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The "Missing Link" in Ground and TOMS Satellite Total Column Ozone Measurements in Equatorial Africa

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Abstract

Comparisons have been made between ground-based Dobson Spectrophotometer instrument measurements for 1993-999 with those of the Meteor 3 and Earth Probe Total Ozone Mapping Spectrometer (TOMS) satellite for Lagos, Nigeria. Results show that both measurements are similar. Both instruments report the expected peak total column ozone period of April – October for an equatorial site.

Keywords: TOMS; Dobson Spectrophotometer; equatorial Africa; Ozone, LIDAR.

1.0 Introduction

Aircraft jet engines emit aerosols and condensable gases leading to particles that can influence atmospheric chemistry, clouds, and climate. The world now has a fleet of about 10,000 commercial aircraft flying several billion miles per year. Engines that burn more than 100 billion kg of fuel per year at high temperatures power these aircrafts. They inject Nitrogen oxides (NO_x) from this combustion at their cruise altitudes in the upper troposphere and lower stratosphere. Ferry et al. (1999) reported that subsonic aircraft are a source of detectable sulphuric acid aerosol. A significant increase in sulphuric acid aerosol concentration was detected above 10-km pressure altitude during a single cross-corridor flight out of Shannon, Ireland, on October 23, 1997. NO_x is also produced at the ground in both fixed sources (i.e. power plants) and mobile sources (i.e. automobiles). This NO_x is converted to soluble nitric acid (HNO_3) and poured out of the atmosphere during rainfall. Thunderstorms can also be a significant local source of NO_x in the troposphere (Cros et al., 1988, Kundu and Jain, 1993).

Characterisation and parameterisation of the profiles of liquid aerosols, solid particles like dust, and atmospheric gases (O_3, CO) are important for weather forecasting, climate modelling and environmental monitoring. Quantifying 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 reserves of aerosols (Barnes and Hofmann, 1997). Due to the emission of CO_2, NO_x and SO_x from the combustion of fossil fuels, ozone networks need to be enlarged in Africa to obtain more ozone information in the tropics and upper atmosphere. Aerosols and sulphates, as forcing agents for climate, also need to be measured in the region.

Several workers (Fishman and Larsen, 1987, Fishman and Watson, 1990, Andrea et al., 1992) 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 and lightning discharges (Cros et al., 1988, Fishman and Larsen, 1987). Since the atmospheric chemistry over the tropics is greatly influenced through tropical rainforest which has great biomass activity coupled with the Savannah where large-scale bush burning incidents are prevalent, real-time atmospheric measurements need to be undertaken. These will be needed to confirm and validate the satellite measurements. The need of real-time ground observations of atmospheric ozone and aerosol levels in West Africa cannot be neglected. Presently, such measurements are sparse and discontinuous.

In the work done by (Fioletov et al., 1999), who compared the measurements of total ozone from the world ground-based ozone network with the TOMS satellite measurements, none of the sites is in West

Africa. At present, in the whole of West Africa, measured total column ozone data can only be obtained from one site which is Lagos. As part of a future work therefore, in this report is presented the Total Ozone Mapping Spectrometer (TOMS) total column ozone measurements with Meteor 3 and Earth Probe spacecraft from 1993 - 1999 and those measured by the Dobson Spectrophotometer at this site. The need for establishing a LIDAR station for atmospheric profiling of ozone and aerosols in equatorial Africa has been underscored.

2.0 Data and Methodology

Total Ozone Mapping Spectrometer (TOMS) instruments have been 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). The ADEOS data that completely overlaps the Earth Probe was not used. There was no TOMS data for the year 1995 and between January - July 1996. As the spacecraft carrying the TOMS orbits the earth, it passes a number of ground stations that conduct research in atmospheric science or having ozone and aerosol measuring instruments. Such sites in West Africa are Lagos, Nigeria (3°19'E, 6°35'N), Lamto, Cote D'Ivoire (5°01'W, 6°13'N) and Ekona (9°19'E, 4°25'N) in Cameroon whose monthly mean TOMS total ozone data for 1993 – 1999 were used.

For the purpose of this work, West Africa is taken as the region of Africa located between longitudes 20°W to 20° E and latitudes from the equator to 20°N. This was done to take the modulators of the local weather and climate over the region into consideration. They include, the Cameroon mountain, (around 10°E, 5° - 8°N), which is a known source of volcanic aerosols. Others are the tropical rainforests and associated biomass burning in the Sahel region. Also, gases arise 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.

Of the 26 African stations in the World Ozone and Ultraviolet Radiation Data Centre (WOUDC) archive (http://www.msc-smc.ec.gc.ca/woudc/), only one of them, Lagos, Nigeria, is located in West Africa. The measurements of the total ozone column ozone with the Dobson Spectrophotometer, started at the site in April 1993. The measured total column ozone data for Lagos used in this study was obtained from the WOUDC archive. In this study, the Meteor 3 and Earth Probe TOMS, and measured monthly mean total column ozone data for the years 1993 – 1999 at Lagos have been analyzed using Grid Analysis and Display System (GRADS) software (http://www.grads.iges.org). Student's T-test was also used to compare the TOMS and Dobson Spectrophotometer measurements. A small numerical value of the probability (say 0.01 or 0.05) implies that the observed difference between the TOMS and Dobson measurement is very significant (Press et al., 1992).

Method:

Calculate the Mean values (M1, M2) and standard deviations (*SD1* and *SD2*) of both samples.
Determine *SDg* = sqrt (((*n1*-1)**SD1***2 + (*n2*-1)**SD2***2)/(*n1*+*n2*-2))
The test parameter is *t* = (M1 - *M2*) / (SDg * sqrt (1 / *n1* + 1 / *n2*)).
The number of *Degrees of Freedom* = *n1* + *n2* - 2.

Level of Significance:

The significance levels of *t* for different *Degrees of Freedom* are available in any Statistics textbook having information on Student's T-test.

3.0 Results

In this section is presented the results of comparing the Dobson measured and TOMS satellite total column ozone at Lagos for the period 1993-1999. The monthly mean ozone measured by the TOMS spacecraft was higher than the Dobson ground measurements at Lagos for the months of April - December 1993 (Fig. 1). The disparity between the measured and TOMS data were greatest in the months of July - October which falls within the monsoon season in West Africa, April - October. This is the period of the year when there is significant biomass burning and thunderstorm activity. This of course does affect the ozone and aerosol levels at tropical sites (Fishman and Larsen, 1987, Cros et al., 1988, Kalicharran et al., 1993, Fioletov et al., 1999). The TOMS satellite over-estimated the Dobson ground-based measurements, a fact further confirmed by the results of the Student's T-test (Table 1). The probability (0.0038) is low (degree of freedom is 19).

In the year 1994, the Total Ozone Mapping Spectrophotometer aboard the Meteor 3 satellite had measurements of the total ozone that were higher than the Dobson ground-based instrument for 7 out of the 11 months for which measurements were available (Fig. 1). That notwithstanding, the differences between the monthly mean Dobson instrument recordings and TOMS satellite were not significantly different, 95 percent of the times. One could not compare the Dobson measurements with TOMS data between January 1995 to July 1996 when the NASA/Goddard Space Flight Center (Code 916) did not have any satellite-carrying TOMS in orbit. The main disadvantage of TOMS or any other satellite for atmospheric near real-time measurements, is that of maintaining calibration over time (Kalicharran et al., 1993).

For the period August - December 1996, the TOMS instrument on the Earth probe satellite launched in July 1996 again over-estimated the ground-based Dobson spectrophotometer measurements (Fig. 1). The results of the Student's T-test show that the differences between them are significant (Table 1). For the two months, January and April in 1997 when both TOMS and Dobson instruments had measurements of total ozone in Lagos, the TOMS values were higher (Fig. 1). In the year 1998, the entire Earth Probe TOMS measured total ozone data were higher than those from the ozone station in Lagos. For the year 1999, the differences between the TOMS satellite and Dobson ground instrument were significant, 95 percent of the times (Table 1). The TOMS instrument seemed to over-estimate the total column ozone at this equatorial site (Fig. 1).

Table 1: Mean monthly total ozone data (in Dobson Units) at Lagos and the Student's T-test results

Month	1993		1994		1996		1997		1998		1999	
	DOB	TOM	DOB	TOM	DOB	TOM	DOB	TOM	DOB	TOM	DOB	TOM
January	x	257.6	244.4	232.3	246.5	x	236.1	250.9	x	240.0	240.6	259.0
February	x	255.7	280.3	246.1	230.8	x	x	252.3	x	245.4	243.7	263.9
March	x	258.0	270.1	259.6	235.5	x	x	261.0	x	254.0	253.0	271.8
April	257.3	266.1	248.6	263.1	253.3	x	256.5	272.8	258.7	264.6	259.8	275.3
May	255.1	270.0	248.1	269.1	239.6	x	x	275.1	253.3	269.4	262.2	282.5
June	246.0	262.3	255.0	269.1	x	x	x	281.4	259.7	276.2	275.7	287.6
July	252.0	274.7	256.7	275.5	x	276.0	x	288.6	254.8	283.8	X	291.3
August	250.9	276.8	x	275.4	259.0	279.0	x	287.0	256.4	287.2	250.9	293.3
September	251.5	273.4	250.3	270.8	250.7	277.6	x	285.4	251.6	283.2	251.1	293.1
October	252.7	253.6	251.6	268.3	256.3	272.5	x	277.9	247.8	279.0	246.8	281.4
November	243.9	254.4	250.0	261.0	253.7	259.9	x	262.4	258.7	266.5	246.1	272.5
December	237.0	244.7	254.8	x	252.5	255.0	x	247.0	248.0	267.9	240.6	260.3
Mean	249.6	262.3	255.4	262.8	247.8	270.0	246.3	270.2	254.3	268.1	251.9	277.7
T-value	-3.34		1.44		4.45		2.10		2.61		5.32	
Probability	<0.0038		<0.1660		<0.0008		<0.0587		<0.0175		<4.81e-05	

Legend: DOB = Dobson ground-based instrument TOM: TOMS satellite measurements x denotes missing values

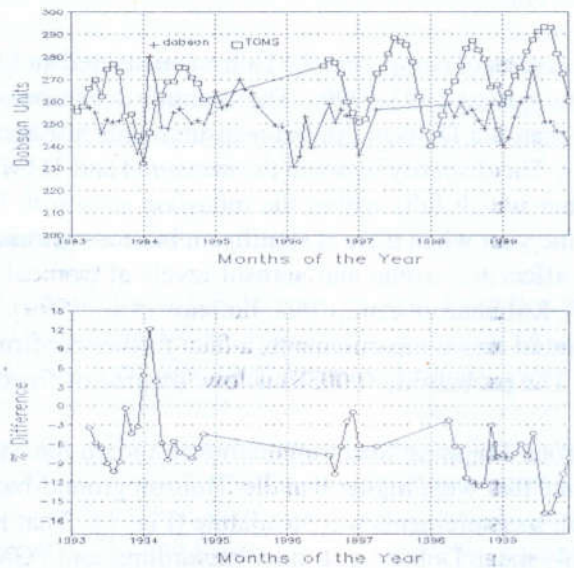

Fig 1. TOMS and Dobson total column ozone measurement for Lagos, Nigeria.

Table 2. Stratospheric DIAL O_3 & Tropospheric-Stratospheric Aerosol System

TRANSMITTER	
Laser source	Double cavity excimer laser (XeCl, XeF)
Emitted wavelengths	308nm, 351nm
Energy	~~300mJ at 308nm , ~~100mJ at 351nm
Repetition rate	> 50 Hz
RECEIVER :Stratospheric system	
Telescope	Parabolic mirror (0.8m diameter)
Detected channels	
95% of the elastic (Rayleigh scattering) lidar returns @ 308 and 351nm	Ozone density and aerosol back-scattering ratio profiles @ 351nm in the high stratosphere (25-40km)
5% of the elastic (Rayleigh scattering) lidar returns @ 308 and 351nm	Ozone density and aerosol back-scattering ratio profiles @ 351nm in the low stratosphere (~~10-30km)
All the anelastic (Raman Scattering) N_2 lidar returns @ 332nm and 382nm	Ozone density and aerosol extinction profile in the low stratosphere (~~10-30km)
Tropospheric system	
Telescope	Parabolic mirror (0.3m diameter)
Detected channels	
The elastic (Rayleigh scattering) lidar returns @ 351nm and the anelastic (Raman scattering) N_2 lidar returns @ 382nm	Aerosol back-scattering ratio and extinction profiles

4.0 Discussion

The percentage differences (Dobson-TOMS)/Dobson was high in 1994 and 1999. It should be noted that there were no TOMS measurements between January 1995 to July 1996. There are also many days without Dobson instrument measurements at Lagos, the only site in West Africa (latitudes 0^0 to 20^0 N, longitudes 20^0 W-20^0 E) with a Dobson instrument. The levels of the total column ozone oscillate depending on the location of the Inter-

Tropical convergence zone (ITCZ). The measurements made at Brazzaville, Congo had provided evidence for large-scale photochemical ozone production in West Africa (Cros et al., 1988, Andrea et al., 1992). The ITCZ further encourages a lot of vertical exchange in West Africa. Of great significance are the maximum values of total column ozone in the months of August - October at Lagos, Nigeria, where the case of thunderstorm outweighs biomass burning and dust transport.

Analysis also showed that the monthly mean total column ozone at the other TOMS sites in West African had the same pattern, increasing with latitude as noted earlier by Cros et al. (1988). The minimum values were in the months of December - February, which also marks the southern-most descent of the ITCZ over West Africa. During this time, the lower atmosphere is enriched with dust aerosols from the dry lakes near Lake Chad and Sahara desert. The northeast trade winds driven by the ITCZ transports lots of the dust particles into the lower atmosphere. On the other hand, the maximum total column ozone values were noticed in the months of August to October (peak summer monsoon and northern-most ascent of the ITCZ near 20°N) when thunderstorm activity rather than biomass burning is more pronounced. That may suggest the dominance of thunderstorms rather than biomass burning in controlling the total column ozone in West Africa during the peak of the wet season.

The Nimbus 7, Meteor 3 and Earth Probe TOMS zonal monthly mean total column ozone data for the years 1979 – 1999 had earlier been analyzed Chineke et al. (2000). The TOMS data was able to reproduce signatures of the Quasi-Biennial Oscillation (QBO) in West Africa. 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/).

5.0 Conclusion

Satellite data complemented by aircraft and ground data helps atmospheric science communities understand, assess and track global, regional and local environmental changes. There are few papers reporting total column ozone measurements over equatorial sites. Interestingly, this paper has addressed a very interesting scientific question: the behaviour of atmospheric ozone at a station located in Nigeria, slightly north of the equator in West Africa. The missing link is a lidar station that will provide on a continuous basis, detailed measurements of atmospheric variables like ozone and aerosols. Ozone/aerosol lidars (stratospheric and tropospheric DIAL) will provide ozone data both for the troposphere and stratosphere over yearly periods.

A proposal is being made (Table 2). This will help in understanding an unsolved question about tropospheric ozone formation in equatorial Africa. The ozone maximum of the northern hemisphere dry season that has been shown by aircraft measurements and Ozonesonde data is not retrieved from satellite like TOMS, SAGE, etc and Dobson spectrophotometer measurements. The missing link continuous LIDAR measurements of atmospheric ozone and aerosol will help better to understand the role of deep convection in the ITCZ regarding ozone formation, depletion and transport in equatorial West Africa. The data from Dobson Spectrophotometer, TOMS and other satellite instruments will not allow understanding fully the question of ozone formation over West Africa.

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