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RESEARCH PAPER

INVESTIGATING TEMPORAL VARIABILITY OF TOTAL OZONE COLUMN OVER KATHMANDU USING OMI SATELLITE OBSERVATIONS

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ABSTRACT

The objective of this work was to analyze the trend of temporal variability of the atmospheric Total ozone column (TOC) over Kathmandu, during the last 13 years of observations using remote sensing-derived data. For this study, long-term TOC data derived from the Ozone Monitoring Instrument (OMI) for the period of October 2004–April 2016 were used. The daily, monthly, seasonal, and annual variations of TOC were analyzed. During the whole study period, the highest value of TOC is found to be 344 DU in March and the lowest value of TOC is 219 DU in December. The average TOC calculated during the whole study period over Kathmandu is found to be 268 DU. The trend of TOC shows a distinct seasonal pattern, with maximum in summer and minimum in winter season, specifically high value in April or May and lower value in December and January. The long-term variability also represents a notable increase in TOC for the period from 2004 to 2015 illustrating the significant recovery atmospheric ozone over Kathmandu. The ozone recovery during the recent years may be due to the reduction of the ozone depletory agents.

Keywords: Total ozone column, Temporal variability, OMI, Stratosphere, Dobson unit

INTRODUCTION

Ozone, a trace gas in the Earth's atmosphere, plays a significant role in regional and global climate change, human health and environmental conditions. About 90% of the total ozone in the atmosphere concentrates in the stratosphere from about 10 to 40 km above the Earth's surface. Although the proportion of ozone in the atmosphere is very low, it filters certain wavelengths of incoming harmful solar ultraviolet (UV) radiations (Molina & Rowland 1974) and protects living organisms from UV effects. In 1974, scientists discovered that anthropogenic chemicals release such as chlorofluorocarbons (CFCs) and other chlorine-containing volatile gases have a potentially damaging effect on ozone layer in the stratosphere (Rowland & Molina 1975). The destruction of the ozone layer has been clearly mapped out and has been observed in Polar Regions. The process of stratospheric ozone depletion in the Antarctica during spring months was mapped out in several studies (Stolarski *et al.* 1986, Bojkov 1990, Silva 2007, Cheng *et al.* 2013). Further studies have also shown that ozone depletion occurred not only in the Polar Regions but also observe significantly in other latitudes, which indicate it has become a global phenomenon (Staehelin *et al.* 1998, Varotsos *et al.* 2012). In addition to the anthropogenic factor, there are many geophysical parameters that affect the ozone, including the Quasi-Biennial Oscillation, an 11-year solar cycle, the scaling effect in planetary science, the stratosphere-troposphere exchange, etc. (Zerefos *et al.* 2014, Svendby & Dahlback 2004).

The stratospheric ozone depletion leads to the increase of UV radiation on the Earth's surface (Madronich 1998), resulting in the increased risk of several severe human diseases, such as skin cancer and eye cataracts (Caldwell *et al.* 1998, Schmalwieser 2003). The penetrating of the UV radiations not only effects on mankind but can also disturb the normal genetic activity of plants, which has negative impacts on the growth of plants. In addition, ozone is also a strong greenhouse gas in the Earth's atmosphere, as it absorbs both UV and infrared radiations (Ziemke *et al.* 2005, Hoffmann 2012). Consequently, atmospheric ozone variations inevitably affect regional as well as global climate change (Houghton 1995). So investigations of the temporal and spatial variability of the total ozone column (TOC) become very important (Caldwell *et al.* 1998, WMO 2006). TOC measurements derived from remotely sensed data collected by multiple satellite platforms was demonstrated to be effective to quantify the spatiotemporal variability of TOC at various scales by many researchers (Bowman 1985, Stolarski 1991, Chapagain 2002, Fahey & Hegglin 2011, Ganguly & Tzanis 2011).

The Dobson unit (DU) is a unit of measurement of the columnar density of a trace gas in the earth's atmosphere. It originated and continues to be widely used, as a measure of total column ozone, which is dominated by ozone in the stratospheric ozone layer. One Dobson unit refers to a layer of gas that would be 10 µm thick under standard temperature and pressure (Herman *et al.* 1991), sometimes referred to as a 'milli-atmo-centimeter'. For example, 300 DU of ozone bought down to the surface of the earth at 0^oC would occupy a layer only 3 mm thick. One DU is 2.69×10^{16} ozone molecules per square centimeter, or 2.69×10^{20} per square meter. This is 0.4462 millimoles of ozone per square meter (Fioletov *et al.* 2002).

Kathmandu, capital of Nepal, lies in the valley with the most populated (population more than six million people) metropolitan city in Nepal. So the UVB variability and climate change due to the variability of Atmospheric ozone may significantly contribute to many human health issues. Thus, investigating the spatiotemporal variations of TOC in Kathmandu from satellite-derived data can improve the understanding of the spatiotemporal distributions of ozone in Nepal. Although there is an increasing interest in monitoring TOC, the ground stations for automatic TOC measurements was carried out only for limited time period. A Brewer Spectrophotometer was deployed in 2001-2003 at Kirtipur, Kathmandu and the results of the ozone measurements were reported (Chapagain 2002, Chapagain 2015]. Similarly the data recorded using satellite measurements over Kathmandu were analyzed in previous studies (Bhattrai 2006, Parajuli, 2015). The main objective of this work is to quantify the temporal TOC variability over Kathmandu using long-term data set from satellite observations from an Ozone Monitoring Instrument (OMI).

DATA AND METHODOLOGY

An OMI instrument installed on Aura provided daily data from October 2004 to April 201. The OMI is the successor of the NASA's TOMS (on the Nimbus-7, Meteor-3, and Earth Probe) instrument and ESA's GOME instrument (on the ERS-2 satellite). These instruments measured solar irradiance and the backscattered radiance from the Earth at six wavelengths (312.5, 317.5, 331.2, 339.8, 360, and 380 nm) (http://ozoneaq.gsfc.nasa.gov/index.md). The OMI TOC data have been processed by the algorithm (V.8) developed by NASA Goddard's Ozone Processing Team. The OMI can measure many key air quality components such as NO_2, SO_2, BrO, OClO, and aerosol characteristics (Levelt *et al.* 2006). It can also provide much better ground resolution than TOMS. Many researchers have validated the results of the TOC data products of OMI (Kroon *et al.* 2008a, 2008b, Tandon & Attri 2013, Chen*et al.* 2013).

OMI's data is extracted over Kathmandu (27.7° N and 83.3° E) from 1 October 2004 to 15 April 2016 for total 4213 days, from NASA official website (https://ozoneaq.gsfc.nasa.gov/tools/ozonemap).

Sometimes, the satellite measures the zero data, which denote the missing data, which is data that could not be collected due to lack of sunlight or other problems. In such case, we have taken average between neighboring data and this average data is considered as data for this particular day. From the large data set of daily total ozone column, we calculated the monthly, seasonal and yearly averages of TOC.

RESULTS AND DISCUSSION

Daily Variations of TOC

The daily averaged TOC values over Kathmandu from October 2004 to April 2016 are plotted as shown in Figure 1. The scattered plot represents the daily ozone over Kathmandu. The result shows the pattern of variation of TOC is symmetric with increasing TOC at every half of a year and decreasing alternatively in the next half of the year.

The minimum and maximum values of TOC of each year from 2005 to 2015 are tabulated on Table 1. The results show that the TOC values are low in winter days mostly in December and January with a few exceptional cases in February 2009 and November 2011. Similarly, the maximum values of the ozone were mostly found on March, April and May. In the table, data from 2004 and 2016 are not included as we donot have full year data in these years.

During the whole study period, the highest value of TOC was found to be 344 DU in March 18, 2010 and the lowest value of TOC was 219 DU in a few days in December 3, 4 and 17, 2005 and December 20, 2008. The average total ozone content calculated during the whole study period over Kathmandu was found to be 268 DU. The TOC data from the entire study period revealed that TOC value over Kathmandu exhibited above the critical value total ozone, which was supposed to be about 210 DU to 220 DU.

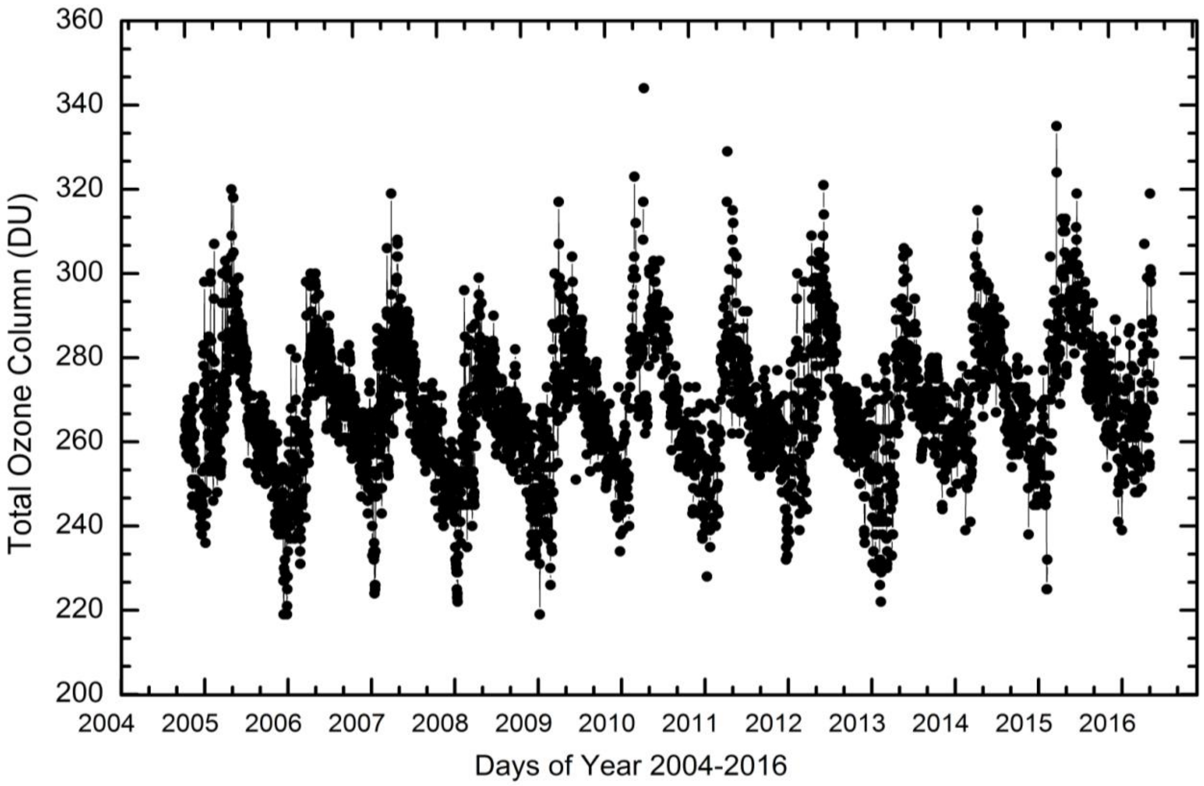

Fig. 1. Daily variations of total ozone column over Kathmandu from October 2004 to April 2016.

Table 1: Minimum and maximum values of TOC over Kathmandu during each year of study period.

Year	Minimum TOC		Maximum TOC	
	Days	**Value (DU)**	**Days**	**Value (DU)**
2005	Dec 3, 4 &17	219	Apr 20	320
2006	Dec 31	236	Mar 30	300
2007	Jan 3	224	Mar 16	319
2008	Dec 21	219	Mar 24	299
2009	Feb 5	226	Mar 12	317
2010	Dec 30	235	Mar 18	344
2011	Nov 25	232	Apr 6	315
2012	Dec 16	230	May 6	321
2013	Jan 10	222	Apr 20	306
2014	Jan 14	239	Mar 7	315
2015	Jan 1 & 2	225	Feb 12	335

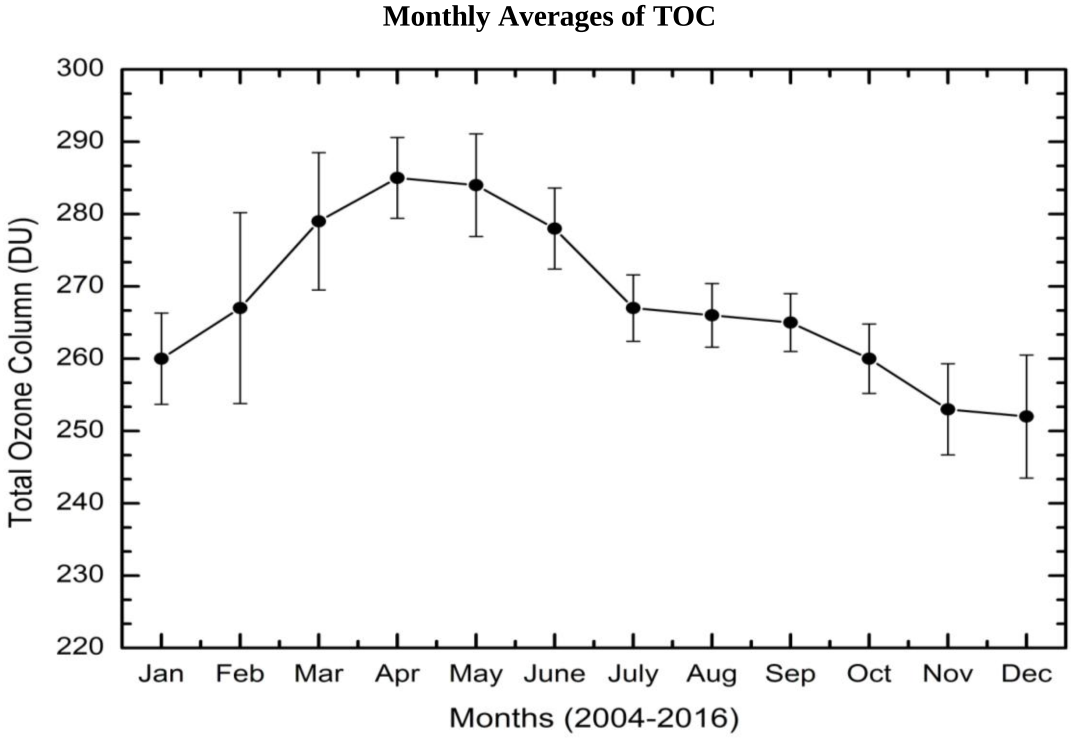

Fig. 2. Monthly variations of average total ozone column over Kathmandu using long-term data set from October 2004 to April 2016.

The monthly average of TOC for separate year was calculated by statistical analysis of data obtained from OMI satellite. Here the monthly averages of TOC from all data set for 13 years period have been calculated and its graphical plot is shown in Figure 2. The vertical bars in the plot represent the standard deviations from the mean of TOC. The results indicate that the TOC value increased from January (average TOC of 260 DU) to April (average TOC 285 DU) by 9.6%. On other hand, the average TOC value decreased by 11.92% from April to December. The maximum value of average TOC was 285 DU in April, while the minimum average value of TOC was 251 DU in November and December. Throughout the study period in the month of April, the maximum value of TOC was 295 DU in 2015 and the least value was 277 DU in 2009. The amplitude of variations of monthly average TOC was 34 DU in absolute unit and 13.5 % in terms of the percentage of the mean. Hence, the result illustrates that the trend of monthly ozone variations were significantly high in which TOC values were higher in the months in March, April, May and June and the TOC was lower on January, November and December.

The monthly variations of total ozone over Kathmandu are similar pattern to the results reported from other studies (Ganguly and Tzanis 2011, Chen *et al.* 2013). For instance, monthly variation of total ozone over Tibet has a maximum in March and May and a minimum in October and November.

In order to examine the variation of TOC from month-to-month, we determined the coefficient of relative variation (CRV) using a relation (Chen *et al.* 2013) as

$$CRV_{i,a} = 100\frac{TOC_{i,a}^{max} - TOC_{i,a}^{min}}{TOC_{i,a}^{mean}}$$

where, $TOC_{i,a}^{max}$, $TOC_{i,a}^{min}$ and $TOC_{i,a}^{mean}$ denote the maximum, minimum and mean daily TOC. Their uncertainties (the standard errors) were computed. The average value of the CRV was 7.64±1.18 % (average value ± standard error), ranging between 3.47±0.00 % and 15.36±2.16 %. The CRV presented a notable annual cycle with maximum values in February and minimum in September and October, which is shown in Figure 3. The variation in the ozone level is also affected by the meteorological conditions, such as, wind speed, wind direction, solar radiation and outdoor temperature. The ozone level generally increases with the increase in solar radiation and outdoor temperature.

Seasonal Variations of TOC

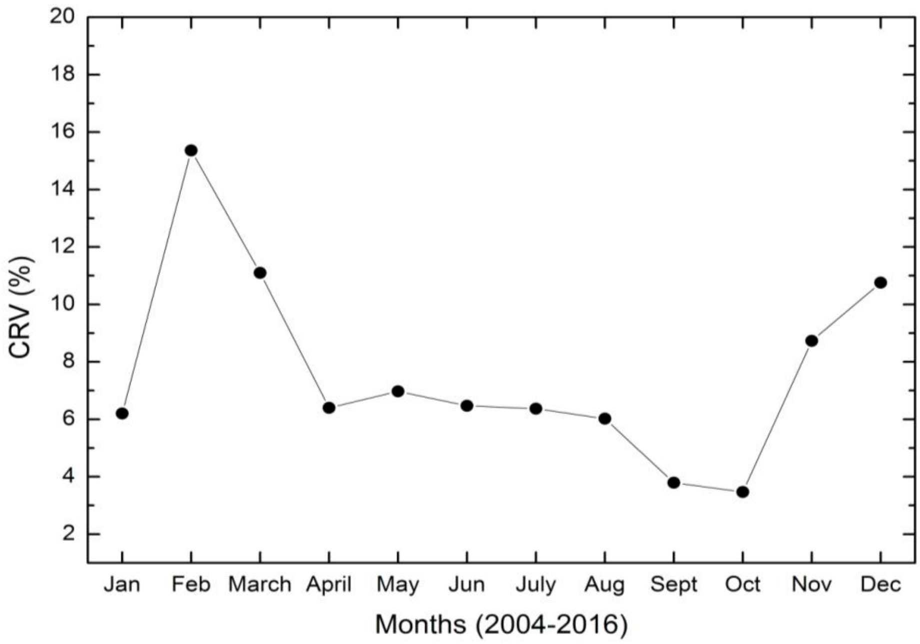

Fig. 3. Coefficient of variation of monthly total ozone column over Kathmandu.

All data were grouped for three seasons: as summer (May, June, July, and August), Equinox (March, April, September, and October) and winter (January, February November and December). The average values of TOC for every season have been calculated for each year and are plotted as shown in Figure 4. The plot shows that pattern of TOC variations are similar in all seasons. However, the magnitudes of the TOC values were different on season-wise. The TOC in summer was found higher than winter season up to by 8.5%. The average ozone concentration exhibited 257 DU in winter, 274 DU in summer and 267 DU in equinox. The winter TOC was smaller compared to other seasons on every year of the measurements. Similarly, the average TOC was larger in summer season, while in the equinox, the TOC have moderate values compared to two other seasons.

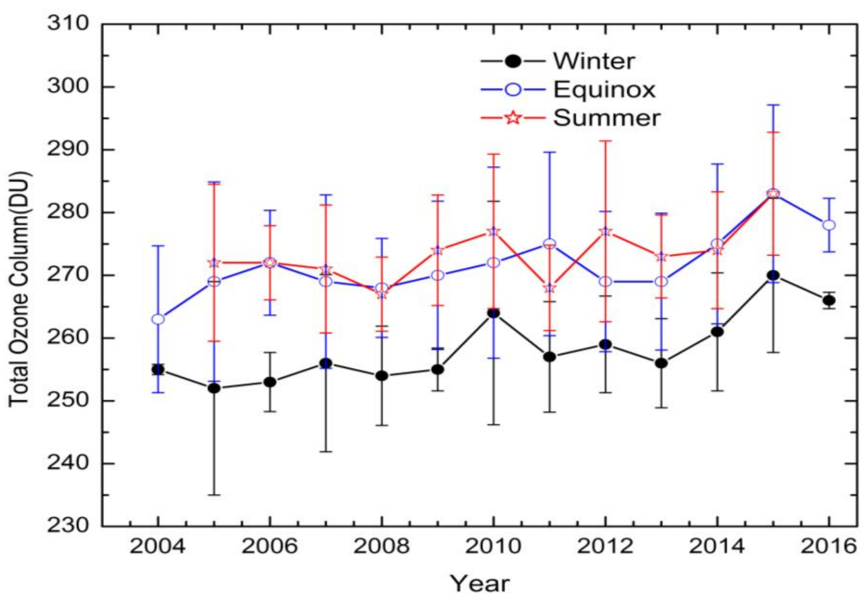

Fig. 4. Seasonal variability of total ozone column over Kathmandu from 2004 to 2016.

For seasonal variability, a distinct seasonal signature on TOC was found. Thus, the seasonal variations in total ozone measurements over Kathmandu are in good agreement with the measurements made by other studies in Tibet (Chen *et al.* 2013). In tropical region, the total ozone value was higher in summer and smaller in winter season (Antón *et al.* 2011). Such variation is due to fact that during the summer season, intensity of global solar flux incident on the Earth's atmosphere is stronger, as a result, the rate of ozone production high enough. While during the winter season, the solar flux incident on the Earth's atmosphere is relatively less intense. Consequently, the ozone production rate is smaller in the winter season. Hence, the reason of the higher ozone concentration in summer and low in winter seasons is mainly due to the seasonal variations of solar intensity over the Earth's atmosphere. Such seasonal variations of the ozone concentrations with the solar cycle and hence photochemical factors are also explained in previous studies (Fioletov & Shepherd 2005).

The day-to-day variations have also demonstrated a significant seasonal cycle, with a maximum in May and a minimum in January or December. This is related to tropospheric weather patterns including the free tropospheric temperature, the lower stratospheric temperature, the geopotential height, the tropopause height and the potential vorticity of the lowermost stratosphere.

Annual Variations of TOC

The yearly averages of TOC over Kathmandu valley from 2004 to 2016 is shown in Figure 5. It shows that the average ozone value slightly increased from year 2004 to 2005 by 2.7%, while it nearly remained same in 2006. The TOC value slightly decreased in 2007 and 2008 then slowly increased in 2009 and 2010. The increase in ozone was by 1.8% in 2010 from 2009. The total ozone value gradually decreased by 1.4% from 2010 to 2011 and lower in 2013. Again, the ozone value slightly increased from 2014 and was maximum (280 DU) in 2015. The TOC value increased by 5.5% in 2015 compared to the value in 2014. Here the average ozone values in 2016 and 2004 seemed to be minimum as the average value in the plot is only considered for October to December in 2004 and January to May 2016 that do not represent actual annual average values for the entire year. As we compared the ozone value from 2005 to 2015, it was found that the average value of TOC over Kathmandu increased in 2015, illustrating the good sign of ozone recovery in the recent years.

The yearly variations of TOC showed a notable increase in TOC values for the period from 2004 to 2015 illustrating the significant recovery of atmospheric ozone over Kathmandu.

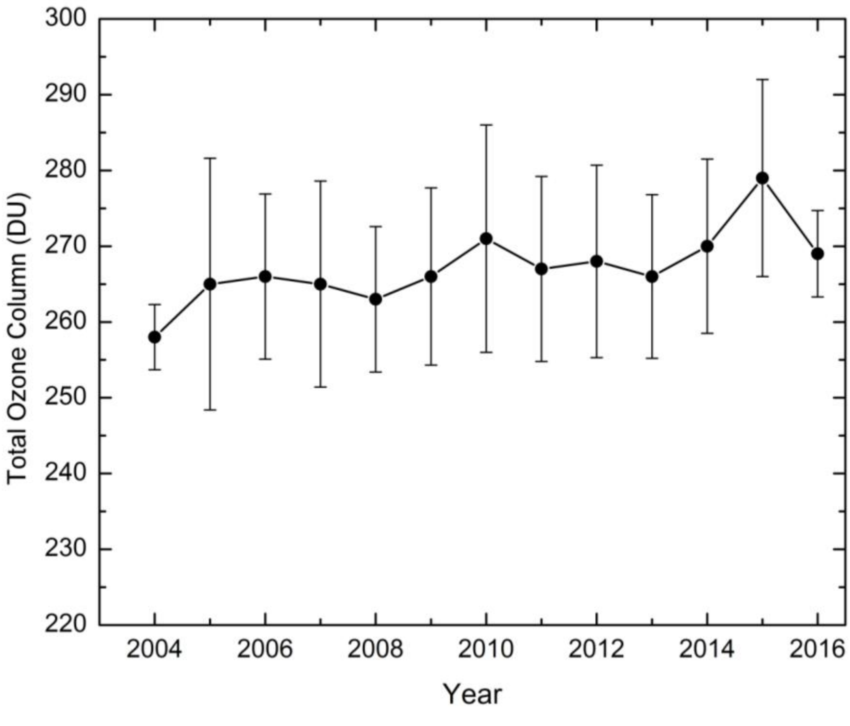

Fig. 5. Annual variations of total ozone over Kathmandu from October 2004 to April 2005.

CONCLUSIONS

In this study, the statistical analysis was performed to examine the trend in the variability of total ozone column over Kathmandu using long-term data set from October 2004 to April 2016 extracted from Ozone Monitoring Instrument (OMI).The results showed the daily, monthly, seasonal and annual variability of TOC over Kathmandu. The day-to-day variability have demonstrated a significant seasonal cycle, with an increased TOC in half year and became maxima in March, April or May and a decreased value in next half year with minimum values mostly in January or December. During the study period, the minimum TOC was 219 DU in December 2004 and 2008 and maximum TOC was in March 18, 2010 with a value of 344 DU. The trend of TOC observed was higher in summer, while lower value occurred in winter season due to the stronger intensity of global solar flux in summer compared to that in winter season. The yearly variations of TOC showed a notable increase in TOC values for the period from 2004 to 2015 illustrating the significant recovery of atmospheric ozone over Kathmandu.

The combined data set with OMI and TOMS can be used to study the long trend of total ozone over Kathmandu Valley and all other cities in Nepal. In addition, the satellite-based ozone data can also be compared with the ground-based ozone measurements as for further research study.

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REFERENCES

Antón, M., Bortoli, D., Costa, M. J., Kulkarni, P. S., Domingues, A.F., Barriopedro, D., Serrano, A. and Silva, A. M. 2011. Temporal and spatial variabilities of total ozone column over Portugal. *Remote Sens. Environment* **115**: 855-863.

Bhattarai B. K. 2006. Total column ozone over Kathmandu Using OMI Satellite *Journal of the Institute of Engineering* **8**(1):287-283.

Bojkov, R., Bishop, L., Hill, W., Reinsel, G. and Tiao, G. 1990. A statistical trend analysis of revised dobson total ozone data over the northern hemisphere. *Journal of Geophysical Research Atmosphere* **95**: 9785-9807.

Bowman, K. P. and Krueger, A. J. 1985. A global climatology of total ozone from the Nimbus 7 total ozone mapping spectrometer. *Journal of Geophysical Research Atmosphere* **90:**7967-7976.

Caldwell, M. M., Björn, L. O., Bornman, J. F., Flint, S. D., Kulandaivelu, G., Teramura, A. H. et al. 1998. Effects of increased solar ultraviolet radiation on terrestrial ecosystems. *Journal of Photochemistry and Photobiology B: Biology* **46**: 40-52.

Chapagain, N. P. 2002. Total Ozone Measurements over Kathmandu Using Brewer Spectro-photometer. *M. Tech Thesis*, *Andhra University, Visakhapatnam,* India.

Chapagain, N. P. 2015. Variability of the Atmospheric Ozone over Kathmandu using Ground-based Measurements, *Bibechana* **10**: 8-17: RCST p.9.

Chen, Z., Yu, B., Huang, Y., Hu, Y., Lin, H. and Wu, J. 2013.Validation of total ozone column derived from OMPS using ground-based spectro-radiometer measurements. *Remote Sensing Letters* **4:** 937945.

Cheng, Z., Wang, S., Jiang, J., Fu, Q., Chen, C., Xu, B., et al. 2013. Long-term trend of haze pollution and impact of particulate matter in the Yangtze River Delta, China. *Environtal Pollution* **182:** 101-110.

Fahey, D. W. and Hegglin, M. I. 2011. Twenty Questions and Answers about the Ozone Layer 2010 Update: Scientific Assessment of Ozone Depletion 2010, *World Meteorological Organisation: Geneva, Switzerland*.

Fioletov, V., Bodeker, G., Miller, A., McPeters, R., Stolarski, R. 2002. Global and zonal total ozone variations estimated from ground-based and satellite measurements: 1964–2000. *Journal of Geophysical Research Atmosphere* **107**: ACH 21-21–ACH 21-14.

Fioletov, V. E. and Shepherd, T. G. 2005. Summertime total ozone variations over middle and polar latitudes. *Geophysical Research Letters* **32**: L04807.

Ganguly, N. D. and Tzanis, C. 2011.Study of stratosphere-troposphere exchange events of ozone in India and Greece using ozonesonde ascents. *Meteorological Applications* **18:** 467-474.

Herman, J., Hudson, R., McPeters, R., Stolarski, R., Ahmad, Z., Gu, X. Y., et al. 1991. A new self-calibration method applied to toms and sbuv backscattered ultraviolet data to determine long-term global ozone change. *Journal of Geophysical Research Atmosphere (1984–2012)* **96:** 7531-7545.

Hoffmann, M. J. 2012. Ozone Depletion and Climate Change: Constructing a Global Response, SUNY Press: New York, NY, USA.

Houghton, J. T. 1996. Climate Change 1995: The Science of Climate Change: Contribution of Working Group I to the Second Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press: Cambridge, UK, Volume 2.

Kroon, M., Petropavlovskikh, I., Shetter, R., Hall, S., Ullmann, K., Veefkind, J., et al. 2008a**.**Omi total ozone column validation with Aura-AVE CAFS observations. *Journal of Geophysical Research Atmosphere* **113**: D15S13.

Kroon, M., Veefkind, J. P., Sneep, M., McPeters, R.D., Bhartia, P. K. and Levelt, P.F. 2008b. Comparing OMI-TOMS and OMI-DOAS total ozone column data. *Journal of Geophysical Research Atmosphere* **113:** D16S28.

Levelt, P. F., van den Oord, G. H., Dobber, M. R., Malkki, A., Visser, H., de Vries, J., et al. 2006. The ozone monitoring instrument. *IEEE Transaction of Geoscience and Remote Sensing* **44:** 1093-1101.

Madronich, S., McKenzie, R.L., Björn, L.O. and Caldwell, M. M. 1998. Changes in biologically active ultraviolet radiation reaching the Earth's surface. *Journal of Photochemistry and Photobiology B: Biology* **46:** 5-19.

Molina, M. J. and Rowland, F. S. 1974. Stratospheric sink for chlorofluoromethanes: Chlorine atom-catalysed destruction of ozone. *Nature*, **249:** 810-812.

NASA Ozone & Air Quality. Available online: http://ozoneaq.gsfc.nasa.gov/index.md (10 December 2013).

Parajuli, K. 2015. Mapping of total ozone content over Kathmandu valley using OMI satellite data, M. Sc. Thesis, *Institute of Science and Technology*, *Tribhuvan University*, Kathmandu.

Rowland, F. and Molina, M. J. 1975. Chlorofluoromethanes in the environment. *Review of Geophysics* **13:** 1-35.

Schmalwieser, A. W., Schauberger, G. and Janouch, M. 2003. Temporal and spatial variability of total ozone content over central Europe: Analysis in respect to the biological effect on plants. *Agriculture and Forest Meteorology* **120:** 9-26.

Silva, A. A. 2007. A quarter century of TOMS total column ozone measurements over Brazil. *Journal of Atmospheric and Solar-Terrestrial Physics* **69:** 1447-1458.

Staehelin, J., Renaud, A., Bader, J., McPeters, R., Viatte, P., Hoegger, B., et al. 1998. Total ozone series at Arosa (Switzerland): Homogenization and data comparison. *Journal of Geophysical Research Atmosphere* **103:** 5827-5841.

Stolarski, R. S., Krueger, A. J., Schoeberl, M. R., McPeters, R. D., Newman, P. A. and Alpert, J. 1986**.** Nimbus 7 satellite measurements of the spring time Antarctic ozone decrease. *Nature*, **322:** 808-811.

Stolarski, R. S., Bloomfield, P., McPeters, R. D. and Herman, J.R. 1991. Total ozone trends deduced from Nimbus 7 TOMS data. *Geophyical. Research Letters* **18:** 1015-1018.

Svendby, T. and Dahlback, A. 2004. Statistical analysis of total ozone measurements in Oslo, Norway, 1978–1998. *Journal of Geophysical Research Atmosphere* **109**: D16107.

Tandon, A. and Attri, A. K. 2011. Trends in total ozone column over India: 1979–2008. *Atmospheric Environment* **45:** 1648-1654.

Varotsos, C. A., Cracknell, A. P. and Tzanis, C. 2012. The exceptional ozone depletion over the arctic in January–March 2011. *Remote Sensing Letter* **3:** 343-352.

WMO, W. 2006. Scientific Assessment of Ozone Depletion: 2006, Global Ozone Research and Monitoring Project–Report, World Meteorological Organisation, Geneva, Switzerland **50** pp 572.

Zerefos, C. S., Bais, A. F., Ziomas, I. C. and Bojkov, R. D. 2014. On the relative importance of quasi-biennial oscillation and El Nino/southern oscillation in the revised dobson total ozone records. *Journal of Geophysical Research Atmosphere (1984–2012)* **97:** 10135-10144.

Ziemke, J. R., Chandra, S. and Bhartia, P. K. 2005. A 25-year data record of atmospheric ozone in the pacific from total ozone mapping spectrometer (toms) cloud slicing: Implications for ozone trends in the stratosphere and troposphere. *J Journal of Geophysical Research Atmosphere* **110**: D15105.