COMPARISON OF MICROTOPS II OZONEMETER AND OMI SATELLITE TOTAL OZONE COLUMN MEASUREMENTS IN MANILA, PHILIPPINES FROM FEB-OCT 2011

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KEY WORDS: Total ozone column, Microtops, OMI, Philippines

ABSTRACT: Total ozone column (TOC) measurements were performed in De La Salle University, Manila, Philippines (14.71° N, 121.58° E) last February – October 2011 using a hand-held Microtops II Ozonemeter (MII). These are the first local measurements of total ozone column in the Philippines. The Microtops II instrument measures ozone at wavelengths 305.5, 312.5, and 320 nm. Measurements using the device were taken during midday (local noontime) and when the sun is clearly seen. Monthly averages were taken from February to October of 2011 in Manila, which is currently considered to be one of the most polluted cities in Asia. When compared to the total ozone column readings from the Ozone Monitoring Instrument (OMI) satellite, the Microtops II yielded a difference of ~3-15%. The MII Ozone Spectrophotometer provided data of the TOC averaging 280.36 ± 15.13 Dobson units (DU) while OMI TOC data averaged at 262.23 ± 19.26 DU. Analyses have shown the importance of proper user training in the use of the MII instrument especially during the rainy season.

I. Introduction

Ozone has been an essential component present in the atmosphere and can be classified as either stratospheric or troposheric. Naturally occurring ozone gas in the upper atmosphere (Stratosphere; about 10 to 50 km altitude) plays an essential role in protecting humans from the effects of the sun's harmful ultraviolet radiation (which has wavelengths shorter than 320 nm). However, the ozone that shields us from UV is depleting due to Chlorofluorocarbons (CFCs) decomposition which releases Chlorine that catalyze ozone. Other free radicals which catalyze ozone are Hydroxyl, Nitric Oxide, and Bromide (www.geology.wmich.edu, n.d). On the other hand, ozone in the lower atmosphere (troposheric/ground-level ozone), introducing danger to life for it poses as a large factor in smog formation, will bring harm to respiratory systems of humans and animals; and will damage internal cells in plants. Natural Ozone, at ground level, comes in low concentrations (www.esrl.noaa.gov, n.d). Being a critical trace gas which affects the progression of the global environmental crisis called climate change, scientist have been studying atmospheric ozone more intensively.

Throughout the years, ozone measurements have been very limited in the Philippines. One of the primary factors for this is that the amount of technology needed has yet to be acquired. A lot of instruments are being used today in obtaining these data. In this study, Total Ozone Column (TOC) will be obtained through the use of ground-based and satellite instruments. According to studies, satellite measurements of TOC yield only about 1% difference as compared to ground measurements. Equipments for ground-based measurements, such as the Dobson Spectrophotometer, give an accuracy of measurements of about < 2% (Silva, 2012). In similar studies conducted, the Microtops II Ozone Spectrophotometer, which is less expensive yet obtains measurements as accurate as the Dobson Spectrophotometer, is used. Since satellites travel around the globe daily and are only able to take a few scans, the data they are able to measure need ground-truthing.

NASA's AURA, launched eight years ago, carries four instruments, the HIRDLS, MLS, TES, and OMI, which aim to investigate the atmosphere's dynamics and chemistry. All of which takes measurements which would provide us with data about ozone trends, air quality variations, and most importantly, climate change. AURA orbits at a 705 km sun-synchronous orbit at 98^{o} inclination and an equator crossing time of 1:45 PM ±15 minutes. Among the instruments on-board the satellite, the Ozone Monitoring Instrument (OMI) is a spectrophotometer which enable the viewing of direct solar and backscattered solar radiation at wavelengths at the range of 270 to 500 nm (aura.gsfc.nasa.gov, n.d.).

In Kishinev, Moldova (Aculinin, 2006), a ground-based solar monitoring station gathered measurements for the total ozone column and UV-B irradiance. The study was able to show the totals of monthly data of irradiance have a specific seasonal variation where maximums fall in the summer and minimums in winter. Aside from this, the Microtops II ozonemeter was used to obtain data for the average total ozone column. His work showed the correlation of the two sets of data parameters. He also utilized a weather station for other meteorological parameters. It was seen in the results that meteorological conditions, as well as cloud amounts, affected the amount of solar irradiance. Lastly, total ozone column data appeared close to records obtained from the Total Ozone Mapping Spectrometer (TOMS). The TOMS had a maximum of ~540 DU and a minimum of ~204 DU while the Microtops II had ~489 DU and ~259 DU, respectively.

Total Column Ozone observations were also made over a tropical site in Brazil from August 2009 to July 2010 using OMI satellite data and the Microtops II data. About 10 scans were taken daily. The mean TOC for the study was 246.5-269.5 DU. Compared to the OMI, the Microtops II instrument yielded data difference of about 2%. There were a total of 188 paired data points used for comparison. The standard deviation (SD) for the Microtops II measurements was within 4% of the 1.14 DU average TOC (Silva, 2012).

In this study, 10-months of TOC measurements were obtained using a Microtops II (MII) Ozone Spectrophotometer in Manila, Philippines. Ground-based measurements will be compared to the OMI data acquired. Also, the quality of the data taken from MII measurements will be discussed.

II. Methods and Equations

Measurement Site

The location of the ground-based measurements is in De La Salle University, Manila, Philippines (14.71^{o} N, 121.58^{o} E). Metro Manila is composed of 16 cities and has a population density of about 18,567/km^2 or 48,090/sq mi as of 2010. The city is the busiest in the country and is the central district for business along with education. De La Salle University, with a student population of about 16,000, is one of the top four universities and one of the top private universities in the nation. Located in the tropics, and considered as one of the most polluted cities in the whole of Asia, the region is very susceptible to immense air pollution coming from busy human activity, and about 1.8 million registered vehicles which contribute to Manila’s traffic.

Beer-Lambert’s Law

Being a tri-atomic oxygen molecule, ozone readily absorbs the sun’s UV light before it reaches the earth. There are three types of UV radiation that the sun emits– the UVA, UVB, and UVC – which are characterized by their wavelengths and their energies. UVA measures about 315-400 nanometers (nm) and carries about 3.10-3.93 electron volts (eV) while UVB is about 280-315 nm and has 3.94-4.43 eV. On the other hand, UVC measures about 100-280 nm and carries 4.443-12.4 eV. Among the three types, only UVC radiation is not capable of penetrating through the ozone layer in the atmosphere for all of it is absorbed by ozone. In contrast, UVA radiation is totally capable of passing through ozone thus reaching the ground. UVB radiation, however, differs from the two for some reaches the ground while most get trapped in ozone molecules as well. The amount of ozone reaching the ground is then measured through the use of the ratio of the UVA and UVB radiation which is expressed by the Beer-Lambert Law (NTP, 2000; www.eoearth.org, n.d.).

$$A_\lambda = -\log I/I_o \quad \text{(Eq. 1)}$$
$$A_\lambda = \xi_\lambda bc \quad \text{(Eq. 2)}$$

Beer-Lambert's Law, or more popularly known as Beer's Law, explains that the absorbance of a molecule varies linearly with the sample cell path length and the molecule concentration. This law provides a more simplified solution for the interaction of light with matter and is widely used in quantitative spectroscopy.

The absorbance (**A_λ**) is quantified in the spectrophotometer by the passing of a beam of collimated light at a certain wavelength, **λ**, through a plane slab of material which is normal to the beam. **A_λ** is the ratio of light passing through the sample (**I**) to the incident light on the sample (**I_o**). The absorbance can be rewritten in the form similar to Eq. 2 where ξ_λ is the molar absorptivity at wavelength **λ**. The sample path length in centimetres (cm) is represented by **b** while the concentration of the sample compound is represented by **c**. The concentration has the units of moles per litre (mol/L) (www.oceanoptics.com, n.d.)

Mictrotops II Ozone Spectrophotometer

It is a hand-held sun-photometer which is microprocessor based. It is equipped with five collimators, a device which allows the narrowing/collimation of the beams of waves and particles. It has five channels which filters specific ranges of wavelengths. The first three channels (at 305, 312, and 320 nm) are used to derive the atmospheric total ozone column while the two other channels (940, and 1020 nm) are used to measure water vapor and aerosol optical thickness (AOT). When directed towards the sun, these channels capture the sun's radiation using photodiodes that produce current directly proportional to the solar radiation retrieved. The device gives measurements with accuracy < 2% compared to total ozone measurements from larger and more expensive sun-photometers (User's Guide: Microtops II Ozone Monitor and Sunphotometer, 2001)

Methodology

Measurements were carried out at the rooftop of a 20-storey building located inside the De La Salle University campus in Manila, Philippines. The portable MII instrument was used to conduct measurements when the sun was unobstructed by clouds. About 30 scans were obtained per measurement. Researchers took data as frequent as they can. Along with the MII was a Davis Vantage Pro 2 Weather Station (VP2) that actively collected data of meteorological parameters, 24 hours a day, from the rooftop of the same building. The weather became a hindering factor in obtaining data as clouds covered the path of the sun's radiation to the MII's detectors. OMI overpass data were obtained from NASA Goddard Space Flight Center. A ratio was used to compare the datasets obtained.

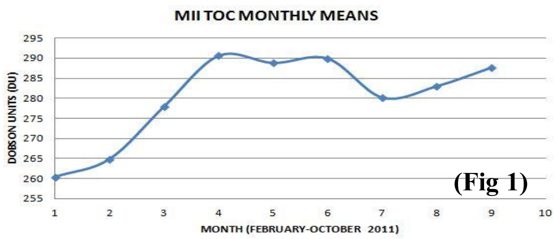
$$R = TOC_{MII}/TOC_{OMI} \quad \text{(Eq. 3)}$$

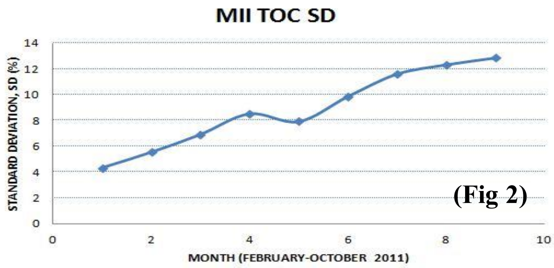
III. Results and Discussion

Microtops II Measurements

A total of 3230 scans of TOC measurements using the MII were taken throughout the duration of the study. Amounts of scans per month varied from 244-1059. Scans during the morning and mid afternoon were also taken. Fig. 1 shows the monthly means of the MII datasets which had measurements at an averaged Solar Zenith Azimuth (SZA) of $40.55^o \pm 20.25^o$, ranging from 1.15^o to 86.94^o, while Fig. 2 gives the distribution of scans and Fig. 3 gives the corresponding Standard Deviation.

Based on the figures, maximum mean occurred during the month of May at 290.60 DU. However, uncertainties in trends become apparent as the rainy months (July-September) approached. A number of outliers, as well as the deviation, increased as scans were obtained during this season. SD's obtained are as follows: 4.34% (Feb), 5.55% (Mar), 6.92% (Apr), 8.53% (May), 7.93% (Jun), 9.87% (Jul), 11.62% (Aug), 12.35% (Sep), 12.88% (Oct). No data with regard to Local Cloud Cover (LCC) were obtained. However, the VP2 was used simultaneously to obtain meteorological parameters which can be used to gather data such as humidity, and rain. The weather station data was utilized beginning March since it was also used in another study conducted during the time. According to a study conducted by Jeong and Li (2010), a directly proportional relationship exists between cloud cover and large deviations in AOT. Another observation in the study is that the magnitude of relative humidity depicted a similar relationship as AOT. The figures below show plots of the AOT and Relative Humidity measurements obtained from the MII and the VP2.





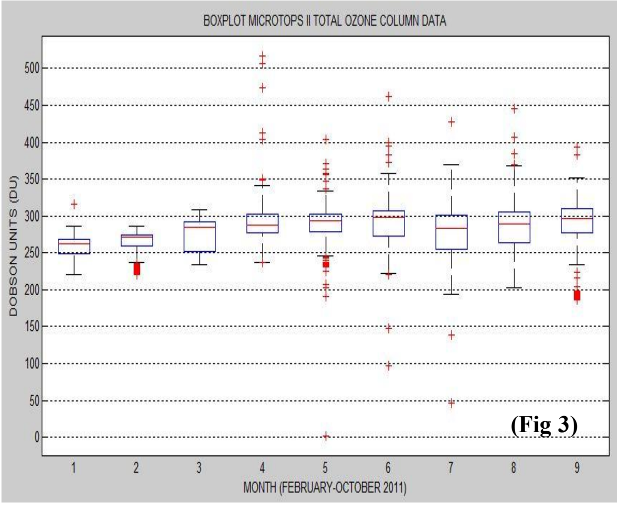
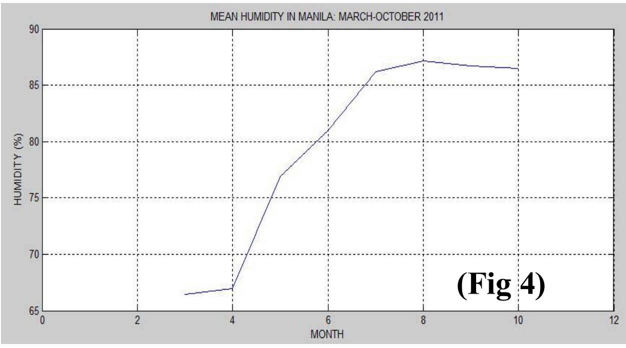


Fig. 1. MII measurements; Fig. 2. Standard Deviation; Fig. 3. Distribution of measurements



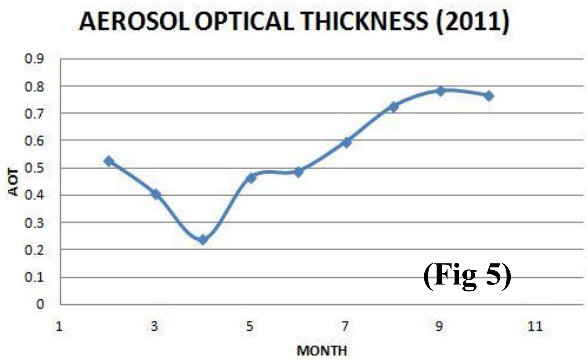


Fig. 4 (left) and 5 (right) above show the means of the Relative Humidity and the AOT.

According to Silva (2012), however, an appropriate explanation for the increased variation in MII measurements is the effect brought by the attenuation or the enhancement of solar radiation in the reflection and transmission of light in the clouds since the scans are only conducted in a short time interval.

MII-OMI Comparison

In order to compare the data with TOC measurements from the OMI, data was processed with respect to the overpass time of NASA's AURA satellite. Due to the pairing, only a total of 706 MII scans were used. The details of the pairing are shown in Table 1.

Table 1 shows TOC measurements (DU) with SZA(^{o})

OVERPASS PAIRED OMI-MII DATAPOINTS				
	N	DU	AVE SZA	RANGE SZA
MII	706	280.36 ± 15.13	37.64 ± 7.04	1.15 ± 76.74
OMI	234	262.23 ± 19.26	26.11 ± 7.14	9.76 ± 47.15

MII scans which were considered in this part of the study were those that were taken within ± 30 minutes of the OMI overpass. Silva's study (2012) shows that there is a difference of a few tens of kilometres and minutes regarding the satellite overpass grid coordinate with the site's coordinate and the actual overpass time with the expected satellite overpass time.

The ratio of TOC measurements are shown in Fig. 6 where, as the rainy months approached, the values which are overestimated increase showing a relation or dependence on the season. Several other factors may have been pivotal in the extreme values for the ratios. Some of which may be attributed to the various users of the instrument during the course of the study or the poor functioning of the instrument since it was already scheduled for recalibration last October 2012. The effect of these factors can be seen in the quality of the MII measurements.

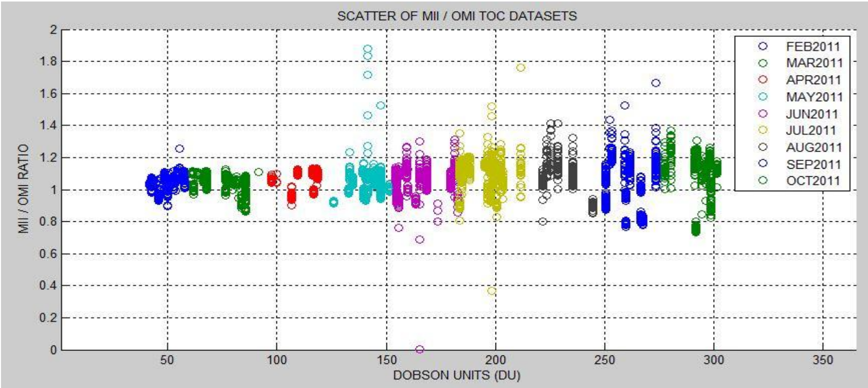
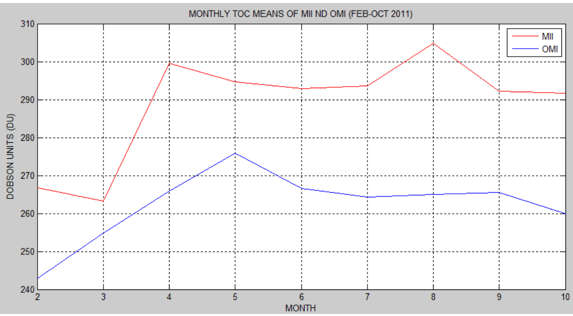


Fig. 6 Scatterplot of MII/OMI TOC Ratio

The monthly averages of the MII data along with its corresponding OMI averages are shown in Fig. 7. On the other hand, Fig. 8 shows the distribution of the MII data paired with the OMI overpass data. Total number of scans paired per month varies from 19 (March) to 186 (June) and the monthly average ratios (R) ranging from 1.034 (September) to 1.153 (October). The average ratio during the rainy season is R_{Rainy} = 1.086.



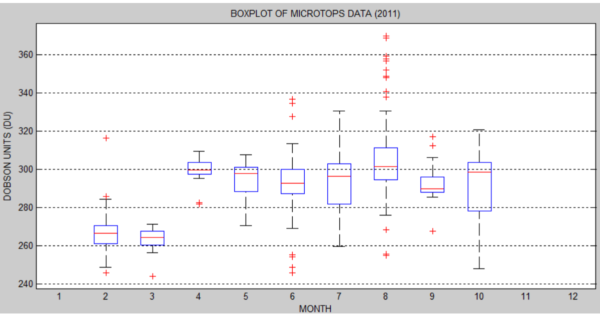


Fig. 7 (left) MII and OMI TOC Monthly Means; Fig. 8 (right) Paired MII TOC Scans Boxplot

The extreme values (outliers) obtained during the month of August can be explained by the frequency and amount of rains during that month. Being a tropical country, the Philippines experiences strong rains during the months of July to September. Fig. 9 (Japan Meteorological Agency, 2012) depicts the typhoons which developed last 2011 in the Philippines. Based on the VP2 data obtained, 30.6 mm of total rainfall was accumulated during paired observations for August 2011.

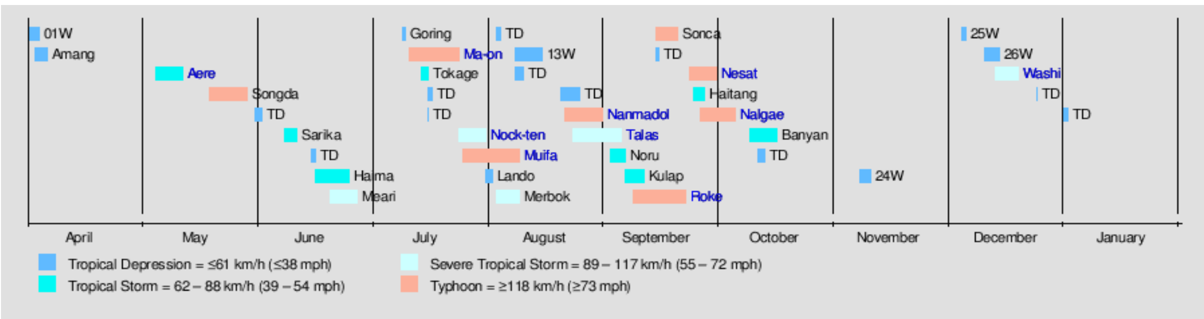
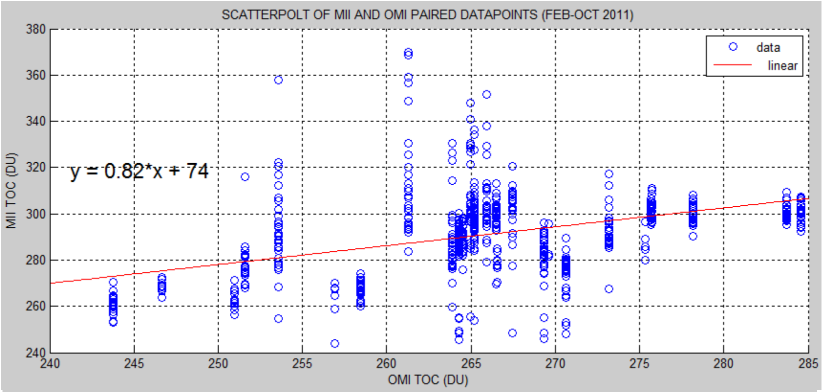


Fig. 9 Season Summary of Typhoons in the Philippines (JMA, 2012)



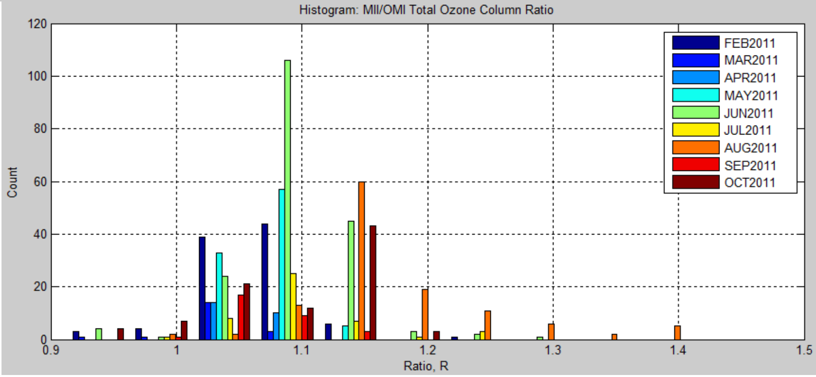


Fig. 10 (top) Linear Fitting of MII x OMI TOC Measurements; Fig. 11 (bottom) Histogram of MII/OMI Ratio

A linear fitting of TOC data from the MII and the OMI (Fig. 10) are placed in a scatterplot as seen above. The data indicates how large the variances are and the mismatches of the two instruments in the study conducted. From the histogram in Fig. 11, an oversampling of more than 10% of the 706 paired MII scans is present in June (26%) and in August (17%). Another observation is that most of MII measurements overestimate the TOC values when compared to OMI readings.

IV. Conclusions and Recommendations

Over the 10-month study in Manila, an average TOC of 280.36 ± 15.13 DU was obtained using the MII Ozone Spectrophotometer while the OMI TOC average was 262.23 ± 19.26 DU. The correlation obtained was affected by various factors such as the AOT, humidity, and the amount of rain. The TOC varied from a minimum of 4.34% (which occurred during the dry season) to a maximum of 12.88% (during the rainy season).

This is the first and pioneering study in TOC measurements in the Philippines and aims to pave the way for future studies in the field of atmospheric ozone research. The methodology can be adopted for studying variations in ground-based measurements of TOC at different hours during daytime. In comparative studies with satellite data, more scans, preferably during the satellite overpass time, are needed for better statistical analysis.

V. Acknowledgements

We would like to thank the people from the DLSU-LIDAR Group, the Commission on Higher Education (CHED project reference number 2008.110), NASA Goddard Space Flight Center (NASA-GSFC), National Oceanic and Atmospheric Administration- Center for Atmospheric Sciences, and the Department of Environment and Natural Resources- Environment Management Bureau (DENR-EMB).

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