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Total Ozone Content over Kathmandu from TOMS Observations

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ABSTRACT
This paper reports the trend of total ozone content (TOC) over Kathmandu for 10 years period from 1979-1988 derived from Total Ozone Mapping Spectrometer (TOMS) satellite observations. The trends of daily, monthly, seasonal and annual variations of TOC over Kathmandu have been analyzed. The result exemplifies that during the whole study period, the TOC is found to be maximum on February 11, 1979 with a value of 352 DU and the lowest ozone concentration is on January 18, 1980 with a value of 243 DU. Similarly, the minimum value of monthly average TOC is 260 DU in November, while the maximum values is 293 DU on May. The amplitude of variations of monthly average TOC is 12.7% in terms of the percentage from the mean value. The results also show that TOC is highly seasonal dependent with larger TOC in summer season compared to the equinox and winter seasons. The summer TOC on average is 7.5% higher than in winter season and only by 1.8% higher than in equinox. The TOC in equinox is higher than winter by 5.7% on average. The average annual value of TOC exhibits slightly variable with a maximum in 1979 (281 DU) and minimum in 1984 (274 DU), which differs only by 2.5%. The average value of TOC during the whole study period is 277 DU, which indicates good amount of stratospheric ozone content over Kathmandu.

Keywords: Dobson unit, temporal variability, Total ozone content, TOMS

I. INTRODUCTION

Ozone is triatomic oxygen (O_3), which is highly unstable molecule with a very short half-life with 22 minutes on average. It desires to revert back to its more stable state O_2, by releasing one atom of oxygen. Since ozone will break down, oxidize, almost anything that it contacts, it is an enormously powerful disinfectant and oxidizer. The most of the ozone concentration exhibits in the altitude range of 25-40 km, is called ozone layer. This ozone layer plays a vital role in protecting us from harmful ultraviolet (UV) radiations incident from sun [1]. But this layer is getting depleted day by day. During the last several decades, human activities have resulted in considerable reduction in the ozone layer of the atmosphere. Scientists have observed reduction in stratospheric ozone since early 1970s and they found more prominent in Polar Regions [2,3]. The negative impacts of zone depletion have been felt globally. This realization has assured the development of the control measures to protect the ozone layer. These measures are directly related to the elimination of chemicals that deplete the ozone layer.

Ozone depletion over Antarctica, first noted by British scientists, was confirmed by measurements from the Nimbus-7 Total Ozone Mapping Spectrometer (TOMS), launched in 1978. TOMS has made polar ozone maps of an ozone hole as large as the United States. Satellite data were invaluable in supporting the first international environmental agreement, the Montreal Protocol [4]. The UV radiations are of shorter wavelengths ranging from 100-280 nm (UV-C), 280-315 nm (UV-B) to 315-400 nm (UV-A). Of the UV radiations, UV-C is completely absorbed by the ozone layer and only 5% of UV-B reaches the Earth's surface, while nearly 95% of UV-A is able to penetrate the atmospheric layers [6-8]. At any given time, ozone molecules are constantly formed and destroyed in the stratosphere. The total amount, however, remains relatively stable. While ozone concentrations vary naturally with sunspots, the seasons, and latitude, these processes are well understood and predictable. Each natural reduction in ozone levels has been followed by a recovery. Recently, however, convincing scientific evidence has shown that the ozone shield is being depleted well beyond changes due to natural processes.

Thus, ozone can be regarded as beneficial UV shield in the stratosphere but a harmful pollutant to human beings at ground level. But the ozone layer is getting depleted day by day. Its depletion has an adverse effect on all livings organisms on the Earth. Many researchers have studied about the atmospheric ozone concentrations globally. But in the context of Nepal, no detail studies have been conducted about the depletion of ozone and its effects. Nepal is situated between two giant industrial countries India and China and their industrial byproduct can directly effect the concentrations and depletion of ozone concentration over Kathmandu. Therefore, detail study of atmospheric concentration is very important.

The total ozone content (TOC) or also simply called total ozone of the Earth's atmosphere can be measured by Dobson unit (DU), which is the most common unit for the measurement of total ozone. The Dobson unit is named after Gordon Dobson and is measured with the help of 'Dobson Spectrometer'. One Dobson unit is the number of molecules of the ozone that would be required to create a layer of pure ozone 0.01 millimeters thick at a STP (i.e., temperature at $0^{\circ}C$ and a pressure at 1 atmosphere). One Dobson unit refers to a layer of gas that would be 10 µm thick under standard temperature and pressure [5]. In other words, one DU is 2.69×10^{16} ozone molecules per square centimeter, or 2.69×10^{20}per square meters. In our data analysis, the total ozone content is expressed in Dobson unit (DU).

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 by Chapagain [9, 10]. Similarly the data recorded using satellite measurements over Kathmandu were analyzed in previous studies [11, 12, 13]. The main objectives of this research project is to study the trend of the daily, monthly, seasonal, and annual variations of total ozone content over Kathmandu using a long term period of 1979-1988 data set obtained from Total Ozone Mapping Spectrometer (TOMS).

II. DATA AND METHODOLOGY

The Total Ozone Mapping Spectrometer (TOMS) is an instrument built and operated by the National Aeronautics and Space Administration (NASA). The instrument uses backscattered ultraviolet radiance to infer total column ozone measurements. Out of five TOMS instruments which were built, four entered successful orbit. Of which Nimbus-7 and Meteor-3 provided global measurements of total column ozone on a daily basis and together provide a complete data set of daily ozone from November 1978 to December 1994. ADEOS TOMS (Advanced Earth Observing Satellite TOMS) was launched on August 17, 1996 and provided data till June 29, 1997 [14]. Earth Probe TOMS was launched on July 2, 1996. The Ozone Monitoring Instrument (OMI) has replaced Earth Probe TOMS since January 1, 2006.

This NASA-developed instrument measures ozone indirectly by mapping ultraviolet light emitted by the Sun to that scattered from the Earth's atmosphere back to the satellite. The TOMS instrument has mapped in detail the global ozone distribution as well as the Antarctic "ozone hole" which forms September through November of each year. TOMS makes 35 measurements every 8 seconds, each covering 30 to 125 miles (50 to 200 kilometers) wide on the ground, strung along a line perpendicular to the motion of the satellite. Almost 200,000 daily measurements cover every single spot on the Earth except areas near one of the poles, where the Sun remains close to or below the horizon during the entire 24-hour period [15].

The extremely high quality of TOMS ozone data has also helps in detecting a small but steady long-term depletion to the ozone layer over several parts of the globe, including most of the heavily populated areas in the northern mid-latitudes. The TOMS satellite provided daily global coverage of Earth's total ozone by measuring the back scattered Earth radiance in the six 1-nm bands in the following wavelength regions: 312, 317, 331, 340, 360, and 380 nm [14]. The measurements used for ozone retrieval were made during the sunlit portions of the orbit as the spacecraft moved from south to north.

From the long-term data set obtained from satellite observations, the temporal and spatial variability of total ozone content can be estimated. The temporal variability is quantified by calculating the coefficient of relative variation (CRV) [17]:

$$CRV_{i,a} = 100\frac{TOC_{i,a}^{max} - TOC_{i,a}^{min}}{TOC_{i,a}^{mean}} \qquad (1)$$

Where, $TOC_{i,a}^{max}, TOC_{i,a}^{min}$ and $TOC_{i,a}^{mean}$ denote the maximum, minimum and mean daily TOC value in band a and day i respectively.

In this work, we have used the satellite data of total ozone content (TOC) for 10 years from January 1, 1979 to December 31, 1988 of total 3653 days of observations. The data were obtained from NASA's official website (https://ozoneaq.gsfc.nasa.gov/tools/ozonemap) [19] derived from Total Ozone Mapping Spectrometer (TOMS) on board NASA's Nimbus-7. Detail of the measurements techniques from TOMS satellite has been discussed in previous studies [9, 14]. For this study, we got the ozone data from Kathmandu (27.7°N, 85.3°E) for everyday during the study period and calculated the monthly, seasonal and annual average values of total ozone content.

III. RESULTS AND DISCUSSION

3.1. Daily Total Ozone Content over Kathmandu

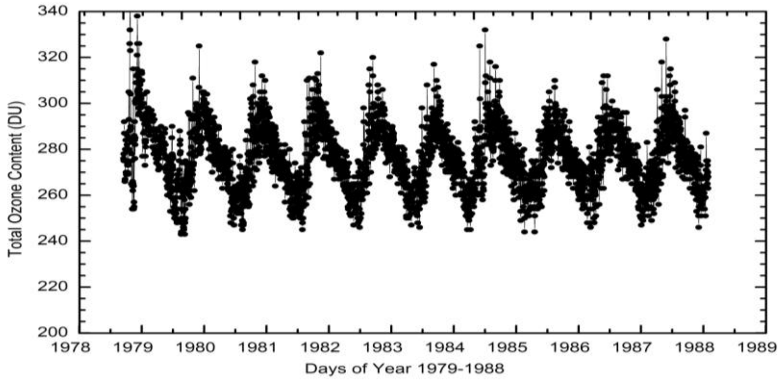

Figure 1: Daily total ozone content over Kathmandu from January 1, 1979 to December 31, 1988.

Figure 1 shows the plot of daily total ozone content (TOC) over Kathmandu for 10 years period from January 1, 1979 to December 31, 1988. The scattered plot represents the daily TOC over Kathmandu, which shows the pattern of variations of TOC is symmetric in every year. The value of TOC increases every half year and becomes peak value and then TOC start to decrease and falls to minimum value. Such variations are symmetric in every year with mostly peak value of TOC occurs on May and lowest value exhibits on November or December. Overall, the result illustrates that the total ozone content values are large during the summer, while these values are smaller in winter season. However during the whole study period, the highest total ozone concentration is found on February 11, 1979 with a value of 352 DU which is the obsessional case being the highest value of total ozone this month. On other hand, the lowest ozone concentration is found on January 18, 1980 with a value of 243 DU. The average TOC calculated during the whole study period of 10 years over Kathmandu valley is found to be 277 DU which is the good level of TOC, that is large enough above the critical value (assumed to be 220 DU) of ozone layer to absorb harmful UV radiations coming from the sun.

3.2. Monthly Average Total Ozone Content

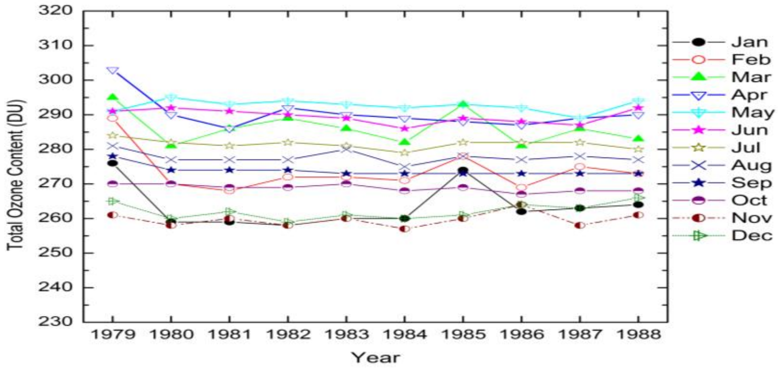

Figure 2: Monthly average total ozone content over Kathmandu for each year during 1979-1988.

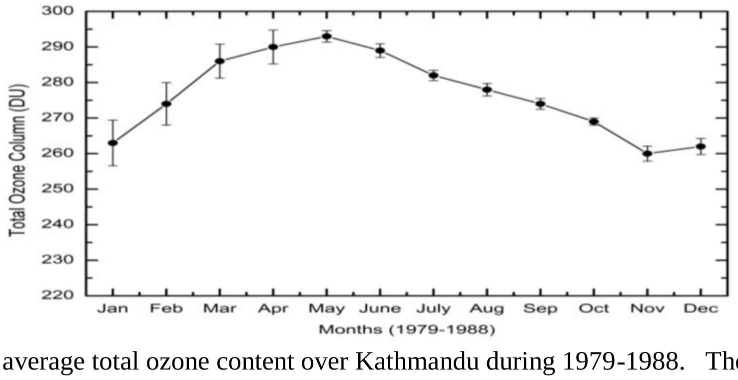

Figure 3: Monthly average total ozone content over Kathmandu during 1979-1988. The vertical bars denote the standard deviations from the mean values.

The monthly average TOC for each year during 1979-1988 is estimated from daily ozone data obtained from TOMS observations and is plotted as shown in Figure 2. The figure shows that the monthly average TOC for each year from 1979 to 1988. This plot reveals that the TOC values are maximum on April 1979, and minimum in November 1984. The results also illustrate that during May, the TOC values are larger compared to other months from 1980 to 1988, while the values of TOC are mostly low during the month of November. Furthermore, the monthly averages TOC exhibit larger values in 1979 as compared to other years.

The average value of TOC data during 1979-1988 were estimated and plotted in Figure 3. The vertical bars in the plot show the standard deviations from mean TOC. It can be observed from that TOC value increases from the month of January with an average value of 263 DU to a maximum value up to 293 DU on May with the percentage change by 11.4%.

From the plot, it shows that TOC value decreases from May to November by about 12%. There is a slight increment in TOC value in December. During the study period, the value of TOC is observed significantly large on the month of May, while the low ozone concentration has been observed in November. The most ozone concentration during ng May was recorded in the year 1982 with the value of 322 DU and the least ozone concentration in May was recorded the value of 273 DU in 1979. Furthermore, the minimum value of monthly average TOC is

260 DU in November and maximum average TOC is 293 DU in May. The amplitude of variations of monthly average TOC is 33 DU in absolute unit and 12.7% in terms of the percentage of the mean. Hence, from the Figures 2 and 3 illustrating the monthly trends of variations, it can be seen that TOC over Kathmandu are mostly low during November, December and January, while the high TOC were recorded during the summer months (April –July) with the peak average TOC on May.

In order to compare the trend of variations in each month from the whole data set observations, the monthly coefficient of relative variation (CRV) is obtained using the relation given in equation (1) in section 2. The average value of CRV is 3.35 ± 0.6% (average value ± standard error). The CRV presents a notable annual cycle with maximum value in February and minimum value in October, as illustrated in Figure 4. This shows that the monthly variations of TOC are larger on February, while TOC variations are lowest in the month of October, which is also illustrated from the Figure 2.

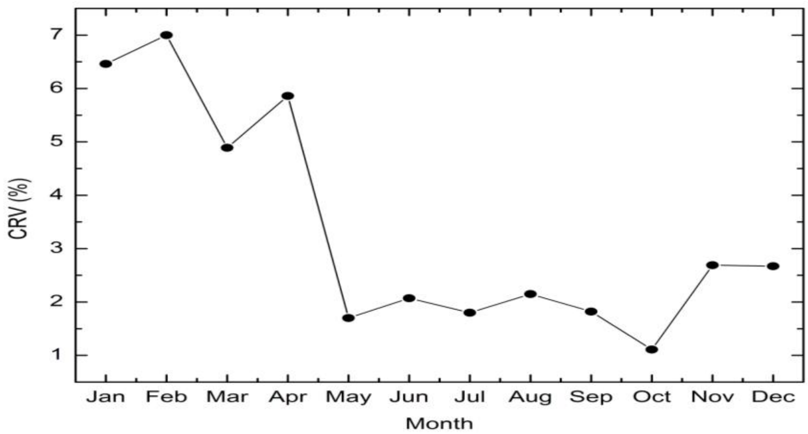

Figure 4: The coefficient of relative variation of monthly mean of total ozone content.

3.3 Seasonal Variations of Total Ozone Content

The seasonal variations of TOC over Kathmandu from long-term data set during 1979 to 1988 have been studied. We grouped the data for different seasons such as summer or June solstice (May, June, July and August), winter or December solstice (November, December, January and February) and Equinox (March, April, September and October). The calculated data for different seasons are plotted as shown in Figures 5. The vertical bars show the error in the measurements of total ozone content. From the plot, we observe that the TOC is higher in summer season (June solstice) and moderate values in spring (equinox) and lower in winter season (December solstice). This is because during the summer season, intensity of solar flux is significantly higher than the intensity during other seasons. The TOC in summer solstice is found to be 1.8% more than that in equinox and 7.5% higher than that in December solstice. The average TOC is 285 DU in June solstice, 280 DU in equinox, and 265 DU in December solstice. TOC value does not vary much within the season as shown by the smooth curve for each season.

For seasonal variability, a distinct seasonal signature on TOC is found which is similar to the variation of TOC over Kathmandu from ozone data obtained from OMI during the period of 2004-2016 as reported by *Chapagain* [10]. Thus, the seasonal variations in total ozone measurements over Kathmandu are in good agreement with the measurements made by other studies such as in Tibet [16]. In tropical region, the total ozone value is higher in summer and smaller in winter season [17]. Such variation is due to fact that during the summer season, intensity of global solar flux is stronger, which is weaker in winter season. This seasonal cycle is also affected by solar radiation and photochemical factors [18].

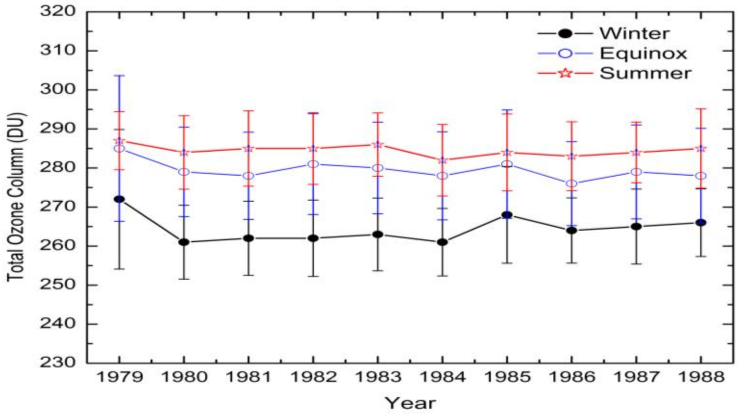

Figure 5: Seasonal variations of TOC over Kathmandu from 1979-1988. The vertical bars denote the standard deviations from the mean value.

The day-to-day variations have also demonstrated a significant seasonal cycle, with a maximum in May and a minimum in November, December or January. 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.

3.3. Annual Average Total Content

The annual average value of TOC over Kathmandu is estimated from 1979 to 1988 and is plotted as shown in Figure 6. The figure illustrates that the average TOC value during 10-year period is found to be almost remains same as shown by smooth line. Here, the small annual variations shows that TOC value slightly decreases from 1979 to 1981 by 2.1% and then shows a slight increment in the year 1982 and that remains almost constant till 1983. Furthermore, TOC slightly decreases by 1.8% in 1984 and then again increases slightly in 1985. Overall, the TOC is found to be maximum with a value of 281 DU in 1979 and minimum with a value of 274 DU in 1984, which differs only by 2.5%. The results clearly reveal that total ozone content over Kathmandu does not fluctuate much during the years from 1979 to 1988, which is the evidence of ozone content over Kathmandu has not been depleted during this study period.

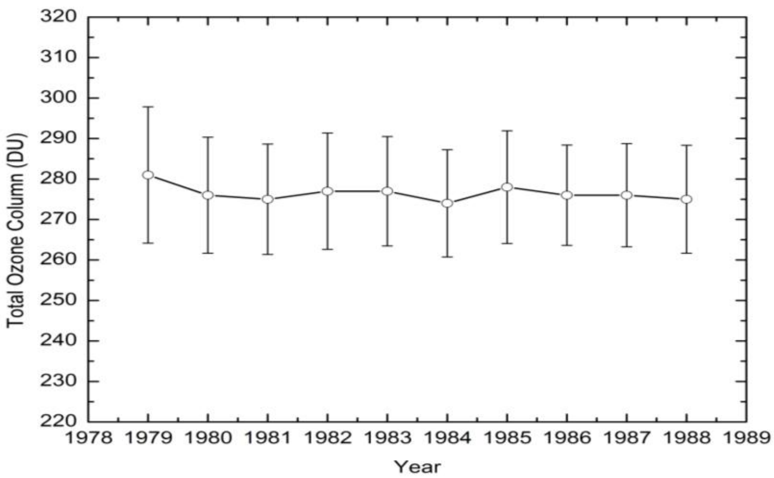

Figure 6: Annual average TOC over Kathmandu during 1979-1988. Here the vertical bars are the standard deviations from the mean values.

IV. SUMMARY

This paper presents the trends of total ozone content (TOC) over Kathmandu for 10 years period during January 1979- December 1988 from the ozone data derived from Total Ozone Mapping Spectrometer (TOMS). The trends of daily, monthly, seasonal as well as annual variations of TOC over Kathmandu have been analyzed. The result exemplifies that during the study period, ozone concentration is found to be maximum on February 11, 1979 with a value of 352 DU and the lowest ozone concentration is observed on January 18, 1980 with a value of 243 DU. Similarly, the minimum value of monthly average TOC is 260 DU in November and maximum on 293 DU on May. The amplitude of variations of monthly average TOC is 12.7% in terms of the percentage of the mean. Furthermore, the results also show that TOC is highly seasonal dependent with larger values in summer season compared to the equinox and winter seasons. The summer TOC on average is 7.5% higher than in winter season and by 1.8% higher than in equinox. The TOC in equinox is higher than winter by 5.7% on average. The average annual value of TOC is found to be slightly variable with a maximum in 1979 (281 DU) and minimum in 1984 (274 DU), which differs only by 2.5%. The average value of TOC during the whole study period is 277 DU, which indicates good amount of stratospheric ozone content over Kathmandu, which is high enough above the critical value of total ozone content below which the harmful UV radiations can penetrate to the Earth's surface.

ACKNOWLEDGMENTS

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