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Full Length Research Paper

Inter-comparison of Dobson Ozone Spectrophotometer, Differential Optical Absorption Spectroscopy and Ozonesonde measurements over Nairobi

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Declining ozone layer due to air pollution and climate change has significant impacts on human health. This study assessed similarity of observed total ozone measurements through inter-comparison of data from ground based ozone measuring instruments (Dobson Ozone Spectrophotometer (DOS), Differential Optical Absorption Spectroscopy (DOAS) and Ozonesonde). Root Mean Square Error (RMSE), percentage difference and BIAS were used. RMSE values of 3.1, 3.3 and 5 DU were found with a BIAS of -1.1, 0.3 and 3.5 DU for DOS/DOAS, DOS/Ozonesonde and DOAS/Ozonesonde respectively. Percentage difference ranged between -4.8 and 5.2% for all ozone measurements. RMSE, BIAS and percentage difference results for all measurements were small, tolerable and thus comparable. Development of a rigorous validation methodology, recalibration and regular validation of ozone measuring instruments on a regular basis will increase reliability of these measurements. This will ensure that inter-comparison with observed data over long periods of time will be possible and thus establish long trends of total ozone column needed for planning and policy related to air pollution in the region.

Key words: Ozone, bias, root mean square error, percentage error.

INTRODUCTION

Ozone (O_3) is an important but toxic molecular species in the troposhere. In the stratosphere, ozone absorbs most of the ultra-violet (UV) radiation, preventing this potentially harmful radiation from reaching the earth's surface and accounting for the temperature increase in this atmospheric layer and thus for the stability of the atmosphere. Ozone is formed and destroyed in complex systems of atmospheric chemical reactions, catalyzed by various other trace gases.

Depletion of stratospheric ozone layer and climate change significantly impact the quality of human life, property and plants (Rowland, 2005). With increased industrialization, rising emissions of pollutant gases have led to a rise in ozone levels close to the ground. This can be part of the so-called smog. Pollution is also responsible for a decline in the stratospheric ozone concentration. Detection of ozone decline and the expected future ozone recovery requires long-term records of ozone measurements with small uncertainties (Fioletov et al., 2008). The expected rate of ozone increase due to the reduction of ozone-depleting substances is about 1% per decade (World Meteorological Organization (WMO), 2007). Even a small long-term drift in the measurements could yield a large error in the estimate of ozone recovery.

Different techniques have been developed and utilized to monitor the ozone concentrations in the atmosphere over the years. Observation of vertical distribution of ozone is significant not only on a global scale but also on a regional and local scale. It is critical to note that a 1% level of precision can be maintained by Brewer spectrophotometers and Ground-based Dobson (Kerr et al., 1997; Fioletov et al., 2005) with averaged ozone

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values from many stations expected to have smaller uncertainties. However, instrument calibration errors are typically independent for individual ground-based instruments and thus proper and regular calibration and maintenance are necessary (Fioletov et al., 2008). Validation of satellite ozone retrievals has widely used ground-based data (Bramstedt et al., 2003; Weber et al., 2005; Balis et al., 2007a, b). In turn, these satellite data are used to estimate performance of the ground-based network as well to detect potential problems with individual station records (Fioletov et al., 1999). Therefore, as a diagnostic tool for Dobson data re-evaluation (WMO, 1993), comparison with satellite data is necessary. However, certain limits on how well ground-based and satellite data can agree are controlled by a difference in the algorithms and assumptions used to calculate total ozone, for example, by the difference in ozone absorption coefficients, their temperature dependence, assumptions about the stratospheric ozone and temperature distribution, and radiative transfer calculations (Vanicek, 2006; Balis et al., 2007a).

Over the equatorial region, stratospheric ozone is critical in temperature distribution due to absorption of solar ultraviolet (UV) radiation despite its small concentrations. A reduction of ozone concentration in the stratosphere has the effect of lowering the temperature in this region (IPCC, 1996). Further, knowledge of ozone distribution is necessary in understanding and quantifying processes related to radiative balance of the Earth-Atmosphere system (Okuku, 2010).

Presently, there exist numerous instrument platforms for ozone measurements. The need for an extended high quality data to a global scale will require a combination of different techniques to provide more information on the temporal-spatial patterns of total column ozone (Okuku, 2010). However, little research to ascertain the similarity of ozone measurements exists. This study was aimed at assessing the similarity of the observed total ozone data from ground based instruments, that is, Dobson Spectrophotometer, Differential Optical Absorption Spectroscopy and Ozonesonde data over Nairobi through inter-comparison of the datasets and determination of their representativeness over the region.

DATA AND METHODOLOGY

Daily datasets from total ozone measurements for MAX-DOAS and DOS measurements between January 2007 and December 2008 were acquired from MAX-DOAS network system, Nairobi and Kenya Meteorological Department (KMD) respectively, while weekly vertical Ozonesonde datasets sought from Global Atmospheric Watch (GAW) located at Dagorreti Corner were integrated to provide total ozone column.

In the present study, inter-comparison based on Root Mean Square Error (RMSE), BIAS and percentage difference were used to determine datasets relationship between different ozone measurements for Ozonesonde, DOS and DOAS.

Estimation of BIAS

Mathematically, Bias B is given as:

$$B = \left\{ \frac{1}{N} \sum_{i=1}^{n} (E_i - O_i) \right\} \qquad 1$$

where is the DOAS or Ozonesonde (Observed), while is the ground based DOS measurements (referenced).

Root Mean Square Error

The RMSE is defined as:

$$RMSE_L = \sqrt{\frac{\sum_{i=1}^{n} \{E_i - O_i\}^2}{n}} \qquad 2$$

where Oi is the DOAS or Ozonesonde (Observed) while Ei is the ground based DOS measurements (referenced).

Percentage difference

This is a way of expressing how large a quantity is relative to another quantity. It is given by the formula below:

$$\text{Percentage difference (\%)} = \frac{(Oi - Ei)}{Ei} \times 100 \qquad 3$$

where Oi is the observed and Ei is the reference.

Graphical time series analysis

Graphical time series analysis was used in the study. It involved plotting of scatter diagrams against time. The time series graphs were plotted with the intention of showing the natural trend of the centre of mass of the data. However, this method is highly subjective and has the weakness of dependency on visual judgment.

RESULTS AND DISCUSSION

This study notes that DOS measurements are well verified and frequently used to measure the total ozone column for a long period over many locations (Galbally, 1991). It is shown in Table 1 that inter-comparison of DOS/DOAS (DOS as the reference) had a bias of -1.1 (Figure 1) with a RMS value of 3.1 and a percentage difference of between -2.2 and 5.2% (Figure 2). This meant that DOS data had slightly lower values than the DOAS dataset. The negative bias indicated the need for calibration. The inter-comparison of DOS/Ozonesonde (DOS as the reference) had a bias of 0.4 with a RMS value of 3.3 and a percentage difference of between -1.4

Table 1. **Inter-comparison of DOS/DOAS, DOS/Ozonesonde and DOAS/Ozonesonde data.**

Instruments	Bias	RMS	% Difference
DOS/DOAS	**-1.1**	**3.1**	**-2.2 to 5.2%**
DOS/Ozonesonde	**0.4**	**3.3**	**-1.4 to -0.3%**
DOAS/Ozonesonde	**3.5**	**5**	**-4.8 to 0.9%**

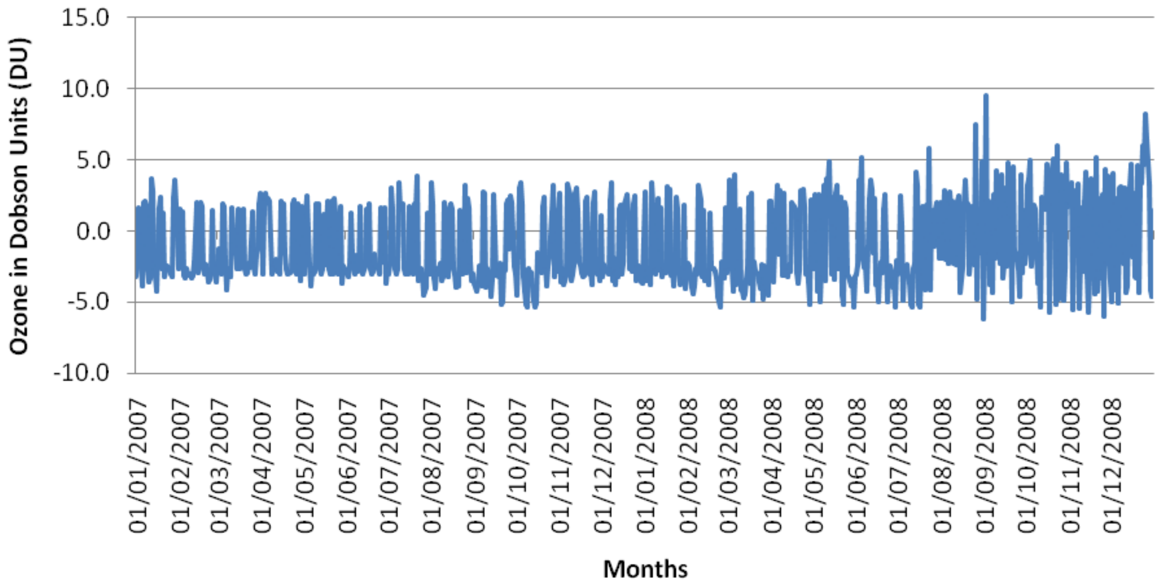

Figure 1. BIAS for DOS and DOAS dataset.

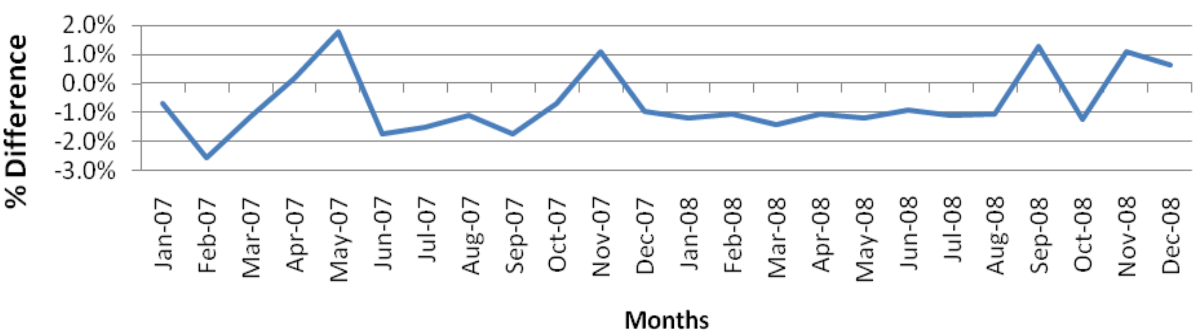

Figure 2. Percentage difference between DOS and DOAS.

and 0.3%. This meant that DOS data had slightly higher values than the Ozonesonde dataset. The inter-comparison of DOAS/Ozonesonde (DOAS as the reference) had a bias of 3.5 with a RMS value of 5 and a percentage difference of between -4.8 and 0.9%. This meant that DOAS data had higher values than the Ozonesonde dataset.

The average total column ozone measured over Nairobi was found to be approximately 259 DU (Figure 3) which was within the expected range of 220 DU to 280 DU in this tropical atmosphere (Lahnemann, 2004). For the DOAS instrument, measurements are usually taken twice a day usually at 7 a.m and 6 p.m. The Dobson Ozone spectrophotometer measurements are usually taken during the day and Ozonesonde measurements are made on a weekly basis usually on Wednesdays (around 9 a.m). These may have contributed to the slight variations observed. Furthermore, since Ozonesonde

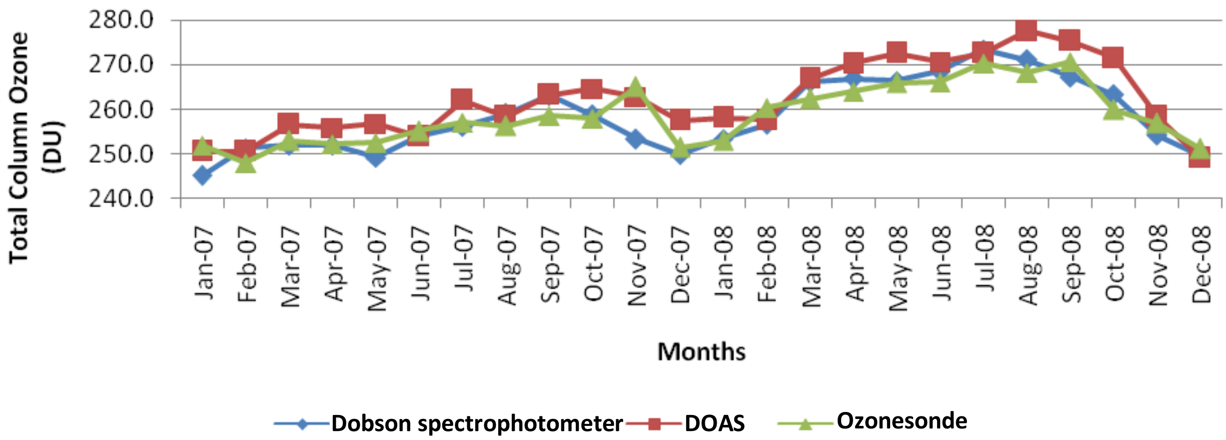

Figure 3. **Comparison of DOS, DOAS and Ozonesonde data.**

measurements yielded vertical profile of Ozone distribution in the atmosphere, in many cases, the balloon busted at around 35 km leaving the rest of the atmosphere unmeasured/unsampled. Data over these layers are usually extrapolated thus creating variability in the deviations of errors. In this study, total column ozone measurements were considered which required conversion of vertical ozone profile for Ozonesonde to total column ozone. The algorithms involved were too complex, thus estimation of some parameters was responsible for the observed variations. The difference in the timing of observations could also result to the observed deviations since measurements from DOAS are carried out at 700 h and 1800 h while the DOS measurements are taken on an hourly basis. For Ozonesonde measurements, weekly launches are usually done on Wednesdays mornings. Although location of the measurements can be a factor of influence, due to the close proximity between the stations, it was assumed that it was not a major influence on the differences observed between these instruments.

CONCLUSION AND RECOMMENDATION

The inter-comparison study indicated that measurements of total column ozone were comparable because RMSE, BIAS and percentage difference values were smaller and within acceptable limits. Although these errors were small and tolerable, there was need to develop a rigorous validation methodology that can properly and explicitly account for the deviation. Furthermore, the study established a need for consistent reading of these validation and recalibration of individual instruments on a regular basis. The study also noted that measurements from the DOS instrument should be taken at synoptic observation time to facilitate comparison of diurnal variation of its measurements with other ozone measuring instruments. This would go a long way in ensuring that inter-comparison of observed data from these instruments with other satellites instruments over long periods of time will be possible so that long trends of total ozone column can be put into perspective over this region.

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