1979-1999 satellite total ozone column measurements over West Africa

Theo Chidiezie Chineke ([1])([3]), **Vincenzo Rizi** ([1]), **Fabrizio Masci** ([2]), **Piero Di Carlo** ([1]) **and Marco Iarlori** ([1])

([1]) *Dipartimento di Fisica, Università degli Studi, L'Aquila, Italy*

([2]) *Istituto Nazionale di Geofisica, L'Aquila, Italy*

([3]) *Department of Physics, Imo State University, Owerri, Nigeria*

Abstract

Total Ozone Mapping Spectrometer (TOMS) instruments have been flown on NASA/GSFC satellites for over 20 years. They provide near real-time ozone data for Atmospheric Science Research. As part of preliminary efforts aimed to develop a Lidar station in Nigeria for monitoring the atmospheric ozone and aerosol levels, the monthly mean TOMS total column ozone measurements between 1979 to 1999 have been analysed. The trends of the total column ozone showed a spatial and temporal variation with signs of the Quasi Biennial Oscillation (QBO) during the 20-year study period. The values of the TOMS total ozone column, over Nigeria (4-14°N) is within the range of 230-280 Dobson Units, this is consistent with total ozone column data, measured since April 1993 with a Dobson Spectrophotometer at Lagos (3°21′E, 6°33′N), Nigeria.

Key words *ozone – aerosol – lidar – satellite – QBO*

1. Introduction

Characterisation and parameterization of the profiles of liquid aerosols, solid particles like dust, and atmospheric gases (O_3, CO_x) are important for weather forecasting, climate modelling and environmental monitoring. Quantifying the anthropogenic contribution to the current problem of ozone depletion can be difficult due to the periodic injection of aerosols from volcanic eruptions, global transport and the interacting reservoir of aerosols (Barnes and Hofmann, 1997).

Several workers (Fishman and Larsen, 1987; Fishman and Watson, 1990; Andreae *et al.*, 1992) have reported the existence of high levels of tropospheric ozone and aerosols in the tropics. This has been linked to photochemical ozone production through biomass burning (Fishman and Larsen, 1987; Andreae *et al.*, 1988; Cros *et al.*, 1988; Fontan *et al.*, 1992, Kundu and Jain, 1993). It should be noted that in West Africa (longitudes 20°W-20°E, latitudes 0°20°N), most of the precipitation and associated thunderstorms is recorded during the monsoon months of April to September. It had been suggested (Cros *et al.*, 1988; Randriambelo *et al.*, 1999) that significant convection, lightning, in addition to fires, can be potential contributors to ozone production by generating NO_x in the middle and upper troposphere. Since the atmospheric chemistry over the tropics is greatly influenced by tropical rainforests which have great biomass activity coupled with the Savannah where large-scale bush burning incidents are prevalent, real-time atmospheric measurements need to be undertaken. Atmospheric ozone and aerosol levels in West Africa are sparse and discontinuous. Of the 26 African stations in the World Ozone and Ultraviolet Radiation Data Centre (WOUDC) archive (http://www.tor.ec.gc.ca/woudc), only one of them, Lagos, Nigeria (3°21′E, 6°33′N,

Mailing address: Dr. Theo Chidiezie Chineke, Department of Physics, Imo State University, Owerri, Nigeria; e-mail: chidiezie@yahoo.com

10 m above sea level), is located in West Africa. The measurements of the total ozone column ozone with the Dobson Spectrophotometer, started at the site in April 1993.

Nigeria, a country of over 100 million people with a land mass of about 900 000 km^2, is located between latitudes 4-14°N and longitudes 2-16°E, with diverse climates, ranging from equatorial in the coastal areas, tropical in the centre with semi-arid climates in the northern part bordering Lake Chad (about 15°N, 14°E) and Sahara desert (about 20-25°N, 10°E). Regarding the terrain, there are southern lowlands merging into central hills and plateaus and mountains in the south-east bordering Cameroon. The poorly-studied Cameroon mountain which has an altitude of 4100 m is located around 10°E and 5-8°N, modulates the ozone and aerosol levels over West Africa through its frequent volcanic eruptions. The most recent volcanic eruption was between March 28-June 10, 1999 (http://www.boh.org). Since Nigeria is a microcosm of West African weather and climates, monitoring its ozone and aerosol levels will not only contribute to global atmospheric research but help in sustainable regional planning.

Related studies have been done elsewhere in Africa. Cros *et al.* (1988) presented seasonal trends in tropospheric ozone measured in Congo (4°20′S, 15°20′E) between 1983-1986. They noted that emission of precursor gases from biomass burning lead to high ozone values in the boundary layer especially during the dry season. In the tropics, ozone is transported from the upper troposphere to the lower stratosphere due to the fountain effect caused by cumulonimbus thundercloud columns (Kundu and Saha, 1987), presence of excess CO_x and NO_x from agricultural activities like biomass burning (Cros *et al.*, 1988, Kundu and Jain, 1993, Randriambelo *et al.*, 1999). Kalicharran *et al.* (1993) had noticed a dominance of Quasi Biennial Oscillation (QBO) while analysing TOMS Nimbus 7 satellite data over South African stations. In this paper, we present the TOMS satellite total column ozone levels over West Africa for the period 1979 to 1999 measured with the Nimbus 7, Meteor 3 and Earth Probe satellites. This work concerns some features of QBO in the ozone data over West Africa. This study can be considered a baseline for our long-term goal of designing a Lidar station for monitoring tropospheric and stratospheric ozone and aerosol levels in Nigeria. The site, located at Imo State University, Owerri (5°29′N, 7°12′E, and 35 m above sea level), will consist of a DIAL (DIfferential Absorption Lidar) ozone system and Rayleigh-Mie Lidar (Masci, 1999). This project could be developed within a collaboration between the University of L'Aquila, Istituto Nazionale di Geofisica and Imo State University.

2. Data and methodology

Total Ozone Mapping Spectrometer (TOMS) instruments were flown on four NASA/GSFC spacecraft: Nimbus 7 (November 1978 - May 1993), Meteor 3 (August 1991 - December 1994), ADEOS (September 1996 - June 1997) and Earth Probe (July 1996 - present). In this study, the Nimbus 7, Meteor 3 and Earth Probe TOMS zonal monthly mean total column ozone data for the years 1979-1999 were analyzed using Grid Analysis and Display System (GRADS) software (http://www.grads.iges.org). The ADEOS data that completely overlaps the Earth Probe was not used. There were no TOMS data for the year 1995 and between January-July 1996. The TOMS data for each day are gridded into 1 degree latitude zones by 1.25 degree longitude zones. Latitudes go from −90 degrees (the South Pole) to 0 degrees (the equator) to +90 degrees (the North Pole) in 1 degree steps, so there are 180 latitude zones. On the other hand, the longitudes go from −180 (west longitude) to 0 (Greenwich, England) to +180 (east longitude) in 1.25 degree steps, so there are 288 longitude zones. Other details about the TOMS instruments like orbital characteristics, instrument and measuring techniques can be found on the NASA TOMS web page (http://jwocky.gsfc.nasa.gov/).

For the purpose of this work, West Africa is taken as the region of Africa between latitudes 0-20° north and longitudes 20° west to 20° east. This was done to take the modulators of the local weather and climate over the region into consideration. They include Cameroon mountain (around 10°E, 5-8°N) which is a known source of volcanic aerosols, tropical rainforests and associated biomass burning in the Sahel region, gases arising from fossil fuel burning and UV-absorbing aerosols from dry areas near Lake Chad (around 15°E, 15°N) and Sahara desert near 20°N. Such dry areas contain lots of fine particulate matter that can be easily transported by winds. There are also thousands of oil wells in Nigeria with the associated gas flares since the late 1960's. Regarding the climate of the study area, most of the rainfall is recorded between the months of April-October, while the main dry months are October-March. The peak cases of biomass burning are between December-March while the lightning discharge is pronounced during the wet monsoon months. Earlier workers (Fishman and Larsen, 1987; Cros *et al.*, 1988; Fishman and Watson, 1990; Andreae *et al.*, 1992; Kalicharran *et al.*, 1993) had noted that biomass burning and lightning discharges affect the tropospheric ozone levels in the tropics.

3. Zonal monthly mean ozone levels over West Africa between 1979 and 1999

The zonal mean TOMS total column ozone data for the years 1979 to 1999 over West Africa (0-5°N, 5-10°N, 10-15°N, 15-20°N latitude bands) are presented in figs. 1 and 2. No measurements were available for the months of June 1979, March, June, July and October 1993 and January, February, August, September and December 1994, all 1995, and from January to July 1996.

The minimum values of the TOMS ozone data (figs. 1 and 2) are recorded in the months of December to February when the lower atmosphere over the region contains dust particles from the Sahara desert. This period is also characterized by biomass burning, which significantly affects the photochemical production of ozone in the lower atmosphere (Cros *et al.*, 1988; Kalicharran *et al.*, 1993). This is contrasted with the higher values during the wet season (April-September), with the peak amounts observed between July and September, when thunderstorm and lightning activities, as well as dynamical convection, are enhanced.

A simple analysis of TOMS ozone data maxima and minima show that similar values occur in about 24-months. This is more evident in 0-5°N, 5-10°N bands (fig. 1). We further investigated the QBO signatures by plotting the differences between the total ozone columns and the monthly climatological mean (figs. 3 and 4). In the 0-5°N band of West Africa, the QBO features are quite evident along the whole data set. The QBO seems still to be present in 5-10°N band, but with a reduced amplitude.

In table I, we present the zonal statistics of the TOMS satellite total ozone column measurements over West Africa concerning the 20-years period. We report the yearly average values, minima, maxima and standard deviations. Most of the maxima are in the July-September period, when biomass burning activity is lower than lightning effects. Between 0-5°N, the lowest value of the total ozone was 234.8 DU (February) in 1987 (El Nino year). The 0-5°N 1987 data also have the highest value of standard deviation. The data for the other El Nino years (1982 and 1983) show similar features. Generally the data show that the total ozone column increased from the equator inwards. The standard deviation of the TOMS satellite ozone measurements are higher between latitudes 5-20°N, where the effects of biomass burning can be more pronounced.

4. Discussion and concluding remarks

In this preliminary work, we analysed the zonal mean TOMS total column ozone data measured by three of the NASA/GSFC satellites (Nimbus-7, Meteor-3 and Earth Probe) between January 1979 and December 1999. The duration is long enough to make some observations about the Quasi Biennial Oscillation trends over West Africa. The dry season (January-March), which also marks the northmost ascent of the Intertropical Convergence Zone (ITCZ), recorded the lowest levels of ozone, while during the wet season, the highest amount of total ozone was observed. The West African ozone levels may be modulated by lightning discharges, the more evident increases appear in August, during the southmost descent of the ITCZ (Cros

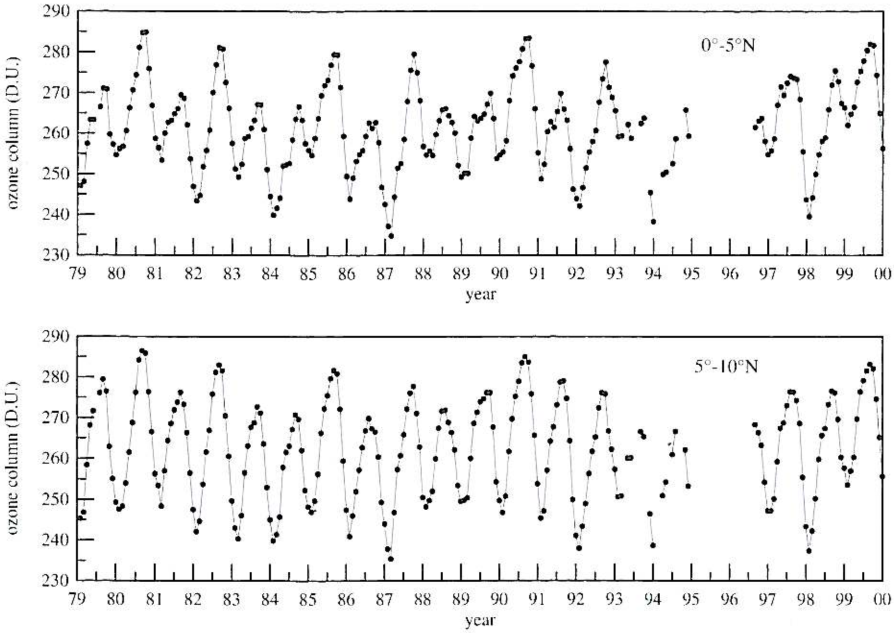

Fig. 1. Zonal mean TOMS total column ozone levels over West Africa between 1979 and 1999 in the months of January to December for latitudes 0-5 and 5-10°N.

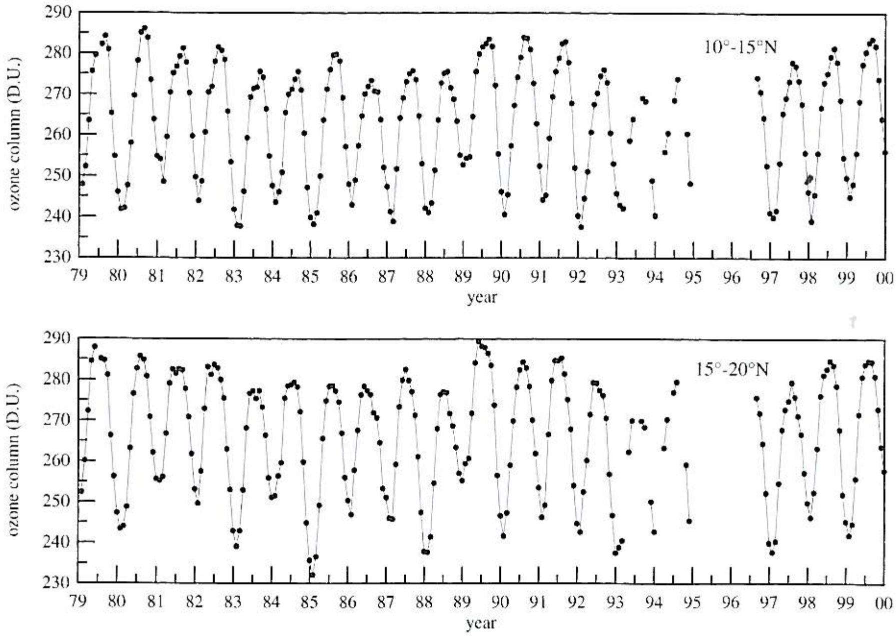

Fig. 2. As fig. 1 for latitudes 10-15 and 15-20°N.

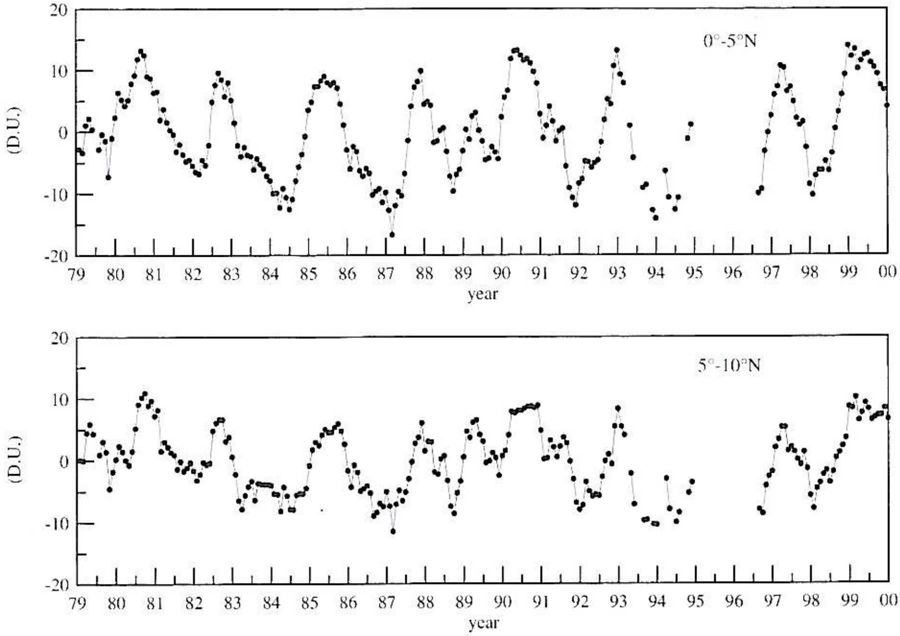

Fig. 3. Differences between the zonal mean and monthly average (1979-1999) TOMS total column ozone levels over West Africa between 1979 and 1999 in the months of January to December for latitudes 0-5 and 5-10°N.

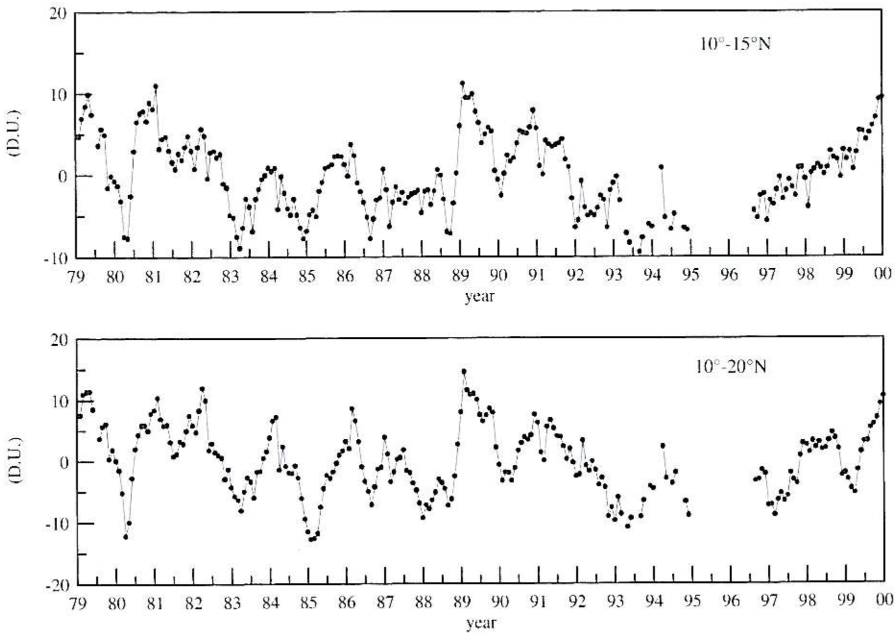

Fig. 4. As fig. 3 for latitudes 10-15 and 15-20°N.

Table I. Zonal statistics of the TOMS satellite total column ozone measurements over West Africa between 1979 and 1999. The minimum (min), maximum (max) and mean values of the total column ozone data are in Dobson Units; sd is standard deviation.

Year	0-5°N				5-10°N				10-15°N				15-20°N			
	min	max	mean	sd	min	max	mean	sd	min	max	mean	sd	min	max	mean	sd
1979	247.1	271.1	260.0	7.7	245.3	279.4	262.7	11.9	246.0	284.2	266.6	14.0	247.3	287.9	270.7	14.2
1980	256.2	284.8	269.8	10.1	247.6	286.5	267.7	13.7	241.8	286.1	265.4	15.8	243.4	285.7	266.6	15.2
1981	246.9	269.5	260.6	6.5	247.5	276.2	263.1	9.8	248.5	281.2	266.9	11.5	253.1	282.6	270.8	11.2
1982	243.4	281.1	263.5	12.7	242.1	283.0	264.3	14.0	241.8	281.5	264.6	14.0	242.9	283.6	268.8	14.2
1983	244.5	267.2	257.2	7.0	240.4	272.7	257.6	11.3	237.8	275.6	259.4	13.5	239.1	277.3	263.0	13.4
1984	239.9	266.7	254.0	8.3	239.9	270.8	256.7	10.4	239.9	275.6	259.6	12.7	235.7	279.4	264.2	14.4
1985	249.5	279.5	267.3	9.5	247.0	281.7	265.7	12.7	238.3	279.8	262.7	14.7	232.1	278.6	261.7	15.9
1986	242.6	262.7	254.2	6.8	241.0	269.9	257.0	9.7	243.0	273.4	261.2	10.5	246.9	278.4	266.0	10.7
1987	234.8	279.5	258.5	14.4	235.4	277.7	259.6	13.7	239.0	275.8	260.2	13.5	237.9	282.5	263.5	15.3
1988	249.3	266.1	259.0	5.4	248.3	271.9	260.2	8.7	241.1	275.6	261.2	11.7	237.7	277.1	262.3	12.8
1989	250.2	269.9	260.3	6.4	249.8	276.2	264.5	10.4	240.6	283.5	269.3	13.0	246.6	289.4	274.0	14.2
1990	255.2	283.4	271.2	10.0	246.8	285.0	269.3	12.9	240.3	283.9	266.7	14.3	241.6	284.3	267.5	14.0
1991	244.0	269.8	258.0	8.0	241.1	279.1	261.9	12.9	237.6	282.9	264.7	15.1	244.7	285.3	268.3	15.3
1992	242.2	277.5	261.5	10.6	238.0	276.2	260.4	11.7	240.4	276.0	259.5	12.5	237.5	279.3	262.5	14.5
1993	238.3	263.7	256.1	8.6	238.7	266.6	254.9	9.1	248.2	269.1	254.3	11.3	238.9	270.0	255.4	12.9
1994	250.2	265.7	256.1	5.6	251.0	266.7	258.1	5.6	241.1	273.8	261.2	8.3	245.4	279.5	265.8	11.5
1996	254.9	263.7	260.2	3.3	247.3	268.4	259.9	8.0	240.0	274.2	260.6	12.2	239.9	275.7	260.8	13.2
1997	243.8	274.1	265.3	9.2	243.4	276.5	263.4	11.3	239.2	277.9	261.7	13.2	237.7	279.4	262.4	13.6
1998	239.6	275.4	260.5	11.0	237.4	276.7	261.4	12.2	245.0	281.4	264.0	13.8	245.2	284.7	267.8	14.8
1999	256.3	281.9	271.5	8.1	253.6	283.2	269.9	10.7	241.8	283.6	268.1	13.4	241.8	284.6	268.5	14.9
Mean	234.8	284.8	261.5	10.5	235.4	286.5	262.2	12.2	237.6	286.1	263.1	13.7	232.1	289.4	265.8	14.5

et al., 1988; Kundu and Jain, 1993, Randriambelo *et al.*, 1999). A detailed analysis of photochemical processes involved in catalytic ozone destruction in the lower atmosphere will probably shed more light on this. Some features of El Nino Southern Oscillation (1982, 1983 and 1987) evidently influence TOMS satellite measurements. The role of the El Nino Southern Oscillation phenomenon, especially on the tropospheric ozone amounts, needs to be investigated with altitude resolved measurements (*i.e.* Lidar).

The TOMS observations in the 5-10°N band agree with the measurements of a Dobson spectrophotometer located at Lagos, Nigeria.

In the months of July to September when the greatest frequency of precipitation is recorded in the region, the incidence of lightning and associated released NO_x gases is greatest over West Africa. The values of the TOMS satellite total column ozone measurements were lowest during the months of October-February, when the incidence of biomass burning and convective atmospheric current arising from lightning discharges is lowest. According to Winterrath *et al.* (1999), the convective zones, which are normally associated with biomass burning induce vertical mixing thereby affecting the ozone concentration in the lower atmosphere.

The measurements made at Brazzaville, Congo had provided evidence for large-scale photochemical ozone production in West Africa (Andreae *at al.*, 1992). These results agree with those of Cros *et al.* (1988), Fishman and Watson (1990) and Andreae *et al.* (1992).

Since the long term goal of this work is the establishment of a lidar station for monitoring ozone and aerosols in the troposphere and stratosphere over Nigeria, the results presented in this paper and those of earlier workers (Cros *et al.*, 1988; Kalicharran *et al.*, 1993) over Africa will be a boost in that regard. While greatly appreciating the work of the NASA/Goddard Space Flight Center (Code 916) for continuous efforts at maintaining the TOMS program since its inception more than 20 years ago, the need for multiplying the present network of ozone sonde and lidar stations world-wide, especially in the tropics, needs to be considered for a better understanding of the troposphere and stratosphere.

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