MEAN OZONE AND WATER VAPOUR HEIGHT PROFILES FOR SOUTHERN HEMISPHERE REGION USING RADIOSONDE / OZONESONDE AND HALOE SATELITE DATA

VENKATARAMAN SIVAKUMAR*

National Laser Centre, Council for Scientific and Industrial Research, P.O. Box – 395,
Pretoria, South Africa (svenkataraman@csir.co.za)

Also at Department of Geography, Geoinformatics and Meteorology, University of
Pretoria Lynnwood Road, 0002, South Africa

DESALEGNE TEFERA, GIZAW MENGISTU

Department of Physics, Addis Ababa University, P.O. Box 1176, Addis Ababa, Ethiopia.

ONDEGO JOEL BOTAI

Department of Geography, Geoinformatics and Meteorology, University of Pretoria
Lynnwood Road, 0002, South Africa

The aim of this work is to construct a model (mean) profile for ozone and water vapor in Southern hemisphere latitude using 14 years (1993-2006) of HALogen Occultation Experiment (HALOE) satellite data and about 10 years (1998-2007) of the Southern Hemisphere ADditional OZonesondes (SHADOZ) balloon measurement data from Nairobi (1.3°S; 36.8°E), Malindi (3.0°S; 40.2°E) and Irene (25.9°S; 28.2°E). A comparison of HALOE mean profile has made between 0° to 10° Southern Hemisphere latitude with Nairobi and Malindi SHADOZ ozonesonde data, 20° to 30° with Irene SHADOZ measurement data respectively. A good agreement in terms of ozone and water vapour measurements has been found between SHADOZ ozonesonde and HALOE. The relative percentage of difference lies within 5 % for the height region from 4.5 km to 30 km altitude whereas, the comparison of mean water vapour show high uncertainty.

1. Introduction

Water vapour (H_2O) and Ozone (O_3) are the most important trace gases in the earth's atmosphere. They play an important role in atmospheric dynamics, in numerous homogeneous and heterogeneous atmospheric chemical reactions as well as in the absorption of long and short wave radiation directly or indirectly. Research work has shown that the concentration of H_2O in the middle

---

* This work is partially supported by Africa Laser Centre, South Africa.

atmosphere increases [1]. The large abundance of H_2O in the atmosphere has a significant consequence on the earth's climate and due to its large energy transfer associated with phase transition, the short-term dynamics of the atmosphere is also affected[2]. Water vapor also has another crucial importance as positive feedback to atmospheric temperature and vice versa. An 1°C increase in atmospheric temperature warming will cause a 6 % increase in H_2O (g) concentration which in turn would lead to further warming, thus initiating positive feedback [3]. Water vapor involves all its three phases in multitude of chemical reactions in the atmosphere. It involves the formation of the Polar Stratospheric Clouds (PSC), which are the reservoirs of halogenated molecules involved in the spring ozone depletion. Acid rain, in the form of (H_2CO_3, HNO_3, H_2SO_4, etc.), is formed by the reaction of CO_2, NO_2, SO_2 in their aqueous phases.

On the other hand, Ozone layer in stratosphere protects us by absorbing the harmful solar Ultra-Violet (UV) radiation. The downward transport of ozone from the stratosphere, where it is produced, naturally contributes to the ozone abundance in the stratosphere, but it is also formed in the troposphere by sunlight driven chemical reaction cycles, involving oxides of nitrogen (NO_x = NO + NO_2), Carbon monoxide (CO), methane (CH_4) and other hydrocarbon compounds. Ozone acts as a green house gas with highest efficiency in troposphere and lowermost stratosphere by absorbing solar and terrestrial infrared radiation [4, 5]. Tropospheric ozone, particularly in the tropics, is not fully understood due to many complex processes taking place. Since both O_3 and H_2O are green house gases, they have great influences on global warming. Increases in their concentrations in the atmosphere causes further global warming effects. In particular, tropical tropospheric air experiences a slow subsidence towards the surface. More rapid upward motions within convective clouds provide sufficient mass to compensate for the sinking motion. This in turn has a consequence on the troposphere-stratosphere boundary.

Because of the crucial roles that water vapor H_2O and O_3 play in atmospheric processes, an accurate knowledge and understanding of the temporal and spatial distribution of these trace gases are important for both climate and weather prediction. An accurate profile of theses trace gases is also very important in atmospheric modeling application. The work of this paper is based on the data obtained from HALOE satellite measurement and the SHADOZ ozonesonde measurements to obtain a height profile of H_2O (g) and

O_3 in Southern region of Africa. Such profiles can be used as a reference for comparisons with other measurements.

2. Data

2.1. *HALOE Data Selection*

HALogen Occultation Experiment (HALOE) was launched in September 1991 the upper Atmosphere Research Satellite (UARS) spacecraft and monitoring atmospheric trace gases since then. The data used here are those of version 19 of the retrieval algorithm on the HALOE website (http://haloedata.larc.nasa.gov/). The selected data is a series of measurements from 1991 to 2005 in consecutive orbits during or as close as possible to periods within latitudinal range from 0°S to 40°S. The data file consists of the ozone and water vapor mixing ratios in altitude levels and the pressure, temperature including the quality (random error) at each altitude. HALOE satellite is a solar occultation experiment designed to monitor vertical distribution of HCl, HF, CH_4 and NO by gas filter correlation radiometry and H_2O, O_3, NO_2 and temperature versus pressure using CO_2 absorption by broadband filter radiometry [6]. HALOE uses the Solar Occultation technique to make measurements of the vertical profile of atmosphere parameters. Here, we have considered the data which corresponds to altitudes greater than 10 km since it is less accurate at height regions lower than 10 km.

2.2. *SHADOZ Ozonesonde Data*

The SHADOZ network was initiated by NASA in 1998 to develop a coordinated ozonesonde network at tropics. Ozonesonde is used for measuring height profile of ozone from see level to about 30 km altitude, adding ozone sensor into it. The recorded ozone measurements are taken in units of parts per million by volume, ppmv. The details about the data and quality of ozonesonde measurements can be found in the literature [7,8]. We used about 10 years of ozonesonde data gathered from 1998 to 2007 of Irene station, from 1999 to 2006 of Malindi station and from 1998 to 2007 of Nairobi stations. The measurement data for a height up to 30 km altitude are collected from SHADOZ data which are archived at http://croc.gstc.nasa.gov/shadoz/ site2.html/. The SHADOZ data measurement contains pressure, temperature, relative humidity and ozone. The mean value of ozone concentration is calculated from the data obtained and the mean value of water vapor mixing ratio in ppmv is found from the data using the relation below;

$$\chi_{H2O} = 61121*RH*\exp(17.502\ T(z)/[240.97 + T(z)])/\ P(z)$$

Where, χ_{H2O} is water vapor mixing ratio, RH is relative humidity, T(z) is temperature in degree centigrade

3. Results

The height profile of water vapor and ozone are obtained for the regions of southern latitude hemisphere. The mean values of 14 years of HALOE satellite data and 10 years of SHADOZ ozonesonde in-situ measurement data are further used for making comparison. The HALOE data measurement ranges up to 75 km while the SHADOZ data measurement ranges up to 30 km altitude. For the sake of uniformity the SHADOZ ozonesonde data, height resolution was stepped down to 300 m.

3.1. *HALOE mean Ozone profile*

The height profiles of mean ozone concentration for the southern hemisphere tropical latitudes in the range 10°S are plotted in Fig.1. It is noticed that HALOE measurement underestimate the ozone values in the lower troposphere region in particular below 5 km as expected from the satellite instruments that measure from top to bottom and uncertainties increases downward in the troposphere. The mean ozone profile from HALOE data in the four-latitude region shows that the maximum value occurred at around 30 km altitude. The relative variability of mean ozone profile in all four cases is high in tropospheric region and low in stratospheric region. The relative variability greater than or equal to 20 % is observed below an altitude of 21 km (not shown in figure). The maximum values of variability observed in the latitude range of 0 to 10 degrees, indicates that the variation of ozone with time is very strong in tropical latitude between altitudes of 7 km to 12 km (noted from by zooming the plot). In addition, the satellite radiometer measurement is in general coarse due to the land surface emissivity, high scattering of aerosols and clouds cause a difficulty to obtain a profile of constituents of the lower layer of the atmosphere (troposphere). In over all variability of ozone profile in the tropical tropospheric latitude confirms that the instability of ozone in troposphere is due to different factors. Some of the different factors that caused instability of ozone are the seasonal and spatial variability of ozone in troposphere such as chemical production and destruction, convective and advective transport processes.

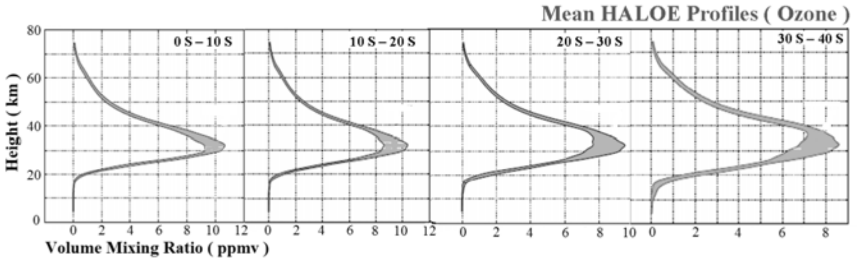

Fig-1: The height profile of mean ozone obtained from HALOE datasets

3.2. HALOE Mean Water vapor

The mean water vapor profiles calculated from HALOE satellite data are displayed in Fig 2. It is noted here that the height profiles are only plotted for height regions above 10 km, due to the high error in the measurements below 10 km and lesser number of observations. From Fig 2, we observe that the mean water vapor profile increases with altitude in the stratospheric region above the tropopause (17 km) of the HALOE data. This is reasonable when considering the chemical production of water vapor by oxidation of methane (CH_4). The profile also indicates a decrease in water vapor within the tropopause approximately from 12 km to 17 km. This can be viewed from the drying temperature of tropopause. The HALOE satellite measurement underestimate the value of water vapor below the tropopause as expected from the satellite observation. The relative variability of water vapor in the respective latitude ranges is found to be very high in the over all tropopause region and low above the tropopause in stratosphere. The maximum relative variability observed between 20 and 30-degree latitudes is ~32 % and 30 and 40-degree latitudes ~44%. This shows the variation of water vapor with latitude, i.e. high concentration in low latitude and low in high latitude.

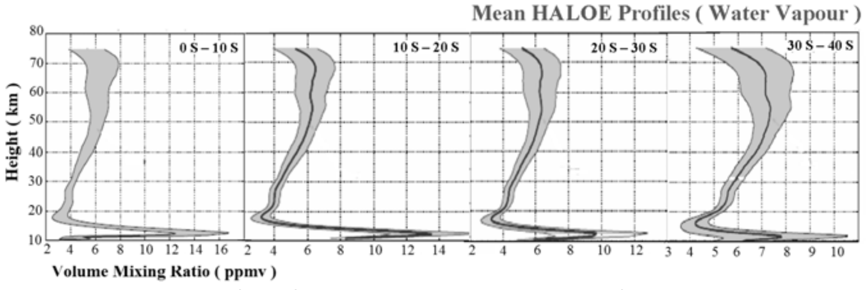

Fig-2: The height profile of mean water vapour obtained from HALOE datasets

3.3. *SHADOZ mean Ozone*

The mean ozone obtained from SHADOZ ozonesonde insitu measurement; from Nairobi located at 1.27°S and 36.8°E, Malindi at 2.99°S and 40.2°E and Irene at 25.9°S and 28.22°E, stations are displayed in Fig 3. It is found that the variability (standard deviation compared to mean) of ozone concentration below 19 km and in the troposphere region is highly variable. Though, the figure does not display much variability below 15 km due to scaling, we have zoomed the region manually and identified the variability. The variability of ozone below 19 km, increases, and reaches a maximum of 45 % (Irene at 16 km) and then slightly lower values. The variability is less above the tropopause at about 20 km and it varies from 4 - 20 %. The larger relative variability found below 19 km, might be due to the complex chemical and dynamical processes occurred. Several processes contribute to the variability of tropical tropospheric ozone including the horizontal and vertical transport, convective lifting of ozone poor air from the surface and the photochemical production by precursors. The low ozone variability in the region above 20 km height confirms the stability of ozone.

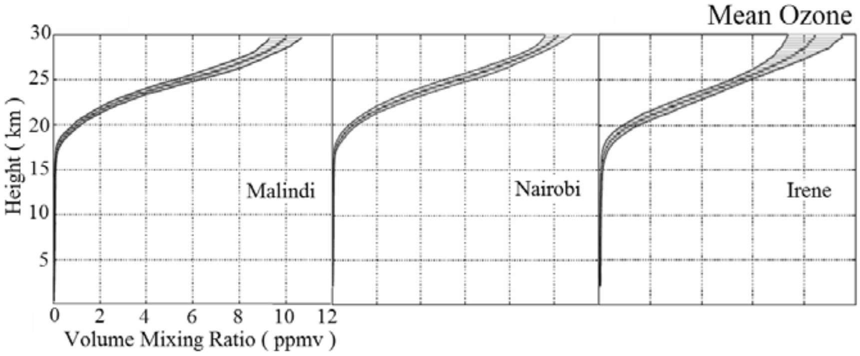

Fig-3: Height profile of mean ozone obtained from SHADOZ datasets.

3.4. *SHADOZ Mean Water vapor*

The mean water vapour profile calculated from the SHADOZ ozonesonde measurement for stations at Malindi and Irene is displayed in Fig 4. Fig 4 shows the variability of water vapor increases with altitude and very high above 2 km. The relative variability of water vapour is greater than 20 % in Malindi measurement and 43 % in Irene measurement above 2 km. Such difference indicates that the variation of water vapor concentration with latitude region.

The variation of relative humidity with temperature also contributes to the variability of water vapor in the stratospheric region. The questionable accuracy with altitude can affect the variability by large.

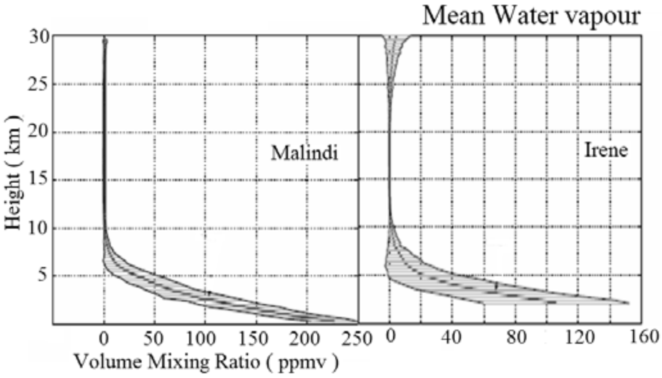

Fig-4: Height profile of mean water vapour obtained from SHADOZ datasets.

4. Concluding Remarks

The mean Ozone and water vapor profile is calculated from 14 years of HALOE measurement from 0 to 40 degree South and about 10 years of SHADOZ sonde Nairobi, Malindi and Irene and a comparison was made with respect to the latitude range using the relative variability as a diagnostic criterion. The variability of mean ozone found in HALOE satellite is comparable to that of the SHADOZ Sonde measurement. The variability of mean water vapor in HALOE satellite is found higher in troposphere below 20 km and low in stratosphere. The mean ozone profile difference found between SHADOZ sonde and HALOE satellite measurement data is less than 7 %. The difference in water vapor measurement between SHADOZ and HALOE found maximum value in the lower troposphere below 12 km and upper mid-stratosphere. This confirms that measurement of water vapor is much complicated. In conclusion, the mean ozone profile obtained from both HALOE data and SHADOZ ozonesonde balloon measurement are helpful as a model profile.

5. References

1. Zahn,A., et al.,(2006) Modeling the budget of middle atmospheric water vapor isotope. Atmospheric chemistry and physics, 6, 2073 - 2090.

2. Lohmann, M.S., et al., Water vapor profile using LEO - LEO Intersatellite Links. Danish Metereological Institute. Atmospheric Ionosphere Research.
3. Jones, R.L. and Mitchell,J.F.B., (1991) Climate change - is water vapor is understood. Nature 353(6341);p.210
4. Ioan BALIN Measurement and Analysis of Aerosols, Cirrus-Contrails, Water vapor and Temperature in the upper troposphere with the JungFraujoch LiDAR System. Ph.D. Thesis in atmospheirc Sciences-LiDAR applications at EPFL/LPAS- Lausamme-Switzerland.
5. Buchdahl, J., (1999) Atmospheric, Climate and Environment Information program:Air. http://www.doc.mmu.ac.uk/ airc.
6. Russel, et al., (1993) The HALOGEN OCCULTATION EXPERIMENT. J. Geophys. Res. 98, 10777 - 10797.
7. Borchi,F., et al., (2005) Evaluation of SHADOZ sondes, HALOE and SAGE II Ozone Profiles at the tropics from SAOZ UV-Vis remote measurements onboard long duration balloons. Atmos. Chem. Phys., 5, 13811397, 2005.
8. Sivakumar,V., et al., (2007) Strtatospheric Ozone Climatology and Variability Over a Southern Subtropical site: Reunion Island (210 S; 550 E). Annales geophysicae, 25, 2321-2334.