Temporal and Spatial Variability of Ozone Concentration over Four African Stations

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Abstract: The temporal and spatial variability of ozone at four different locations over Africa were studied using satellite data from 1997 to 2002. The stations were Lagos and Dakar in the northern tropics, Kinshasa and Nampula in the southern tropics. The analysis revealed both high and low frequency time component. The temporal variation of ozone was of the high frequency component, while the seasonal oscillations were either annual or biannual. Annual seasonal oscillations were observed at Lagos and Dakar with oscillation period varying between 295 and 375 days, while biannual seasonal oscillations were observed at Kinshasa and Nampula with oscillation period varying between 120 and 200 days. Ozone temporal oscillation periods in all the four locations were between 2 and 6 days. The temporal amplitude varied between 1.0 and 6.5 DU. The observation of the effect of the Quassi Biennial Oscillation (QBO) was more prominent at Lagos than the other three stations. In the years of QBO occurrences, the annual mean of ozone concentration at Lagos were higher than those of Dakar by an average value of 10 DU. While the difference in the years of non-QBO were marginal with an average value of ±1.4 DU. Seasonal and annual variations of ozone concentration over the tropics had higher correlation with location than the temporal variation. Temporal variation was found to be less dependent on the spatial variation.

Key words: Spatial variability, temporal variability, ozone concentration

INTRODUCTION

Ozone layer acts as a regulator of the amount of UV radiation reaching the earth's surface and hence prevents the health hazards associated with it on both terrestrial and aquatic life forms (Parker, 2000). Without the filtering action of the ozone layer, more of the sun's UV-B radiation would penetrate through to the earth's surface. The filtering of ultraviolet radiation by ozone depends on other factors, such as time of day, season and the solar zenith angle.

Ozone can be produced in a number of photochemical reactions; 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 (WMO, 1962). Ozone has also 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 (WMO, 1962). Consequently, changes in ozone concentrations affect climate, with the effect depending on the altitudes where the changes occur. The most sensitive region to these changes is the lower stratosphere and upper troposphere. Ozone thus plays vital role in the temperature structure of the Earth's atmosphere (WMO, 1995).

As mentioned, ozone is found both in the stratosphere and the troposphere. The ozone molecules in these two regions are chemically identical as they both consist of three oxygen atoms and have the same formula O_3. But it has been discovered that they have different effects on humans and life forms in general. While stratospheric ozone plays a beneficial role by absorbing the biologically harmful UV-B rays allowing only a small percentage to reach the Earth's surface, the tropospheric ozone (low-lying ozone) which is in direct contact with life-forms is destructive and dangerous.

Tropospheric ozone, is a by-product of urban air pollution emitted from the combustion of fossil fuel in vehicles, industries etc. In the presence of high solar radiation, these emissions react with other atmospheric gases like nitric oxide at different chemical stages to produce ozone. It is generally agreed that tropospheric ozone has increased considerably as a result of these photochemical reactions (Roelofs and Lelieveld, 1997; Jacobson, 2000).

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Ozone in direct contact with life-forms is highly toxic as it readily reacts with other molecules. Several studies have confirmed the harmful effects of tropospheric ozone or low-lying ozone as it is sometimes called on crop production, forestry and human health. Besides, it has adverse effect on visibility range especially in the urban centers. This is commonly referred to as photochemical smog (Jacobson, 2000).

Also tropospheric ozone reduces the concentration of oxygen atoms in the urban air in some of its photochemical reactions thereby complicating the problem of atmospheric stagnation in the urban region. Atmospheric stagnation occurs when the ventilation rate is very low because of lack of air motion. This usually occurs in the weak pressure gradient near the center of an anticyclone with a warm core, thus resulting in very little air movement near the center. Atmospheric stagnation coupled with high level of low-lying ozone in urban air produces a lot of discomfort for the urban dwellers (Boubel *et al.*, 1994). Heavy tropospheric ozone pollution is often manifested as eye and lung irritation experienced at hot spot during peak-periods or rush-hours.

These double roles of ozone result in two environmental issues of importance in the science world. There is a general concern on the increase of low-lying ozone in the boundary layer of the troposphere, which is resulting in photochemical smog and other air pollution related problems especially in urban centers. There is also the wide spread interest and concern on the depletion of ozone concentration in the stratosphere, brought about by the emission of chlorofluorocarbons (CFCs) and other halons from anthropogenic activities (Molina and Rowland, 1974).

Justification of the study: The analysis of ozone concentration over Norrköping in Sweden (58.6°N, 16.2°E) has been carried out by Chen and Nunez (1998). They observed a seasonal variation for the whole period, a mean of 330 DU, a standard deviation of 48 DU, giving a Coefficient of Relative Variation (CRV) of 14.6% was obtained. The maximum during the period was 521 DU and the minimum 213 DU, with a range of 308 DU (93.3% of the mean).

Similarly a study of total ozone concentration trends over five U.S. mainland mid-latitude stations, Caribou (46.9°N, 68.°W), Bismark (46.8°N, 100.8°W), Boulder (40.0°N, 105.3°W), Wallops (37.9°N, 75.5°W) and Island (36.3°N, 86.6°W) was reported by Komhyr *et al.* (1997). Their results revealed negative trends with averages of -3.4, -4.9, -2.6. -1.9 and -3.3% per decade for winter, spring, summer and autumn months and on an annual basis, respectively. However, there has not been significant analysis of total ozone concentration carried out over different locations in Africa, hence the need for this study.

The general objective of the study is to investigate the variability of total atmospheric ozone concentration over the four African stations. The specific objectives are:

- To make a comparative study of the ozone concentration in the four specified stations.
- To investigate the seasonal and temporal variability of ozone concentration at the stations.

There was no difference in the seasonal, annual and temporal concentration among the four African stations studied.

MATERIALS AND METHODS

The data used in this study were obtained from satellite Earth Probe Total Ozone Mapping Spectrometer (EPTOMS) of NASA Goddard Institute for Space Study USA through the Internet service. From comparison of satellite data with those obtained from either Dobson or Brewer spectrophotometer, they have been found to be consistently close, with less than 1% error differences per decade between them (Kerr *et al.*, 1988). This makes the satellite data reliable.

The temporal and spatial variability of ozone concentration over four tropical cities as revealed by satellite instrument EPTOMS were studied for the period from 1997 to 2002 at the University of Ibadan, Ibadan Nigeria between year 2003 and 2005. The cities are Lagos in Nigeria, Dakar in Senegal, which are located in the northern tropics, Brazzaville/Kinshasa in Congo Republic and Nampula in Mozambique located in the southern tropics (Fig. 1).
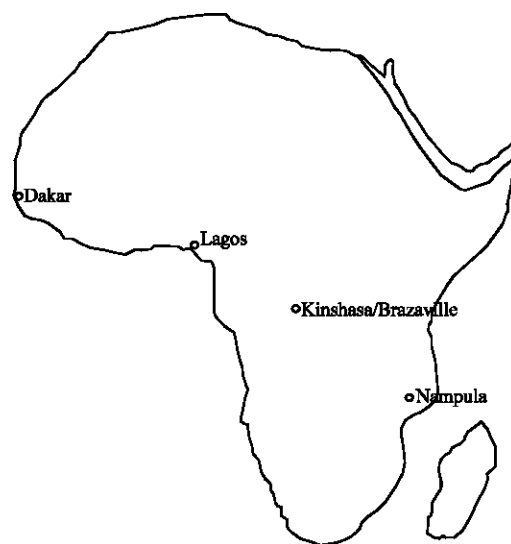

Fig. 1: A sketch of Africa showing the four stations for which ozone concentration was studied

Lagos and Dakar are West African cities situated at latitude 6.6°N, longitude 3.3°E and latitude 14.7°N, longitude 16.5°W respectively. Lagos is at an altitude of 10 m above sea level while Dakar is at an altitude of 35 m. Brazzaville/Kinshasa is in the central part of Africa located at latitude 4.3°S, longitude 15.3°E and at an altitude of 314 m above sea level. Nampula is situated at latitude 15.1°S, longitude 39.3°E and at an altitude of 440 m. Figure 1 shows a sketch of Africa and the four locations for which this study was carried out.

The daily ozone data were released the day following the measurement along with the sun's solar zenith angle (SZA) and the reflectivity of the cloud at the time of measurements. The data were analysed to determine the temporal, seasonal and annual variability of ozone concentration over the four stations.

RESULTS AND DISCUSSION

Considerable daily variations of ozone concentration were observed at Lagos and Dakar (Fig. 2a and b). The temporal oscillation period for the two stations varied between 2 and 6 days while the amplitude of the oscillation varied between 1.0 and 6.5 DU. Furthermore, a seasonal change was indicated by the periodic trend. The mean concentration of total ozone of about 270.8±0.3 DU was observed at Lagos for the entire studied period, a standard deviation of 15.3 DU and a Coefficient of Relative Variation (CRV) of about 5.4% were observed for the same period. The maximum recorded total ozone concentration for Lagos during the period was 309.5 DU with a minimum value of 216.4 DU, giving a range of 93.1 DU.

Similar analyses were carried out for Dakar, Kinshasa/Brazzaville and Nampula. The mean of the daily total ozone obtained for Dakar was 264.9±0.3 DU while its standard deviation was 15.8 DU for the period, the maximum value was 300.7 DU and the minimum was 223.1 DU, giving a range of 77.6 DU for the period. Kinshasa/Brazaville has a mean of 272.3±0.2 DU with a standard deviation of 11.1 DU, a maximum value of 318.8 DU and a minimum of 237.7 DU giving a range of 81.1 DU for the period. As for Nampula, the mean of the daily total ozone for the period was 270.0±0.3 DU, with a standard deviation of 12.0 DU, a maximum value of 305.4 DU and a minimum of 236.3 DU giving a range of 69.1 DU.

The daily total ozone at Lagos and Dakar (Fig. 2a and b) showed an annual variation, while those of Kinshasa and Nampula (Fig. 3a and b) were biannual. The maximum ozone concentration for the two West African stations all occurred in either the months of July and
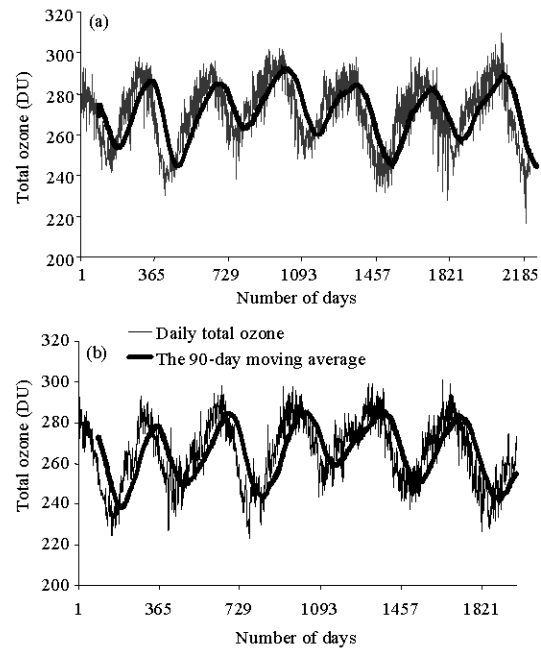

Fig. 2a and b: Daily total ozone and the 90-day moving average in Lagos, Nigeria and Dakar, Senegal, respectively
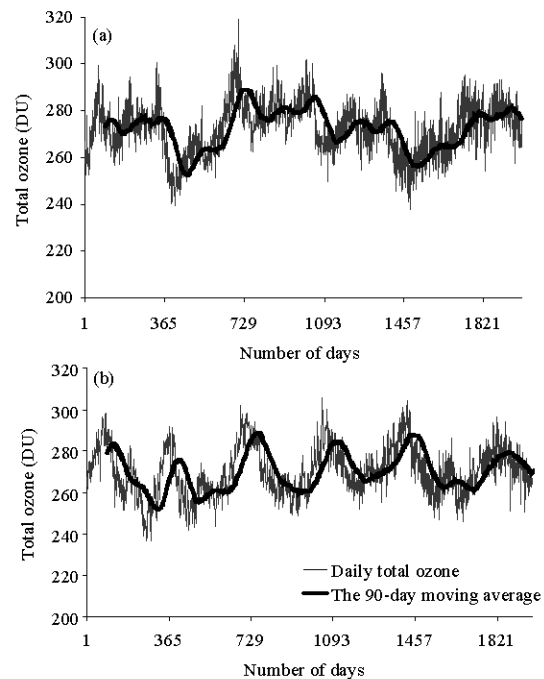

Fig. 3a and b: Daily total ozone and the 90-day moving average in Kinshasa, Congo and Nampula, Mozambique, respectively

August for the six years studied. Their minimum occurred within the months of December and January except in 2001 at Lagos, when it occurred in February.

Harmattan or dry season coincided with the period of minimum ozone concentration at Lagos in Nigeria and the raining season coincided with the period of maximum concentration at the same location. In all the six years studied, Lagos recorded its average minimum ozone concentration of 248 DU in the months December, January and February coinciding with the harmattan period. The average maximum of 288.6 DU occurred in July and August coinciding with the raining season. This is in accordance with some of the findings of Gallani *et al.* (1996) who conducted research study on ozone variation in the temperate region. He observed a decrease in total ozone concentration when a large blocking high-pressure center was located upstream of the studied area. Thus according to Gallani *et al.* (1996), occasional large-scale velocity convergence or divergence in the atmospheric flow pattern may be an important cause of ozone variation.

Annual seasonal oscillation periods of ozone concentration were observed at Lagos and Dakar with values varying between 295 and 375 days while those of Kinshasa/Brazzaville and Nampula were biannual and varied between 120 and 200 days. This is in conformity with the studies of Chipperfield *et al.* (1994) which reported increase in seasonal variations in ozone concentration at locations within the tropical reservoirs were found to increase with altitude amongst other factors. Thus the observation from this study showed similar trends with the previous findings. Kinshasa/Brazzaville and Nampula, are at higher altitudes of 314 and 440 m above sea level, respectively, recorded more frequent seasonal oscillations in total ozone concentrations than Lagos and Dakar, which are at much lower altitudes of 10 and 35 m, respectively. The average value of the annual amplitude of ozone concentration at Lagos and Dakar was 12 DU while that of Kinshasa/Brazzaville and Nampula was 7 DU (Fig. 3a and b).

The results obtained from the study of the spatial variability showed that Lagos/Dakar had the highest correlation coefficient of 0.7, followed by Lagos/Kinshasa 0.5 and Lagos/Nampula -0.1. Lagos had a mean concentration of 270.8±0.3 DU for the whole studied period, a standard deviation of 15.3 DU and mean annual variability of 14.1%. Dakar, Kinshasa and Nampula had corresponding mean of 264.9±0.3, 272.3±0.2 and 270.0±0.3 DU, standard deviation of 15.8, 11.1 and 12.0 DU, mean annual variability of 15.1, 9.8 and 10.9%, respectively.
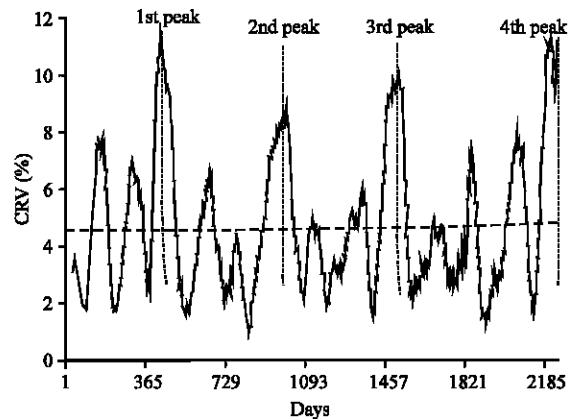

Fig. 4: CRV of ozone in Lagos smoothed over 30-day period

From the moving average analysis as shown in Fig. 4, the Quassi Biennial Oscillation (QBO) of the total ozone concentration at Lagos was observed around October/November 1997, May 1999, December 2000 and December 2002 with ranges of 25 to 30 DU. Comparing the spatial variability of ozone at Lagos and Dakar, the annual mean ozone concentration at Lagos were consistently higher than those of Dakar averagely in two-year periodic pattern. The annual mean at Dakar in 1997, 1999 and 2002 were 259.7, 266.6 and 262.4 DU, while those of Lagos for the same period were 269, 277.7 and 273.0 DU, respectively. This gave an average difference of about 10 DU.

In 1998, 2000 and 2001 the annual mean ozone values at the two stations were 267.9, 270.4 and 267.3 DU at Lagos and 265.7, 271.4, 266.3 DU at Dakar. This gave an average difference of about ±1.4 DU. This observation also confirmed that the QBO of ozone concentration was more pronounced at Lagos than Dakar. And this is also in conformity with other findings that QBO effect increases as one approach the equator (Holton and Lindzen, 1972).

Ozone temporal oscillation periods in the four stations had the same mean value. Each of them varied between 2 and 6 days while their average amplitude of temporal oscillation also varied between 1.0 and 6.5 DU. Thus temporal ozone variation at the four stations was independent of latitudinal location and attitudinal range. The temporal variation of ozone concentration at any location amongst other factors had been found to be interrelated with the prevalent vorticity around the location (Jacobson, 2000).

Vertical velocity of atmospheric motion determines how much of the atmospheric component at a given level is transported downward or upward. Thus vorticity affect the vertical distribution of ozone concentration in the atmosphere.

CONCLUSIONS

Annual seasonal oscillations were observed at Lagos and Dakar with oscillation period ranging from 295 to 375 days. While biannual seasonal oscillations were observed at Kinshasa and Nampula with oscillation period varying between 120 and 200 days. Kinshasa and Nampula are located at higher altitudes of 314 and 440 m, while Lagos and Dakar are at lower altitudes of 10 and 35 m, respectively. Seasonal variations in ozone concentration at locations within the tropical reservoirs were found to increase with altitude amongst other factors.

The annual mean values of ozone concentration at Lagos were higher than those of Dakar by an average value of 10 DU in the years of QBO occurrences. While the difference in the years of non-QBO were marginal with an average value of ± 1.4 DU.

Ozone temporal oscillation periods in the four stations were between 2 and 6 days while the average amplitude of the temporal oscillation varied between 1 and 6.5 DU irrespective of the latitudinal location and attitudinal range. Thus ozone temporal variation was found to be less dependent on the spatial variation. Spatial variation had higher correlation with both seasonal and annual variations than the temporal variation of ozone concentrations in the four stations studied.

REFERENCES

Boubel, R.W., D.L. Fox, D.B. Turner and A.C. Stern, 1994. Fundamentals of Air Pollution. Acad. Press, San Diego, pp: 273-288.

Chen, D. and M. Nunez, 1998. Temporal and spatial variability of total ozone in Southwest Sweden revealed by two ground-based instruments. Int. J. Climatol., 18: 1237-1246.

Chipperfield, M.P., L.J. Gray, J.S. Kinnersley and J. Zawodyn, 1994. A two-dimensional model study of the QBO signal in SAGE II NO_2 and O_2. Geophy. Res. Letters, 21: 589-592.

Gallani, A., A.M. Siani, N.J. Muthana and S. Palmeri, 1996. Synoptic scale fluctuation of total ozone in the atmosphere. Annales Geophysicae, 14: 1044-1050.

Holton, J.R. and R. Lindzen, 1972. An updated theory for the quasi-biennial cycle of the tropical stratosphere. J. Atmos. Sci., 29: 1076-1080.

Jacobson, M.Z., 2000. Fundamental of Atmospheric Modeling, Cambridge Univ. Press, pp: 352-358.

Kerr, J.B., I.A. Asbridge and W.F.J. Evans, 1988. Intercomparison of total ozone measured by the brewer and dobson spectrophotometer at toronto. J. Geophy. Res., 93: 11129-11140.

Komhyr, W.D., G.C. Reinsel, R.D. Evans, D.M. Quincy, R.D. Grass and R.L. Leonnard, 1997. Total ozone trends at sixteen NOAA/CMDL and cooperative dobson spectrophotometer observations during 1979-1996. Geophys. Res. Letters, 24: 3225-3228.

Molina, L.T. and F.S. Rowland, 1974. Chlorine atom catalyzed destruction of ozone. Nature, 249: 810-812.

Parker, L., 2000. Stratospheric Ozone Depletion: Implementation Issue IB.9-7003 NCSE, Washington D.C. pp: 1-18. http://A.\ozonedepletion\ Stratospheric Ozone Depletion Implementation Issue. htm

Roelofs, G.J. and J. Lelieveld, 1997. Model study of the influence of cross-tropopause ozone transport on tropospheric ozone levels. Tellus, 49B: 38-55.

World Meteorological Organisation (WMO), 1962. Ozone Observations and their Meteorological Implications.

World Meteorological Organisation (WMO), 1995. Science Assessment of Ozone Depletion, 1994 Global Ozone Research and Monitoring Project. Report No., 37, Geneva.