Ozone Climatology obtained by a combination of MLS/AURA and SHADOZ ozonesondes profiles over southern tropic and subtropic

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OZONE CLIMATOLOGY OBTAINED BY A COMBINATION OF MLS/AURA AND SHADOZ OSONESONDES PROFILES OVER THE SOUTHERN TROPIC AND SUBTROPIC

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Abstract

In this paper a new ozone climatology (1998-2012) is presented over 8 southern tropic and subtropic sites. The climatology has been formed by combining data from Aura –MLS (Microwave Limb Sounder) and from SHADOZ (Southern Hemisphere ADditional OZonesondes) balloon sonde. Prior to combine the two observations, a preliminary study has been conducted to validate MLS profiles by comparison with ozonesondes. A satisfactory agreement is observed between MLS and ozonesonde measurements especially from 20 km to 30 km where the monthly relative difference between the two observations with respect to ozonesonde measurement is between 0.36% and 9.30%. The bias between the two observations decreases with the increase of altitude; from 20 km to 30 km the observed mean bias is assessed to be 3.69±1.13% with respect to SHADOZ observations. The presented climatology consists of monthly averages of ozone profiles for each site obtained from 1 km to 62 km. This climatology is established from hybrid profiles, normalized with the corresponding total column ozone (TCO) measured by Aura Ozone Monitoring Instrument, OMI satellite. Ozone below 26 km is based on ozonesonde while ozone above 29 km is based on MLS measurements. SHADOZ and MLS profiles are merged between 26 and 29 km where the best agreement (around 1%) between SHADOZ and MLS is observed. The obtained climatology captures with more accurately the principle behavior of ozone seasonal and spatial distributions; the integrated total ozone amounts from the presented climatology are consistent with the measured TCO from SAOZ (Système d'Analyse par Observation Zénitale) and Dobson at Reunion and Irene respectively.

1. INTRODUCTION

Climatological studies allow to analyse the ozone distribution in its annual cycle and to understand the mechanism that control ozone variability at seasonal and intra-seasonal scale. Two kinds of distributions have been used: total column ozone (TCO) and ozone profiles. The technical used to measure ozone profiles are the Lidar, instruments onboard satellite and ozonesonde. However ozone measurements by ozonesondes are mostly adopted due to its high resolution and low uncertainty. SHADOZ (Southern Hemisphere ADditional OZonesondes) is the only network providing ozonesonde profiles with precision around 5 % and vertical resolution between 50 m and 100 m (Thompson et al., 2003b). It is worth noting that balloons borne measurement rarely exceed 32 km, thus satellite observations remain the main technique to complement ozonesondes measurements on altitudes above 32 km. The MLS (Microwave Limb Sounder) is one of the powerful and recent satellite instrument dedicated to observing the Earth system. MLS is a microwave radiometer limb viewing which measures the thermal emission in infrared spectral bands where vertical profiles of ozone, temperature and pressure are retrieved.

Ozone profile from SHADOZ network and MLS instrument recorded over 8 southern tropic and subtropic sites are used in this work to construct ozone climatology over the noted area. Satellite instruments offer the best way to observe the upper stratosphere, however data from satellite contain high uncertainty and low vertical resolution in comparison to in-situ measurements. Of this, it is necessary to evaluate the accuracy of satellite measurement for a given area before using them for any major scientific work. In this paper, MLS profiles recorded overpasses over the 8 stations are compared with collocated measurements from ozonesondes in order to assess the quality of MLS profiles. After the MLS profiles validation, the climatology are constructed by merging the MLS and SHAODOZ profiles. The technics used to merge profile is a coupled method based on method of McPeters and Labow (2012) and Sivakumar et al. (2007). The paper is organised as follows: after a brief description of the data source and the obtained results from their comparison in section 2, the section 3 illustrates method used for combination and data validation. Section 4 presents the main features of climatology obtained from the combined profiles. Finally, a summary and conclusion are presented in section 5.

2. DATA DESCRIPTION AND COMPARISON

Ozone profiles from SHADOZ and MLS are used. SHADOZ radiosondes are launched from ground over the selected 8 stations while MLS profiles are derived from overpasses over each station. A radius of 2° (longitude and latitude) are used to delimit the satellite overpass zone around each station. Figure 1 presents geo-location of the selected stations.

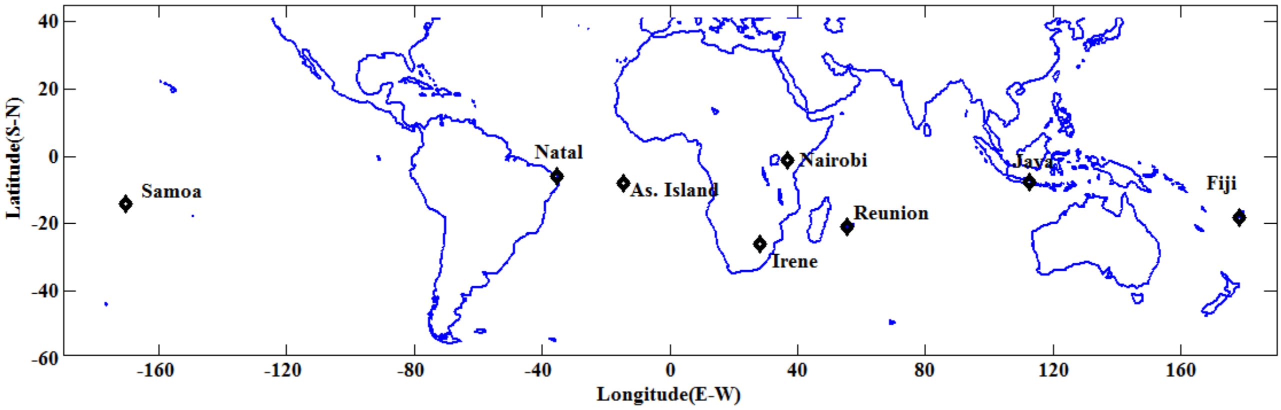

Figure 1: **Geolocations of the 8 stations in the southern hemisphere selected for this study.**

2.1. Ozonesonde from SHADOZ

SHADOZ is a network of stations located in the tropics and subtropics which provide high quality of ozonesondes measurement; more detail about this project is found in Thompson et al. (2003a and 2003b). Ozone is measured using an electrochemical concentration cell (ECC) ozonesonde. This device is coupled with standard radiosondes for pressure, temperature and relative humidity measurements, after the balloon sonde launching, the information are transmitted to ground by radio while the vertical and spatial location of the equipment are performed through a GPS. For more details on the instrument validation and the ECC SHADOZ ozonesonde operation mode, the reader may refer to Smith et al. 2007, Thompson et al. 2003a and 2007. Ozone profile from SHADOZ are often used as reference in the southern tropic and subtropic to validate satellite measurements (Mze et al. 2010, Jiang et al. 2007). The frequency of observation varies between 2 and 6 launches per month. The s data are downloadable from http://croc.gsfc.nasa.gov/shadoz/ . Here, we have used a temporal cover of 15 years of observation. Table 1 shows the number of monthly profiles recorded during the period of observation (1998-2012).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	sum
Irene	17	16	22	20	21	19	17	19	24	26	23	22	246
Reunion	44	35	43	42	43	44	33	22	41	43	40	31	461
Fiji	25	25	34	33	19	26	33	27	24	24	29	20	319
Samoa	40	49	51	42	42	40	48	43	39	41	44	39	518
Ascension	51	40	52	39	49	46	44	51	47	43	47	40	549
Java	28	26	27	23	23	26	28	33	32	25	28	24	323
Natal	46	39	44	36	41	42	35	36	39	42	40	38	478
Nairobi	51	47	51	44	54	58	55	56	56	57	53	45	627
sum	302	277	324	279	292	301	293	287	302	301	304	219	3521

Table 1: **monthly profile number recorded over each station during the observation period (1998-2012)**

Considering the limited number of observation, it is necessary to achieve a pre-processing step of all the profiles aiming to identify and remove the possible anomalies. The anomaly can be observed on the complete profile or a given altitude. This step is important in order to depart the unusual events which can modify the behaviour of the climatology. An ozone concentration value is considered as anomaly in a given altitude, if it is defined beyond ± 2σ with respect to the climatological value record in the same altitude. If such case is identified, the value is removed and replaced by a NaN (Not a Number) value.

2.2. Profile from MLS/ Aura satellite

MLS instrument was for the first time onboard the UARS satellite which was operational from September 1991 to August 2001, then for the second time onboard the EOS-Aura satellite launched on 15 July 2004 into a near polar heliosynchronous orbit at an altitude of approximately 705 km. The MLS instrument observes microwave emission from the Earth's limb in the "forward" direction of the Aura orbit (Livesey et al., 2013). MLS prvide around 3500 vertical profile of ozone , temperature and other chemical traces gases per day from the troposphere to the mesosphere. The measurements are acheived every 1.5° along the sattelite orbit track which correspond to a horizontal spacing of ~165 km. The observations are achieved from 82° S to 82°N at two fixed local solar time and cross the tropical region at around 01:30 a.m./p.m. According to the considered geographical delimitation around the station (radius of 2°), the number of profile recorded over the site varies between 0 and 6 per day. Then the daily profile is taken as the average of profiles daily retrieved. Note that the uncertainty of MLS profiles is higher than 10% in the troposphere; because of this high uncertainty and according to Livesey et al. (2008) and Jiang et al. (2007) the profile values considered in the present work are those recorded between 215.44 hPa and 0.1hPa. Other criterions are taken in account in order to ensure the reliability of profiles. According to Livesey et al. (2011) the considered criterion are: the profile used are those in which the status field is an even number, the quality of field is greater than 0.6 and the convergence field is less than 1.18. MLS profiles with these criteria are available online via http://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/MLS/V03/L2GPOVP/O3/. We have worked with the version 3 of Level 2 overpass product. The uncertainty of these ozone products is estimated at less than 5% in the middle and upper stratosphere (Livesey et al. 2011).

2.3. Comparison of ozone profiles from LMS with SHADOZ ozonesondes

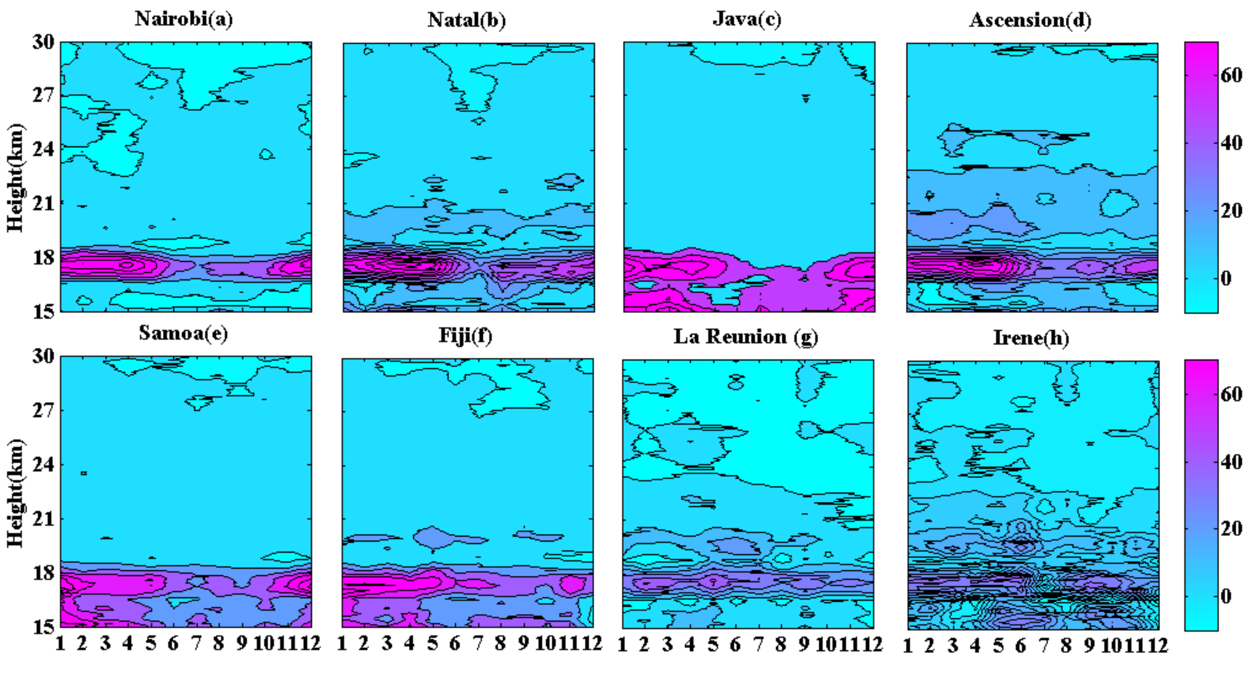

Figure 2: **monthly distribution of the relative difference between SHADOZ and MLS with respect to SHADOZ observed on the 8 sites.**

Prior to combine the MLS and ozonesonde profiles, a comparative study was conducted between the monthly climatological profiles of the two datasets. The main objective of this exercise is to examine and to assess the MLS observations quality with respect to SHADOZ. This exercise leads also to detect the conducive altitude level for the combination of the two datasets in order to obtain a climatology covering the troposphere and stratosphere up to 62 km. considering the large variability of MLS profile in the troposphere and the altitude level that can reach a balloon borne, the comparison exercise was performed at 15-30 km. The monthly profiles of MLS and SHADOZ are interpolated with a vertical resolution of 100 m and 150 altitude levels have been found between 15 km and 30 km. in each altitude level, the relative difference between MLS and ozonesondes with respect to ozonesondes was calculated as follow:

$$RD_{MLS\_Sonde} = \frac{(O_3)MLS - (O_3)Sonde}{(O_3)Sonde} \times 100$$

Figure 2 presents the relative difference obtained between MLS and SHADOZ for individual site. The relative difference varies from station to another and from the altitude as well. High values of relative different (> 30%) are observed between 16 km and 19 km, however this high relative difference is reduced during spring and winter periods. The high relative difference observed at 16-19 km is due to the high variability of MLS measurements at the upper troposphere - lower stratosphere (result not presented here). The accuracy of MLS profiles is high in the stratosphere but decreases with the decrease of altitudes to the upper troposphere as explained by Yang et al. (2007). However the quality of MLS measurements is improved during the winter-spring period due to the high ozone mixing-ratio recorded at upper troposphere (Yang et al. 2007). That could be among other reasons of the reduction of the relative difference during the winter-spring. Good agreement between observations is recorded over all stations from 19 km to 30 km where the relative difference varies between 0.36% and 9.30%. This difference indicates that MLS measurements are 3.69±1.13% higher than SHADOZ. The best agreement is recorded at 26-29 km where the bias between the two observations is less than 1%. Thus, the 26-29km altitude band is chosen to merge the MLS and SHADOZ measurements.

3. COMBINATION OF MLS AND OZONESONDES PROFILES

3.1. Description of method used for the combination

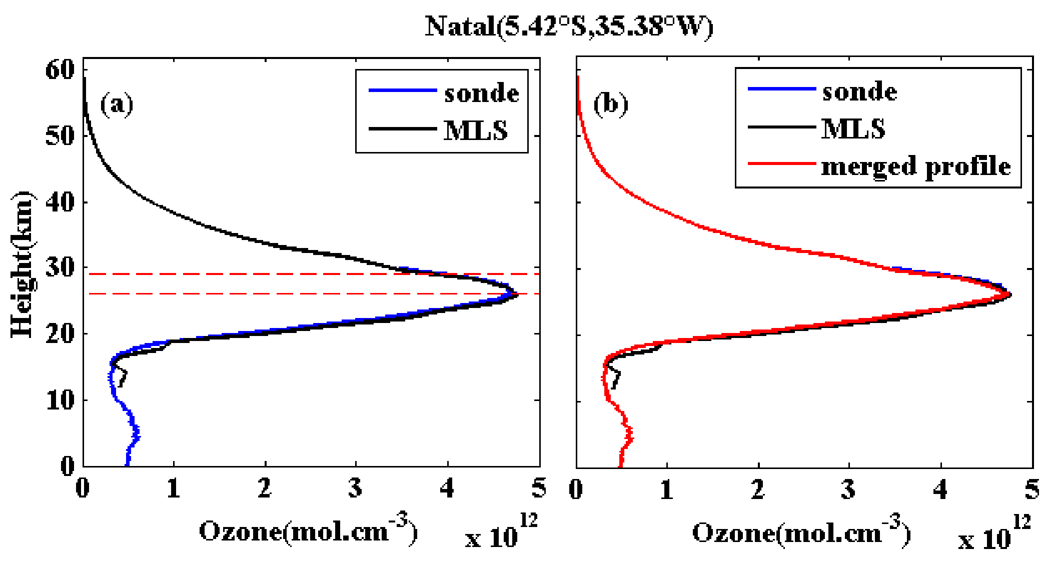

Figure 3: **Comparison showing the climatological profile registered in June at Natal by SHADOZ (blue) and MLS (black). The altitude rang in witch MLS and SHADOZ are blinded is given in red dot line (fig. 3a). The obtained hybrid profile is drawn in red in figure 3b**

The climatology is reconstructed from a combination of MLS and SHADOZ monthly climatological profiles at 26-29 km. Figure 3a presents a comparison between the monthly climatological profiles of June obtained at Natal from MLS (black) and SHADOZ (blue). The hybrid profile is presented in red on figure 3b. This profile is constituted of 3 levels. The 0-26 km altitude level is composed by ozonesonde measurements while above 29 km the profile is formed by MLS. The 26-29 km part is formed by the median average of the two observations. Each hybrid profile was integrated to calculate the corresponding total column amount. The ratio between the TCO recorded by the Ozone Monitoring Instrument, OMI (Bhartia, 2002) and the TCO obtained by integration of hybrid profile gives the normalization factor (NF); this factor is used to create the final normalized profile from the hybrid profile. More detail about this method is found on Sivakumar et al. (2007).

3.2. Comparison of TCO obtained from the combined profile and ground based

TCO obtained from integration of the combined monthly climatological ozone profiles from 1 to 62 km are compared with those recorded from ground-based instruments as SAOZ (Pazmiño, 2010) and Dobson (Komhyr et al, 1993) operating at Reunion and Irene respectively. The aim of this exercise is to validate the calculated profile and to assess the total column of ozone retrieved from the combined profiles. Figure 4 (top) presents the overlap of ozone annual cycle as observed by the ground-based instruments and retrieved from the combined profiles. Good agreement is found between the total column amount obtained by the integration of profiles and those measured by the ground-based instruments. The obtained correlation coefficient are higher than 0.97 for both stations. The climatology described by all instruments exhibits an annual cycle with an ascending phase in winter and descending phase in summer. The minimum annual amount is recorded in summer/autumn period and the maximum during the winter/spring period as expected at these two subtropical sites (Reunion and Irene). The relative difference (RD) between the obtained climatology and the ground-based measurement with respect to the ground-based measurement is presented in figure 4 (bottom). The obtained RD reveals that the TCO calculated from the combination of MLS + sonde is slightly low with respect to that observed by the Dobson instrument over Irene; the obtained bias is estimated at 1.63±1.088%. This bias is in part due to the systematic error according to the different processes followed to calculate the TCO in the two cases. However the expressed bias at Reunion with SAOZ is very low especially between April and December where the relative difference is within ±1%. In contrast, for the 3 first months of the year, the TCO from SAOZ exhibits a bias of 2.14% with respect to the TCO calculated from the normalized profile. Pastel et al. (2014) found similar results and estimated that the SAOZ measurements seem to overestimate ozone between January and March with an average relative difference fluctuating between 0.2% and 2.3%. However, the TCO calculated from the normalized profile and those observed from the Dobson and SAOZ instruments are in good agreement and the average bias between them is less than 3%.

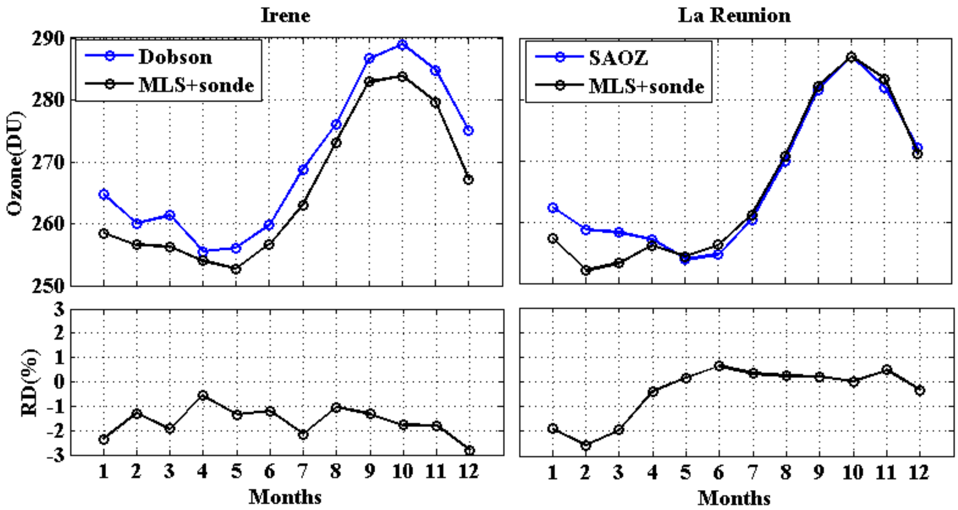

Figure 4: **Comparison between the TCO obtained from integration of the MLS + sonde climatology and the TCO measured by SAOZ and Dobson instruments over Reunion (on the right) and Irene (on the left)**

4. MORPHOLOGY OF THE OBTAINED CLIMATOLOGY

After the construction of Monthly climatological profiles, we defined three climatological zones of stratospheric ozone from Nairobi to Irene, as follows Equatorial (0°- 10°), Tropical (10°-20°) and Subtropical (20°-30°). The equatorial climatology concerns Nairobi, Natal, Java and Ascension sites; the tropical climatology is observed at Fiji and Samoa sites and the subtropical climatology corresponds to Reunion and Irene sites. The annual average of ozone profiles representing the three observed climatology are presented in the figure 5a. These profiles show the ozone variation in its vertical distribution on the 3 latitude bands.

The ozone varies systematically with the latitude as expected with high concentrations at equatorial region which is located at high altitude, while the ozone maximum peak in the subtropic is located at lower altitude, with respect to those of equatorial and tropical regions. Similar results are found by McPeters and Labow (2012). The obtained climatology accurately represents the behavior of ozone in its seasonal variation on the studied region. Figure 5b presents the variation of ozone profiles in the subtropic for different months. Low ozone amount is recorded in the summer, period marked by intensive ozone formation in the tropic. Indeed, the ozone transport is limited in the ascending phase of Hadley cell circulation during the summer; thus the horizontal transport of ozone from the tropical to subtropical region is not effective. In contrast from the autumn period, a transport of ozone rich-air masses is established horizontally from tropical to subtropical following the Brewer – Dobson circulation. This could be the reason why the ozone amount recorded in March (autumn) is superior to that recorded in December (summer) and the maximum is located at approximately 26.5 km, an average altitude level where the maximum ozone concentration is observed in the tropic. The discharge and accumulation of ozone in the subtropical region is effective between July and September due to a stratospheric mechanism which takes place in this period of the year between the tropic and the subtropic (Bencherif et al., 2003 and 2011, Sivakumar et al., 2007) and constitute the main reason why the maximum annual amount is observed in this period (June and September).

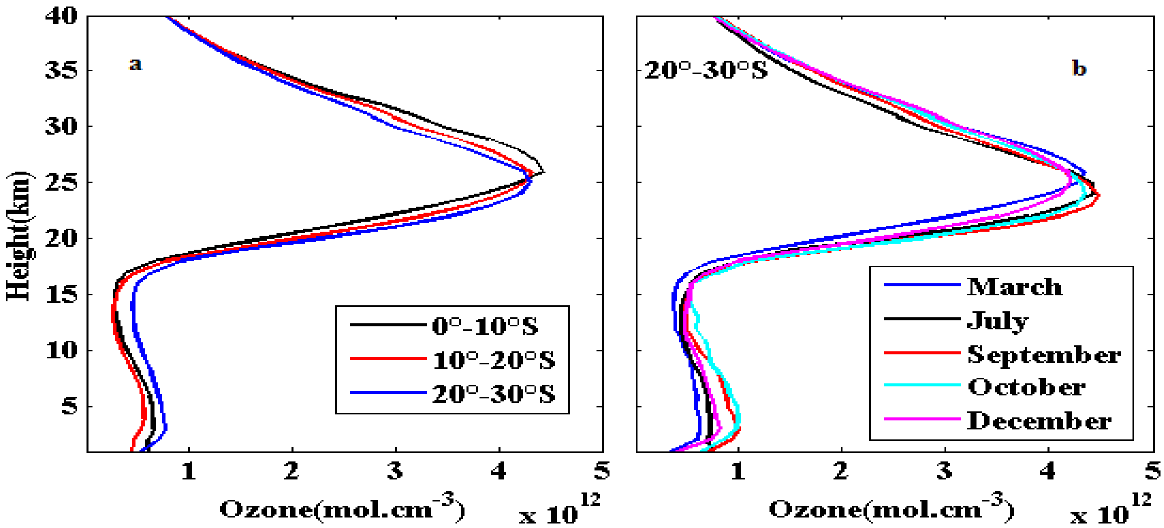

Figure 5: **(a) Climatology as annual average ozone concentration over 3 latitudinal zone and (b) some climatological monthly profiles representing the different season of the year in the subtropics.**

5. SUMMARY AND CONCLUSION

In this work, a new ozone climatology (1998-2012) of ozone is presented over the southern tropics ad subtropics. The presented climatology is obtained from a combination of MLS and SHADOZ ozone profiles recorded over 8 southern hemisphere sites. Prior to merging the two observations, a preliminary study was conducted in order to qualify the MLS profiles by comparing them with radiosonde data. Good agreement was found between the two observations between 20 km and 30 km where their relative difference varies between 0.36% and 9.30%. The best agreement is found at 26-29 km altitude range where both observations were merged. Below 26 km the ozone climatology consists of radiosonde while above 29 km the climatology is based on MLS observations. The 26-29 km part is formed by the median average of the two observations. Each hybrid profile was normalized using OMI observations basing on Sivakumar et al. (2007) method. The obtained climatology accurately captures the characteristics of seasonal and spatial distribution of ozone and are consistent with McPeters and Labow (2012) results. TCO obtained by integration of the obtained climatology is in perfect agreement with that measured by SAOZ and Dobson spectrometers over Reunion Island and Irene in South Africa, respectively.

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