African region. Although significant negative correlation of about -0.99 was observed between the rainfall pattern distribution and total ozone percent variability over the five zones in West Africa on spatial basis, yet in terms of occurrence, the period of maximum ozone concentration coincided with the peak tropical summer rainfall. Tropical summer rainfall over the West African region peaks 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

Table 1. Latitudinal zones of West Africa and the corresponding ACRV of ozone, temperature and annual rainfall.

Latitudinal zones (N)	Avg. ACRV ozone (%)	Avg. temp. (°C)	Avg. annual rainfall (mm)
20 - 25	6.1	34	127
15 - 20	5.7	32	250
10 - 15	5.1	30	1000
5 - 10	4.2	28	2000
0 - 5	3.5	25	3000

Table 2. Correlation of annual CRV of ozone with average annual temperature and rainfall.

Year	Correlation of annual CRV of ozone with average annual temperature	Correlation of annual CRV of ozone with average annual rainfall
1999	0.97	-0.97
2000	0.99	-0.99
2001	0.99	-0.98
2002	0.99	-0.98

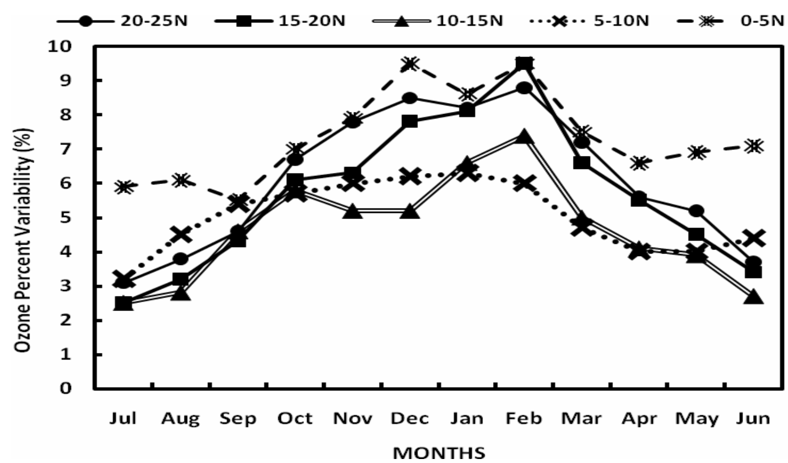

Figure 3. Inter-annual fluctuation of ozone July to June.

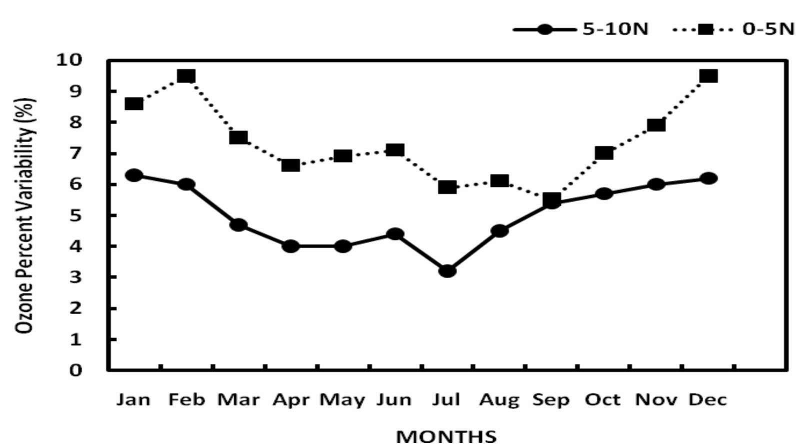

Figure 4. The inter-annual fluctuation at zones 0 - 5 N and 5 - 10 N showing the wide discrepancies except in September.

relevant eddy effects act globally on the tropical stratosphere as a fluid-dynamical suction pump (Yulaeva et al., 1994; Rosenlof, 1995; Holton et al., 1995). 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. According to Akinyemi and Oladiran (2007), ozone temporal oscillation period of between 2 and 6 days were observed at Lagos, Lamto and Ekona, all three locations are in the tropical rain forest region of West Africa, while annual seasonal oscillation period of between 295 and 375 days were observed across the three locations. Lagos, Nigeria is at latitude 6.60°N, longitude 3.33°E and altitude 10 m above sea level, Lamto, Ivory Coast is at latitude 6.22°N, longitude 5.03°W and altitude 76 m above sea level, while Ekona Cameroun is at latitude 4.43°N, longitude 9.33°E and altitude 106 m above sea level. As is well appreciated, changes in stratospheric ozone and winds affect the flow of energy at altitudes just below, this in turn affect the next lower altitudes and all the way to the ground (Allen, 2004).

Ozone percent variability at zone 5 - 10°N was much less in magnitude than that of zone 0 - 5°N, for eleven out of the twelve months in the year (Figure 4). The two zones are located within the tropical rain forest region of West Africa with heavy precipitation for greater part of the year. The discrepancies in the percent ozone variability can be attributed to the variability in atmospheric dynamics over the two zones due to solar insolation. Different amount of sunlight received at the surface of the earth (known as solar insolation) drive the weather and the observed winds on the earth. Likewise, temperature changes across earth's surface (that is, in the horizontal) are directly linked to the speed and direction of the winds, both at the surface and at different heights (Zerefos et al., 1997).

Conclusion

A similarity in ozone ACRV trends over West Africa with temperature was observed with a correlation of 0.99, while a notable inverse relationship was observed between precipitation and ozone ACRV over the region with a negative correlation of -0.99. These observations suggest significant association between the radiative activities and total ozone redistribution over the region and the possibility of total ozone trend over West Africa being used as an indicator of climate variability over the region.

REFERENCES

Akinyemi ML, Oladiran EO (2007). Temporal and Spatial Variability of ozone Concentration over Four African Stations. ANSI J. Appl. Sci. 7(6): 913-917.

Alexander LV, Zhang X, Peterson T, Caesar CJ, Gleason B, Klein-Tank A, Haylock M, Collins D, Trewin B, Rahimzadeh F, Tagipour A, Ambenje P, Rupa-Kumar K, Revadekar J, Griffiths G, Vincent L, Stephensonh D, Burn J, Aguilar E, Brunet M, Taylor M, New M, Zhai P, Rusticucci M, Vazquez-Aguirre J L (2006). Global Observed Changes in Daily Climate Extremes of Temperature and Precipitation, J. Geophys. Res. 111:D05109, doi:10, 1029/2005JD006119.

Allen J (2004). Ozone and Climate Change. National Aeronautics and Space Administration (NASA), Earth Observatory Release.

Azeem SMI, Palo SE, Wu DL, Froidevaux L (2001). Observation of 2-day Wave in UARS MLS Temperature and Ozone Measurements, Geophys. Res. Let. 28(16): 3147-3315.

Bojkov RD, Fioeltov VE (1995). Estimating the global ozone characteristics during the last 30years, J. Geophys. Res. 100: 16537-16551.

Cordero EC, Forster PM (2006). Stratospheric variability and trends in IPCC model simulations, Atmos. Chem. Phys. Disc. 6: 7657–7695.

Forster PM, Freckleton RS, Shine KP (1997). On aspects of the concept of radiative forcing, Climate Dynamics 13: 547-560.

Fusco AC, Salby ML (1999). Interannual Variations of Total Ozone and Their Relationship to Variation of Planetary Wave Activity, Am. Meteorol. Society pp. 1619-1629.

Guiling W, Elfatm ABE (2000). Biosphere-atmosphere interactions over West Africa. I: Development and validation of a coupled dynamic model. Q. J. R. Meteorol. Soc. 126: 1239-1260.

Hansen JM, Sato M, Ruedy R (1997). Radiative forcing and climate response, J. Geophys. Res. 102: 6831-6864

Holton JR (1992). An Introduction to Dynamic Meteorology. Academic Press, San Diego pp. 511-554

Holton JR, Haynes PH, Mcylnty ME, Douglas AR, Rood RB, Pfister L (1995). Stratosphere Troposphere Exchange. Review of Geophy. 33(4): 403-439.

Orsolini YJ, Stephenson DB, Doblas-Reyes FJ (1998). Storm track signature in total ozone during northern hemisphere winter. Geophys. Res. Lett. 25: 2413–2416.

Rosenlof KH (1995). Seasonal Cycle of the Residual Mean Meridional Ciculation in the Stratosphere, J. Geophy. Res. 100: 5173-5191.

Yulaeva E, Holton JR, Wallace JM (1994). On the Cause of Annual Cycle in Tropical lower Stratospheric Temperature. J. Atmos. Sci. 51: 169-174.

Zerefos CS, Tourpali K, Bojkov BR, Balis DS, Rognerund B, Isaksen ISA (1997). Solar activity total column ozone relationships: Observations and model studies with heterogeneous chemistry. J. Geophys. Res. 102: 1561-1569.