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# Long-Term Trend Analysis of Tropospheric Total Column Ozone in Africa

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**Abstract:** General characteristics and trends of tropospheric total column ozone content were investigated using data available at the World Ozone and Ultraviolet Data Centre (WOUDC). Observations are made at four different stations in Africa namely Nairobi (Lat.1°16' S; Long. 36° 48' E), Lagos (Lat. 6° 27' N; Long. 3° 24' E ), Cairo (Lat. 29° 52' N; Long.31° 20' E) and Aswan (Lat. 24° 05'N; Long.32° 56' E). The annual mean total column ozone estimated were 254.35±8.25DU, 254.89±6.07DU, 290.89±6.27DU and 270.28±4.94DU for Nairobi, Lagos, Cairo and Aswan, respectively. An increasing trend in total column ozone of 0.89DU/yr (or 0.35% year$^{-1}$) was observed at Nairobi while Lagos recorded a trend of 1.02DU/yr (or 0.40% year$^{-1}$). A similar but slightly positive trends of 0.10DU/yr (or 0.04% year$^{-1}$) and 0.04DU/yr (or 0.02% year$^{-1}$) were observed for Cairo and Aswan, respectively. The annual value of column ozone reported at Cairo, are lower in the 1990s than in the previous decade: total ozone amounts are 3.9±0.02 lower in 1990s than those observed in the 1980s.

**Key words:** Photochemical, troposphere, total column ozone, trend, biomass burning

## INTRODUCTION

Ozone in the atmosphere exerts different influences on the well being of Man. In the stratosphere where approximately 90% of the atmosphere's ozone is found, ozone dominates in the so-called ozone layer and prevents the sun's ultra-violet radiation from reaching the surface of the Earth. In the troposphere, ozone is a direct greenhouse gas (Prather and Ehhalt, 2001) while in the boundary layer, ozone is a pollutant, which has harmful effects on human, animals and crops. Ozone is triatomic oxygen $O_3$ and it is generally regarded as the most important ion that determines the oxidizing capacity of the troposphere. Ozone is formed at troposphere by the reaction of hydrocarbons or carbon monoxide with OH radicals. Although individual hydrocarbon follows complex reaction pathways, they often conform to the following patterns

$$HC + OH \xrightarrow{O^2} RO_2 + H_2O$$

$$CO + OH \xrightarrow{O^2} HO_2 + CO_2$$

$RO_2$ represents a hydrocarbon chain with $O_2$ attached. The group radicals and $HO_2$ react rapidly with NO to form

$$RO + NO \xrightarrow{O^2} R'CHO + HO_2 + NO_2$$

$$HO_2 + NO \xrightarrow{O^2} OH + NO_2$$

Photolysis of the bye product $NO_2$ then produces

$$NO_2 + hv \xrightarrow{O_2} NO + O$$

The oxygen atom formed combines with atmospheric $O_2$ to form ozone

$$O + O_2 + M \xrightarrow{O^2} O_3 + M$$

Apart from this natural production of ozone there are also anthropogenic factor which leads to ozone production. Photochemical formation of ozone was suggested for the first time by Crutzen *et al*., (1985), who showed enhanced concentrations of ozone associated with air pollution due to biomass burning in vertical ozone profiles in the savanna region of Brazil. In Africa, an episode with surface concentrations exceeding 70 ppbv over several days was reported by Cros *et al*. (1987). Satellite measurements of tropospheric ozone derived from TOMS (Total Ozone Mapping Spectrometry) show a significant longitudinal variability of total columnar ozone in the tropical belt, in agreement with ozone production in air masses affected by biomass burning (Fishman and Larsen, 1987). The general accepted concept of an ozone trough in the whole equatorial belt and a tropospheric distribution of this compound

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dominated by the troposphere-stratosphere exchanges had to be reconsidered, to take into account the influence of continental emissions in Africa and South America. Measurements conducted during the dry season over the tropical rainforest of the Congo River basin within the framework of the 1988 DECAFE Experiment showed enhanced concentrations of ozone associated with air pollution due to biomass burning (Fishman and Larsen, 1987). The same ozone layer as that observed over Brazzaville was found in air masses coming from savanna zones of the Sahel region (Andreae *et al*., 1992). Therefore, it appears that the formation of ozone in the troposphere is a secondary product of biomass burning is a large-scale phenomenon that affects the whole intertropical Africa. This assessment also arises from simultaneous measurements of surface ozone concentrations over a one-year period (1988) at Brazzaville (4°20'S) and Enyele (2°50'N) (Cros *et al*., 1991). The formation of ozone is strongly dependent on meteorological condition among which temperature is the most important factor. In general ozone concentration appears to show no clear dependence on temperature below 20-25°C but become heavily dependent on temperature above 30°C. Ozone production in a station depends on other factors such as coastal location, wind, urbanization, (industrial affluent and automobiles) biomass burning, (vegetation type) frequent temperature inversion, rainfall washout and government legislation. This present work therefore examines the long time trend of ozone at some selected stations in Africa and explains the possible reasons for the trend.

## MATERIALS AND MATHODS

The data used in this study was retrieved from the World Ozone and Ultraviolet Radiation Data Center (WOUDC). Listing of ground based data available in the World Ozone and Ultraviolet Data Center (WOUDC) for Africa is given in Table 1. Some of the stations records were re-evaluated recently by the operating agency in collaboration with WMO, e.g., Nairobi (Angreji, 1989). The introduced corrections based on calibration records are in some cases very substantial (up to 5-10%). They are connected with instrumental problems as well as with the change of wavelength used for calculating the total ozone. The examination of the records shows that in most cases the provisionally archived data had to be re-evaluated, although for some stations (e.g. Lagos) the data were carefully checked by the operating agency and no substantial corrections were required. The data used from this archive are the daily Total Column Ozone which represents the total thickness of the ozone layer in Dobson Units (DU), defined as 0.01 mm thickness at standard temperature and pressure. Monthly and yearly means are calculated based on the measures daily, assuming that they are representative of daily means. To examine trends, time series line plots of the yearly means of total column ozone were plotted. To illustrate larger time scale trends, the seasonal variations were minimized using 12 month running mean. The running mean method is a helpful graphical aid for visualizing any long term patterns or apparent trends (Hill 1982).

## RESULTS AND DISCUSSION

Table 1 shows the periods of total ozone measurements made at the four stations. Only direct Sun observations from the Dobson have been used in the present study. All the ozone data presented have been calculated using the Bass and Paur (1985) ozone absorption cross section. The annual mean (and standard deviation) total column ozone estimated were 254.35±8.25, 254.89±6.07, 290.89±6.27 and 270.28±4.94DU for Nairobi, Lagos Cairo and Aswan, respectively. This clearly shows that the tropospheric ozone recorded for Cairo is 14.12, 14.36 and 7.62% higher than values recorded at Lagos, Nairobi and Aswan. Table 1 further revealed that the maximum and minimum annual mean total column ozone at Lagos are 263 and 247 DU, respectively which gives a range of 6.7% of the mean value. The maximum annual mean total column ozone at Nairobi, Cairo and Aswan were 271, 307 and 281DU, respectively. The minimum annual mean total column ozone were 238, 281 and 261 DU at Nairobi, Cairo and Aswan. The range amount to 12.7, 9.0 and 7.4% of the mean values at Nairobi, Cairo and Aswan, respectively. Figure 1 (a-d) show the plots of annual average of the total column ozone (in Dobson Unit) measured at Nairobi, Lagos, Cairo and Aswan, respectively. The broken lines indicate a 12 month running mean in order to reduce seasonal variation. Also indicated by the solid lines are the trend lines for each plot.

Table 1: List of the Dobson spectrometer stations. The WOUDC identification number of each station is in the first column. Included are the Annual mean and the trend

| WMO station no | station | Measurements period | Max (DU) | Min | (DU) Annual mean (DU) | Trend |
|---|---|---|---|---|---|---|
| 175 | Nairobi | 1984-2000 | 271 | 238 | 254.35±8.25 | 3.5%/decade |
| 317 | Lagos | 1993-2001 | 263 | 247 | 254.89±6.07 | 4.0%/decade |
| 152 | Cairo | 1967-2003 | 307 | 281 | 290.89± 6.27 | 0.4%/decade |
| 245 | Aswan | 1985-2004 | 281 | 261 | 270.28±4.94 | 0.2%/decade |

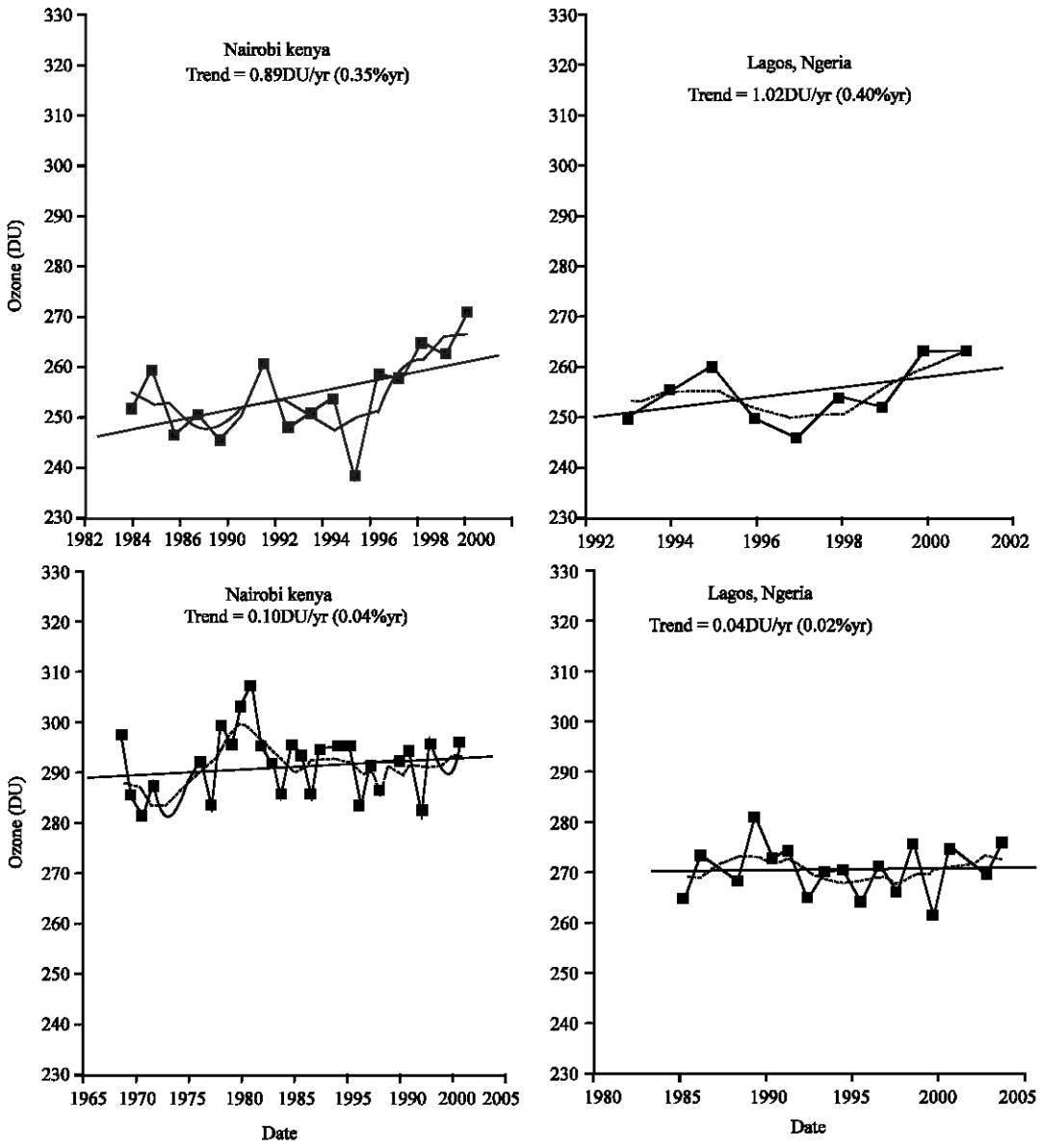


Fig. 1: Monthly mean total ozone amounts (DU) observed at Nairobi, Kenya (1984-1999), Lagos, Nigeria (1993-2001), Cairo, Egypt (1969-2003), and Aswan, Egypt (1985-2003). The solid lines are the trend line for each station. The broken lines are the 12 point running averages

Result from Fig. 1a shows a rapidly increasing trend of 0.89DU/yr (or 0.35% year$^{-1}$) and 1.02DU/yr (or 0 .40% year$^{-1}$) for Nairobi and Lagos, respectively. The trend means that on the average 14.24DU of total column ozone was gained during the period of 16 years in Nairobi while 9.18DU was gained in Lagos from 1993 to 2001. Also interesting to note is the strong increase in total ozone in Nairobi during 1994 to 1999. This may be attributed to the increase in human activities largely the combustion of fossil fuel during this period. Only slight trends of 0.10DU/yr (or 0.04% year$^{-1}$) and 0.04DU/yr (or 0.02% year$^{-1}$) were observed for Cairo and Aswan, respectively as illustrated in Fig. 1 c-d. This indicates that on the average ~3.5 DU of ozone was added up in the troposphere during the 35year period at Cairo while 0.76 DU was gained at Aswan. All the stations with the exception of Aswan show a decline in the total ozone during 1993-1994. The decline over these region have been reported by

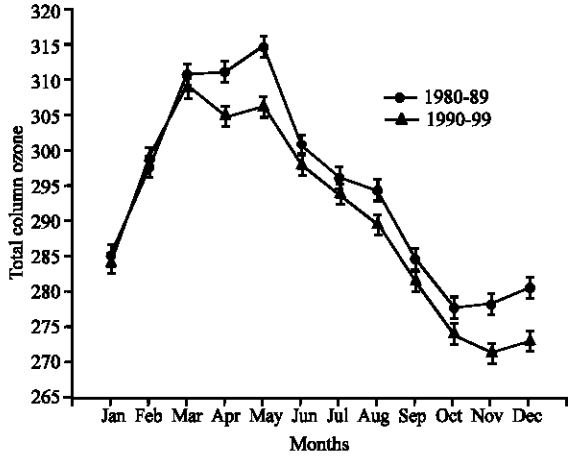


Fig. 2: Mean seasonal variations observed at Cairo during 1980-1989 and 1990-1999. Also shown in vertical bars is the standard deviation for each month

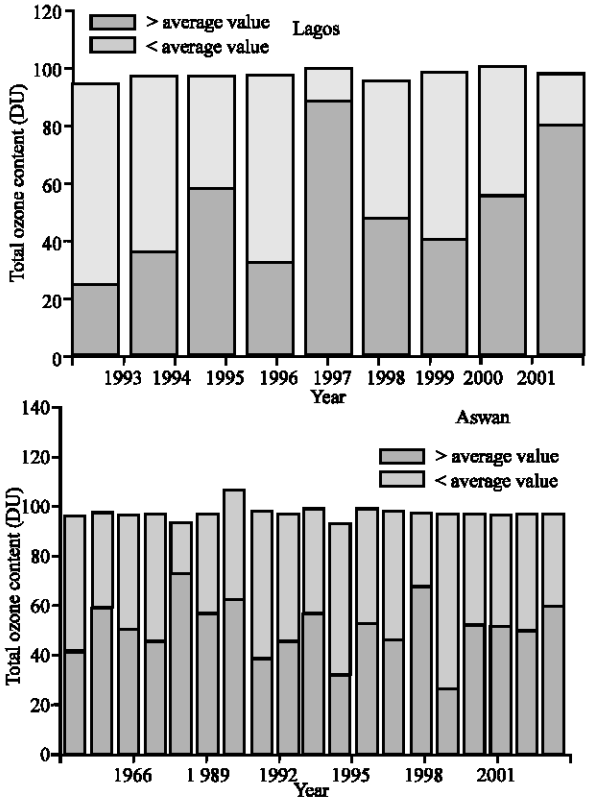


Fig. 3: Number of days exceeding the average values of 254.9 and 270.3 DU for Lagos and Aswan, respectively

Tourpali *et al.* (1997), Harris *et al.* (1997) which is attributed to the effects of the chlorine loading of the atmosphere. The decline in ozone values recorded during

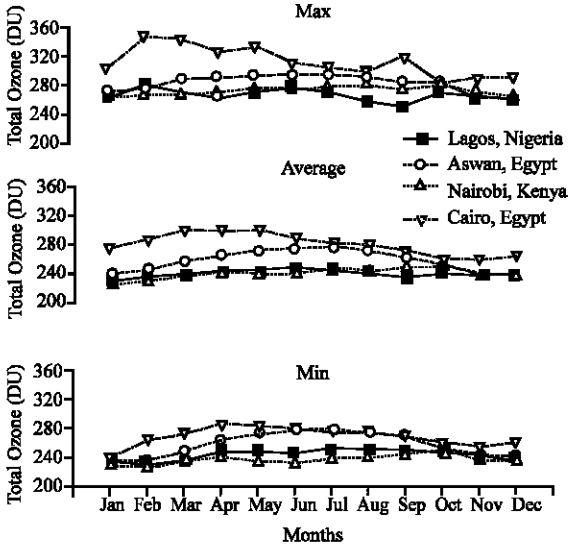


Fig. 4: Monthly mean concentration of daily maximum, average and minimum ozone levels at Lagos, Nigeria, Aswan, Egypt, Nairobi, Kenya, and Cairo, Egypt

this period could further be associated with the effects of Mt. Pinatubo volcanic eruptions of June, 1991, which resulted in a large increase in sulphate aerosol in the stratosphere throughout the globe (WMO, 1994, Sahai *et al.*, 2000). It is interesting to investigate if ozone declines occur in a particular month of the year or if this is rather uniform. Figure 2 shows the mean seasonal variations of total ozone content observed at Cairo, Egypt for the periods 1980-1989 and 1990-1999.

It is observed that total ozone content shows considerable decrease during all months (except February) of the year in the 1990s compared with the period 1980s. The difference of the two seasonal variations (1980-1989 and 1990-1999) and the standard error is 3.9±0.02. The figure shows large difference in the months of April and May. The computed monthly total ozone averages were 286.61±11.29DU and 294.39±13.16DU during the ten year period of 1980-89 and 1990-99, respectively. A linear regression of the monthly values gives an estimated trend of -0.76 and -0.78% during the periods1980-89 and 1990-99, respectively.

To examine the difference in high ozone patterns at Lagos and Aswan, the number of days exceeding the average values of 254.89 DU and 270.28DU for Lagos and Aswan were computed and shown in Fig. 3. Results at Lagos indicate that the numbers of days in which daily ozone values is far more than the average is highest in 1997 representing about 88.2% of the total number of days. However, on the contrary, the

numbers of days in which is less than the average is highest in 1993 representing 69.2% of the total data set.

Observations at Aswan indicate that the numbers of days in which daily ozone values is greater than the average is highest in 1989 with 73.2% of the total number of days. The numbers of days in which daily ozone values is less than the average is highest in 1999.

In order to compare the general ozone characteristics at the four stations, monthly mean concentration of daily maximum, average, and daily minimum for each month are presented in Figure 4. It is observed that the monthly maximum ozone level is higher at Cairo, during all months of the year. For example it was 56, 67 and 78% higher than maximum values recorded at Lagos, Aswan and Nairobi. Lagos and Nairobi almost exhibit same a verage ozone values throughout the year except in September and October. Mean monthly minimum ozone concentration is also higher in Cairo and lowest in Nairobi throughout the year.

## CONCLUSION

The main purpose of this study is to gain some understanding of the total ozone variability in Africa by examining four ground-based instruments for total ozone content. A detailed climatology of ozone at Nairobi, Lagos, Cairo and Aswan describe some of the general features of the ozone variability in the region. Results of the study show a clear upward trend of 3.5%/decade for the 16 years data at Nairobi. Analysis of 9 years data at Lagos also revealed a trend of 4.0%/decade. Result further shows that 14.24DU of total column ozone was gained during the period of 16 years at Nairobi while 9.18DU was gained at Lagos from 1993 to 2001. Slight upward trends of 0.4%/decade and 0.2%/decade were observed for Cairo and Aswan respectively. This indicates that for a period of 35 years in Cairo only ~3.5 DU of ozone was added up in the troposphere while 0.76 DU was gained at Aswan in 19 years. Observations further shows that the TOC shows considerable decrease during all months (except February) of the year in the 1990 s compared with the period 1980 s at Cairo. It is observed that monthly average total ozone content is higher at Cairo during all seasons of the year. Lagos and Nairobi almost exhibit same average values through the year except in September and October.

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