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Influence of AAM-LOD on the lower stratospheric Ozone transport over Lagos–Nigeria

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Abstract

An investigation of the relationship between Atmospheric Angular Momentum (AAM) via Length of Day (LOD) and the variability of Ozone (O_3) in the tropics with much emphasis on Lagos-Nigeria, using the global zonal wind data spanning 1997 to 2005 has been carried out. The mean O_3 concentration, O_3 temporal oscillation period, its average temporal amplitude of oscillation and its average maximum daily variation have been determined to be 273.6 ± 0.04 DU, 5 days, 7.81 Du and 48.8 Du, respectively. The average monthly maximum and minimum O_3 concentrations were found to be 287.8 Du occurring between July and August; and 192.73 Du occurring between December and March respectively. These variations also follow the trend of the zonal wind speeds obtained for Nigeria between the periods under investigation. It was observed that the zonal wind speed has its peak in July and August with a decline from October to March. Consequently, the LOD and AAM vary in similar manner in the study area within the period under investigation. This observed behavior of the LOD and AAM and hence, the variation in the Ozone within the tropics, could be attributed to the effects of the extra-tropical suction pump (ETSP) action which causes the O_3 transport from the tropical stratosphere to the mid latitude region.

Key Words: AAM, LOD, zonal wind, Ozone, Dynamical process, tropics, stratosphere

1. Introduction

Atmospheric processes that change ozone (O_3) amounts are photochemical and dynamical ones. Photochemical processes refer to the production and loss of O_3 driven by solar ultra violet (UV) photochemistry. Dynamical processes refer to how O_3 is transported from one region to another by winds and large-scale circulation patterns in the atmosphere. Ozone variability in the upper stratosphere is driven by photochemical processes. There is the necessary UV radiation that creates and destroys Ozone. Ozone molecules in the lower stratosphere exist for long enough periods to be transported from a region into another.

The sun drives the thermal balance of the Earth and when modulated by orbit based parameters, determines the seasonal weather cycles of the Earth. According to [1] the variability in solar activity correlates with that in the earth rotation as well as in the atmospheric angular momentum (AAM) at inter-annual and decadal time scales.

The Atmospheric Angular Momentum (AAM) is a fundamental geophysical parameter that measures the intensity of the zonal circulation. In other words, AAM is a basic circulation index used to characterize the dynamic state of the general circulation of the atmosphere and climate. The main contributions to the axial AAM components are the global zonal winds in the troposphere and stratosphere.

Conservation of the angular momentum would require an increase in AAM be accompanied by a decrease in the rotation of the earth, and hence an increase in the LOD. The variability of the AAM and LOD at inter annual time scale has been associated with the EL-Niño southern oscillation (ENSO) phenomenon and ozone variability [1–3]. The understanding of the stratospheric parameters leads to the understanding of the issues of O_3 and climate changes. The authors of [4] have investigated effects of some atmospheric parameters on the dynamics of lower stratospheric Ozone in the low latitude. It was ascertained from their calculations of these parameters; like ETSP, QBO and mean Ozone concentration, that, their variations follow the trend of zonal wind speed obtained for Nigeria between the periods under investigation. The variation in the Ozone concentration in the tropics was attributed to the effects of the ETSP action.

This work studies the relationship between the variability of the lower stratospheric O_3 Tigard off by ETSP and the AAM-LOD as indices of circulation in the low latitude. Despite a work [5] carried out in the area using 5-years of data (1997–2002), this work, not only uses 9 years of data (from 1997–2005) but also investigates how AAM and LOD vary with O_3, among other parameters, in the tropics within the period. This is made possible using the zonal wind data obtained for latitude 4° to 15° and longitude 2° to 15° E, where Nigeria lies. This is carried out for pressure levels of 20, 50 and 70 mb.

2. Sources of data

The monthly column ozone data are obtainable from Earth Probe Total Ozone Mass Spectroscopy (EPTOMS version 8 over pass generated 3^{rd} January, 2006 while the zonal wind speed data are obtainable from the recent National Centers for Environmental Predication in conjunction with the National Center for Atmospheric Research (NCEP/NCAR) reanalysis data at the website:

http://www.esrl.noaa.gov/psd/data/reanalysis/reanalysis.shtml

3. Methods

The equation used by [6] was adapted for use in this work. Taking into account the position of the study area, which is situated in the equatorial region, then, the relation becomes

$$AAM = \frac{2\pi R^3}{g} \int_{\mathrm{P}_b}^{\mathrm{P}} \int_0^{\pi/2} \int_0^{\pi} u \cos^2 \phi \partial\phi \partial\lambda \partial\mathrm{P}, \tag{1}$$

where P_b and P indicate the pressure levels with the upper limits as 20 mb and lower limits as the pressure in the troposphere, R is the Earth's equatorial radius $= 6.38 \times 10^6$ m and g is the acceleration due to gravity $=$ 9.8 m•s^{-2}; u is the zonal wind speed, and ϕ indicates the latitude and λ the longitude.

The relation between AAM and LOD as used by [1, 2, 6, 7] is given as

$$LOD = 1.68 \times 10^{-29} AAM. \quad (2)$$

Hence, equations 1 and 2 were employed in writing a program in turbo C++ which was used in generating the AAM and LOD data used in this study.

4. Analyses and discussion of results

Figure 1 shows that the variations in the O_3 concentration is periodic, having a temporal oscillation period of 5 days, and an average temporal amplitude of oscillation of 7.81 DU. Its average maximum daily variation is determined to be 48.8 DU, and the annual seasonal oscillation period is 325 days.

The observation of high frequency daily O_3 variability could be linked to the possible interconnectivity between convective activities and stratospheric O_3 redistribution. And the presence of high convective activities could also be linked with change in stratospheric wind speed both in the horizontal and vertical directions.

Changes in the stratospheric O_3 and wind affect the flow of energy at altitudes just below, which then affect the next lower altitudes and so on, all the way to the ground [8].

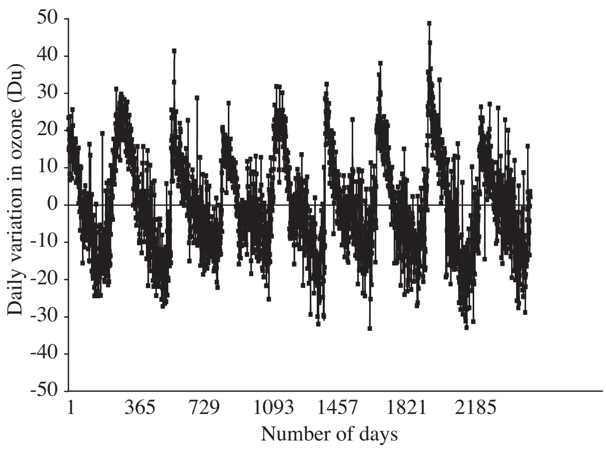

Figure 1. Daily variation of ozone in Lagos Nigeria, 1997–2005.

Statistical analysis of the O_3 distributions (Table 1) shows that the mean monthly maximum O_3 concentrations were found to be 283.6 Du occurring between July and August. This maximum O_3 concentration coincided with the tropical summer rainfall over the West African region, which peaks between June and September as can also be observed in Figure 2 that shows the mean monthly distribution of precipitation in Nigeria between 1997–2006. Thus, there is a relationship between the rainfall patterns and the total O_3 variability in Nigeria. The occurrence of maximum O_3 concentration in the tropics with the peak tropical summer rainfall could possibly be attributed to the reduction in the strength of ETSP action which causes the transportation of O_3 from the tropical stratosphere into the mid and high latitudinal region. This reduction might be due to the decrease in the energy from the atmospheric heat engine expected to drive the ETSP [5].

The tropical rainy season is characterized with minimum tropical surface temperature and evaporation which might be linked with decreases in the atmospheric heat engine responsible for driving the ETSP. Thus, it may be inferred that there is a relationship between reduction in the strength of the ETSP and O_3 distribution during the tropical rainfall season.

Table 1. Statistical Analysis of Ozone at Lagos (1997 – 2005).

Year	Mean	Max	Month (max)	Min	Month (min)	% Var
1997	269.3	284.7	July	248.6	Dec.	12.3
1998	266.5	279.6	July	235.9	Nov.	15.6
1999	278.1	287.4	Aug.	234.8	Mar.	18.3
2000	274.9	281.2	Aug.	246.6	Nov.	12.2
2001	270.0	283.8	Aug.	237.9	Feb.	16.2
2002	279.3	284.8	Aug.	246.3	Jan.	13.5
2003	273.5	282.0	Aug.	245.8	Jan.	12.8
2004	279.6	290.0	Aug.	251.5	Dec.	13.3
2005	271.0	278.5	Sep	239.5	Dec.	14.0

Mean = Annual mean of ozone concentration
Max = Maximum value
Month (max) = month of maximum ozone concentration
Min = minimum value
Month (min) = month of minimum ozone concentration
% Var (variability) = 100 * Range / Maximum value
Ave. % Var = 14.3

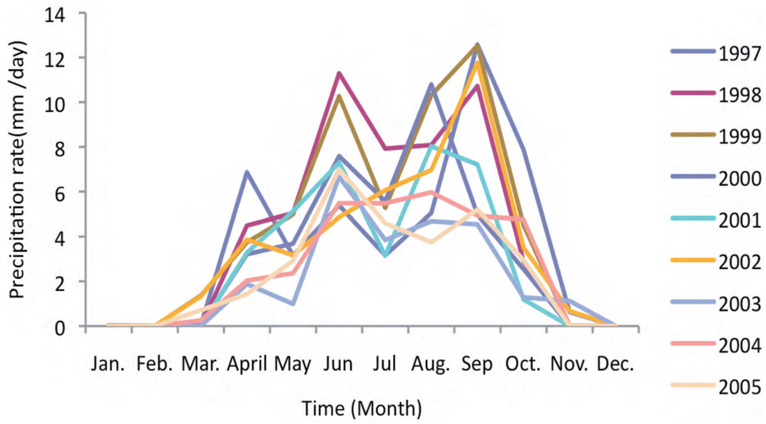

Figure 2. Monthly Distribution of Precipitation Rate in Nigeria (1997–2005).

On the other hand, an average monthly minimum O_3 concentration is found to be 242.99 Du occurring between December and March. This coincides with the period of dry season over West Africa which is characterized by high surface temperature and evaporation. This confirms the earlier suggestion on the link between the strength of the ETSP and O_3 distribution. With high temperature and maximum evaporation during this period, the atmospheric heat engine that drives the ETSP might be suggested to be at its peak performance in lifting of O_3 rich air off the tropical stratosphere into extra tropical region, thus reducing the O_3 amount in the tropics.

4.1. Analyses discussions of the AAM and LOD

The general observation shows that the AAM varies in similar manner with the LOD (appendices A–C). The curves in appendices A, B and C show the mean variations of AAM and LOD for Lagos at 20 mb, 50 and 70 mb respectively between years 1997 and 2005. Observations show clearly that AAM and LOD have their peak amplitudes in July and August, but have their minimum values between December and March. This trend in variations of AAM and LOD is also shown at 50 mb, but with some slight deviations. Again at 70 mb, although the peak amplitudes are between July and August there are several slight changes in the months for minimum amplitude. The implication of these observations in the variations of AAM and LOD at these pressure levels may be that at higher pressure levels (that is below the stratosphere), the variations in the AAM and LOD do not have a distinct minimum and maximum values, unlike at 20 mb, where the variations in AAM have distinct maximum and minimum amplitudes.

Hence, the variations of AAM and LOD at 20 mb and 50 mb are similar to the variation of the O_3, that is, maximum in rainy season and minimum in long dry season. However, at higher pressure levels such as 70 mb, the variations in the AAM and LOD do not have uniform trend with that of O_3. This confirms the work carried out by [1, 2] and [6] that the AAM and LOD are significant factors in the transportation of O_3. Variations at 20 mb depict the variations at the lower stratosphere. Hence, the O_3 data obtained is a stratospheric O_3.

Furthermore, since the ETSP is seen to affect the O_3 variation in the low latitude [6], the AAM and LOD also are affected by the ETSP.

4.2. Comparisons with the related works

Although some research has been carried out on the variation of O_3 concentration in the tropics, [5], using 5 years of data, the effect of the AAM and LOD on the O_3 transport in the tropics was not considered.

On the other hand, some works have been carried out on the relationship, between O_3 concentration and AAM and LOD [2, 8, 9] but these investigations were carried out in the mid and higher latitude regions. In the present work, the effects of AAM and LOD among other atmospheric parameters on the O_3 variation have been investigated using 9 years of O_3 data in the tropical region.

The result of [9], which associated the main causes of O_3 hole appearance and O_3 trend in the middle and high latitudes of the Northern hemisphere with a decadal decrease of planetary wave activity in the mid and high latitude of the stratosphere was confirmed by the action of ETSP in the tropical stratosphere. As stated by [5], and is in line with annual variation of O_3 concentration in this work.

The result in this work, therefore, supports the downward propagation in the stratosphere and upward propagation in the troposphere of AAM observed in earlier studies for other variables such as was given by [10] and [11].

All these works were carried out in the mid and high latitude region. Hence, there is a link between the tropical and mid and high latitudinal weather patterns. And this link is based on planetary wave activity.

The similarity in the variation of AAM and LOD in this work confirms the result of the work of [3] which asserts that the time variation of the AAM can largely explain the change of LOD on seasonal scale.

4.3. Conclusions

In this work, it has been established that the variation in AAM caused by variation of the universal time or LOD transfer O_3 by means of zonal wind from the upper troposphere to the lower stratosphere in the tropic.

The mean monthly variations of AAM and LOD at pressures of 20 and 50 mb in the atmosphere follow a definite pattern. That is, maximum amplitude between July and August, and minimum amplitude between December and March. This is also the trend followed in the seasonal variation of O_3 column data in the low latitude. This implies that (since this is the pressure level obtained in the lower stratosphere) the O_3 used in this work is the stratospheric O_3.

In addition, the pressure levels of the atmosphere have very strong effect on O_3 variation due to its effect on the AAM and LOD. And the variation in the LOD is significant in the tropics. This is evident in its effect an AAM which enhances the transport of O_3 from the upper troposphere to lower stratosphere in the tropics. This work confirms previous works ([1, 10, 12]) using other analytical approaches that the influence of atmospheric dynamics is a major factor in the variability of stratospheric O_3 distribution over the tropics year-to-year.

Finally, the effect of LOD and AAM on O_3 is not only seasonal but decadal.

Relating these observations to weather patterns, it is well appreciated that the duration of the dry season gets prolonged as one moved further north particularly in the tropics [5] since the prevalent atmospheric dynamics over the different latitudinal zones is believed to be responsible for these observations.

This work serves as a preliminary study of the effects of AAM and LOD on the O_3 transport in the low latitude. The following suggestions are proffered for more detailed study of the effects of O_3 transport on the weather pattern of the low latitude region.

- A further study of other parts of the tropics should be carried out so as to obtain a detailed influence of the zonal winds in ozone variations in the tropics.
    - More O_3 data on decadal time scale is made available for more stations in the tropics. This will enable a thorough study of the O_3.
    - Mitra (1947) noted that the increase in the O_3 values in the middle atmosphere is always associated with magnetic storms. It is hereby suggested that the effects of magnetic storms on ozone in the tropical latitude be carried out.

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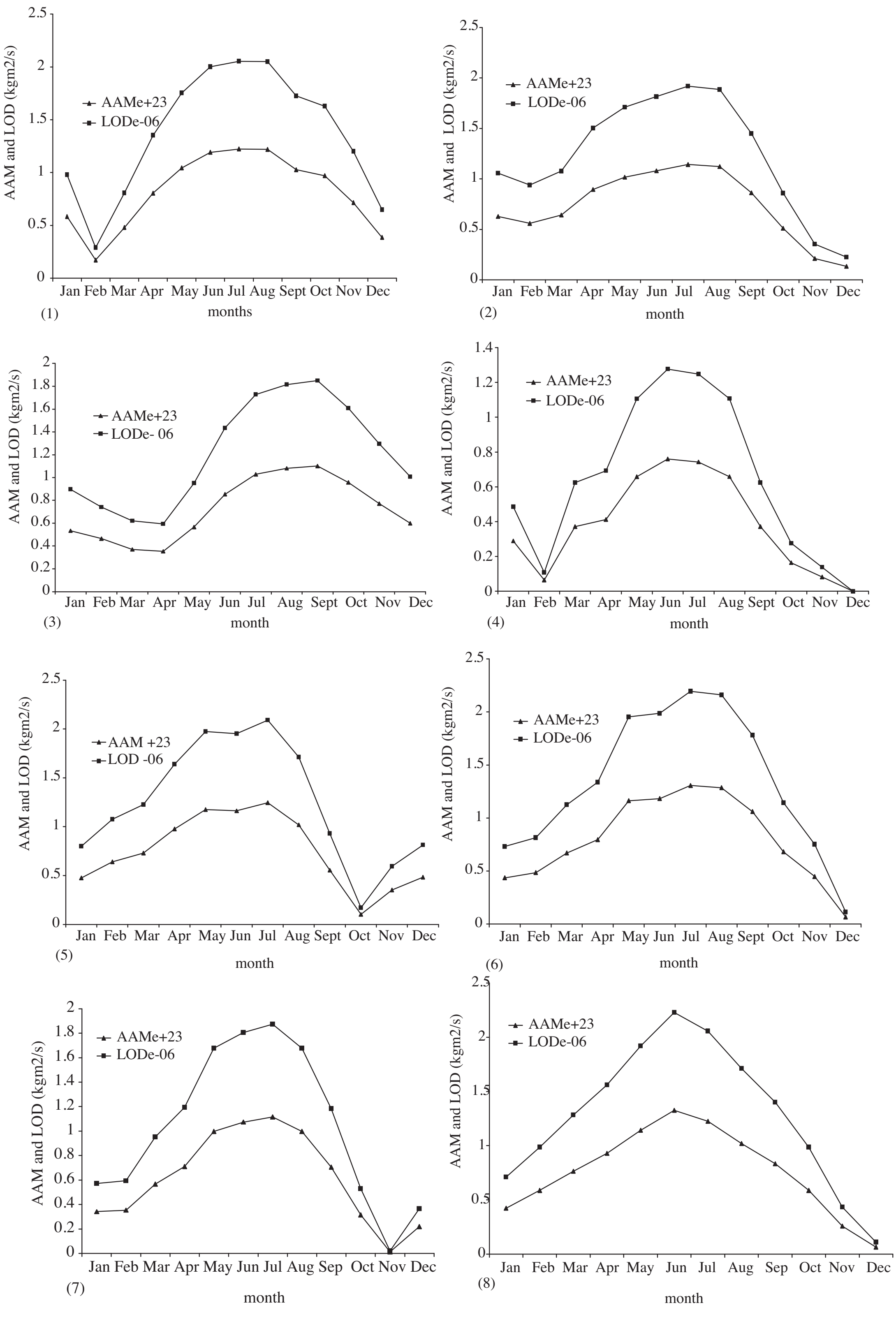
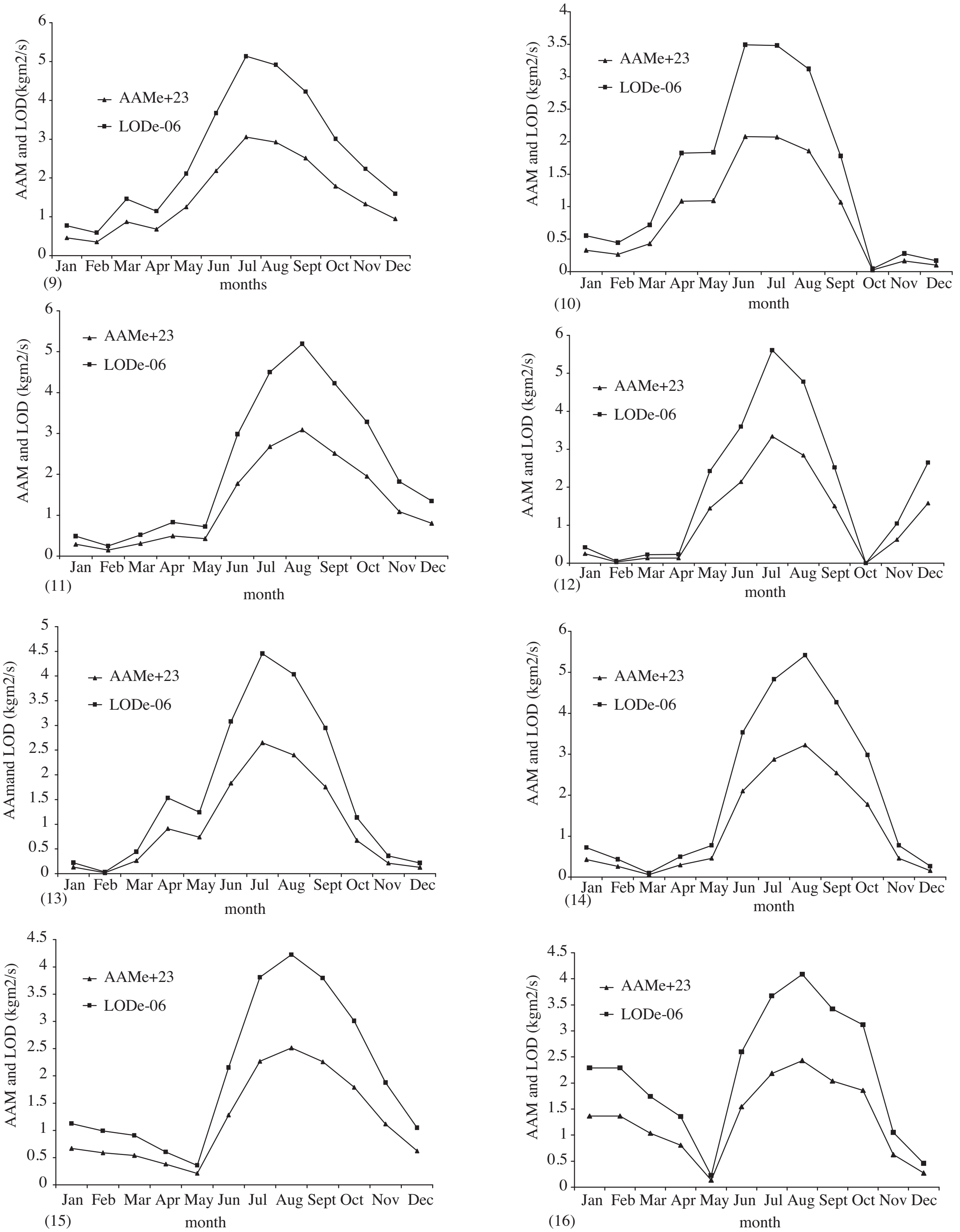
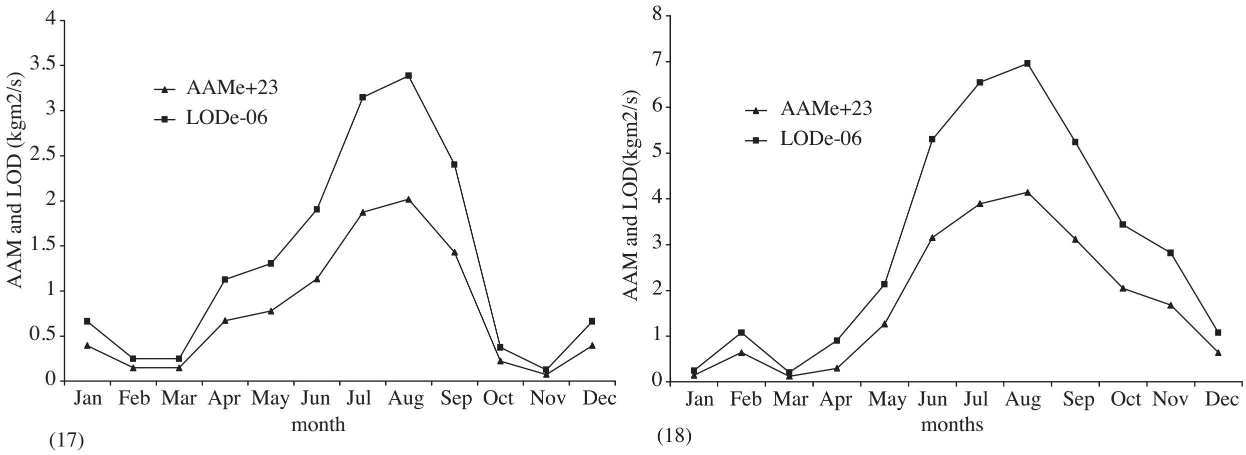


Appendix A. Mean variations of AAM and LOD for Lagos at 20 mb (1) 1997; (2) 1998; (3) 1999; (4) 2000; (5) 2001 and (6) 2005; (7) 2004 and (8) 2005.



Appendix B. Mean variations of AAM and LOD for Lagos at 50mb (9) 1997; (10) 1998; (11) 1999 and (12) 2000; (13) 2002; (14) 2003; (15) 2004 and (16) 2005.



Appendix C. Mean variations of AAM and LOD for Lagos at 70 mb (17) 1998 and (18) 1999.