

Long Term Trend, Diurnal and Seasonal Variations of Atmospheric Ozone at Indian Antarctic Station Maitri

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Abstract

The long term trend, diurnal and seasonal variations of atmospheric ozone at the Indian Antarctic station Maitri has been examined using ground based and satellite data. Total ozone column (TOC) at Maitri exhibits a clear seasonal variation, which is found to be maximum in January and minimum in September/October while the surface ozone does not exhibit any significant diurnal variation. Both, the monthly mean TOC and minimum TOC during the ozone hole period exhibits a sharp decreasing trend for the period 1979-1988, which is observed to slow down during the period from 1989-2001. The observed weakening in ozone trends are discussed in the light of the possible influence of Montreal protocol and other natural and anthropogenic factors, which also influence the recovery in ozone levels.

Key words: Maitri, seasonal variation, diurnal variation, trend, polar vortex, ozone hole.

Introduction

Antarctica is the southernmost continent of the world located between 65°S and 90°S latitudes. Every year about 60% of the total amount of overhead ozone gets depleted over some parts of Antarctica during spring time. This phenomenon known as the Antarctic ozone hole was first discovered in the mid eighties (Farman *et al.*, 1985) and it led to the triggering of intense scientific research and signing of international agreements like Montreal Protocol.

The main factors affecting the Antarctic ozone loss are high chlorine and bromine levels, extremely low temperature during winter, and relative isolation of the polar region from the mid latitudes by the polar vortex. However, in the recent years, it has been established that the development of the Antarctic ozone hole is strongly influenced by photochemical balance (Crutzen *et al.*, 1986), transport of ozone by winds and meteorological conditions in the stratosphere (Jain *et al.*, 2008). In the light of this background, the diurnal and seasonal variations and long term trend of atmospheric ozone at Maitri has been studied using ground based and satellite data.

Measurement site and Data

The Indian Antarctic research station Matri (70 ° 46'S, 11 ° 45'E) is located in the coastal area of Queen Maud Land on a rocky area and is devoid of snow throughout the year (Bhattacharya, 1987). The monthly mean total ozone column (TOC) data for Maitri has been obtained from Nimbus-7 Total Ozone Mapping Spectrometer (Nimbus-7 TOMS) and Earth Probe Total Ozone Mapping Spectrometer (EP-TOMS). This data has been used to study the trend and seasonal variability of TOC at Maitri for the period from 1979–2001. Since TOMS data are either incomplete or unavailable for the years 1993-1996, they have been neglected. Further, due to continuous changes in the optical properties of the front scan mirror on EP-TOMS, a latitude dependent error was observed, which

could not be corrected by a simple calibration correction. Because of this error, data since the year 2002 has not been considered for trend analysis as per the recommendation from NASA (<http://toms.gsfc.nasa.gov/news/news.html#18-Nov-2004>). TOMS provides daily global measurement of the TOC of the atmosphere by measuring solar ultraviolet radiation back scattered from the atmosphere. The surface ozone data and vertical ozone profiles at Maitri have been obtained from India Meteorological department (IMD). The wind direction has been obtained from NCEP/NCAR Reanalysis (Kalnay *et al.*, 1996).

Results and Discussions

1. Diurnal variation of surface ozone:

A comparison of surface ozone measured in units of parts per billion by volume (ppbv) on four different days at Maitri is shown in Fig. 1. Surface ozone at Maitri exhibits an insignificant diurnal variation of around 5 ppbv. This is because, since Maitri lies in the polar region, the sun shines for all the 24 hours every day during October to February. Thus, the solar radiation does not vary much from morning to night hours, resulting in almost constant ozone concentration throughout the day. Apart from this, surface ozone is produced by the photo oxidation of pollutants (carbon mono oxide & hydrocarbons) in the presence of adequate amount of nitrogen oxides during daytime. As vehicular traffic and industrial pollution levels are almost negligible at Maitri, insitu photochemical production of ozone may not be very significant. The general wind direction during all these four days was from the south east direction (NCEP/NCAR Reanalysis; Kalnay *et al.*, 1996), which rules out the possibility of transport of surface ozone and its precursors from polluted continental areas to this region. Moreover, as ozone is destroyed efficiently during transport over the sea/ocean due to relatively high insolation and humidity (Roelofs and Lelieveld, 2000), transport of air over sea/ocean do not cause the ozone levels to increase. Similar results were observed by Tripathi and Jain (2000), who have studied the diurnal variation of total ozone at Maitri during ozone hole period. They have observed that TOC decreased slightly from morning to evening hours.

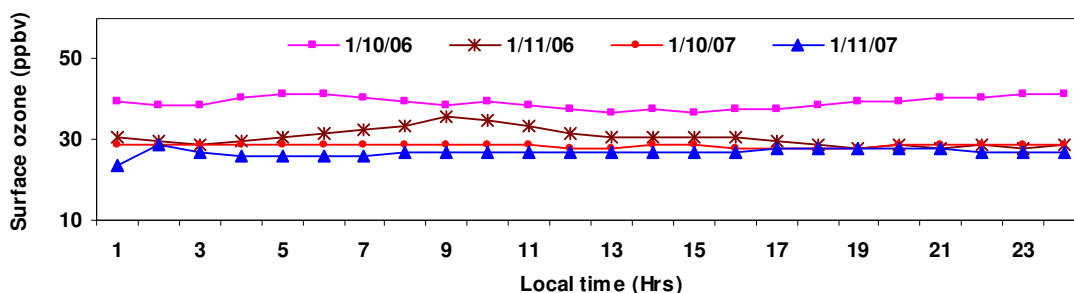


Fig.1: Diurnal variation of surface ozone (ppbv) at Maitri on four different occasions (Source of data: India Meteorological department).

2. Seasonal variation of total ozone column (TOC):

The monthly mean TOC in Dobson unit (DU) obtained for Maitri ($70^{\circ}46'S$, $11^{\circ}45'E$) located at the fringe of the polar vortex, and Station X ($65^{\circ}S$, $11^{\circ}E$) located outside the polar vortex from TOMS data were averaged for the period from 1997 - 2001 to study seasonal variation of ozone (Fig. 2). Since TOMS determines the TOC by measuring the solar ultraviolet radiation back scattered from the atmosphere, TOC data are not available at Maitri during winter darkness (Polar night period). TOC at Maitri is found to be maximum in January (283 DU). It decreases thereafter and reaches a

minimum in September (170 DU). It again increases gradually from October to December and reaches a peak in January. A clear seasonal variation of around 113 DU is observed.

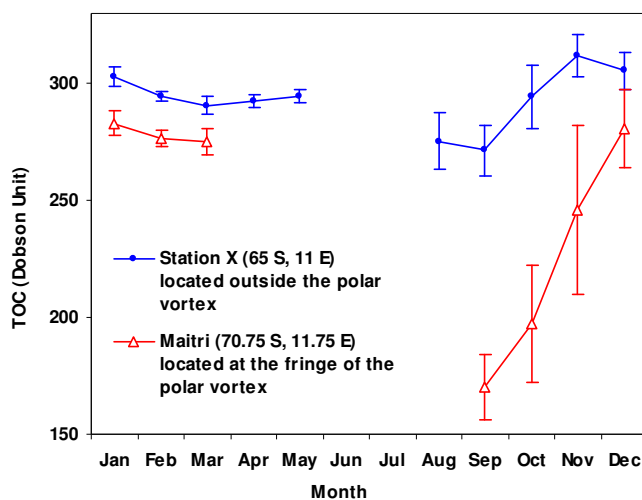


Fig. 2: Seasonal variation of total ozone (Dobson unit) at Maitri and station X for the period 1997-2001. Bars indicate 2σ deviation (Source: EP TOMS).

Unlike Maitri, TOC at Station X is found to be maximum in November (312.2 DU). It decreases thereafter and reaches a minimum in September (271.4 DU). A clear seasonal variation of around 40.8 DU is observed. The observed seasonal variation at Maitri is because during Antarctica's dark winter, air temperatures above the South Pole drops to very low values. This forms a ring of high-altitude winds around Antarctica, which traps the ozone and ozone-depleting substances inside the Antarctic region and blocks outside air from entering into the Antarctic region. With the return of sunlight in September, the chemical reactions that destroy ozone are energized, resulting in low ozone values (<220 DU) in September/October. In November, as the air warms, the vortex breaks down and ozone-rich air from elsewhere mixes with the ozone-poor polar air, thus resulting in an increase in ozone concentration and disappearance of the hole. Unlike station X, which exhibits a standard deviation of around 5.36 DU from August to December, the ozone concentration at Maitri exhibits a high standard deviation of around 36 DU from September to December. The large amplitude of seasonal variation and large standard deviation observed at Maitri confirms the observation of Carswell *et al.* (1996) that ozone at Maitri is strongly affected by the dynamical behavior of the polar vortex and planetary wave conditions. As Maitri is located on the fringe of the vortex (Tripathi and Jain, 2000), the amount of exchange between vortex and mid latitude air influences the amount of chemical processing of ozone and hence TOC (Schoeberl *et al.*, 1991). Singh and Sharma (2008) have studied the seasonal variation of TOC at Maitri in 2003 using Brewer Spectrophotometer. They have observed maximum TOC in the month of January and minimum in October.

3. Seasonal variation in the vertical ozone profile:

A comparison between ozone levels at Maitri during the year 1997 for the months March (which can be considered as a normal ozone profile), August (before the ozone hole started forming) and October (when the ozone hole was at its maximum) is shown in Fig. 3.

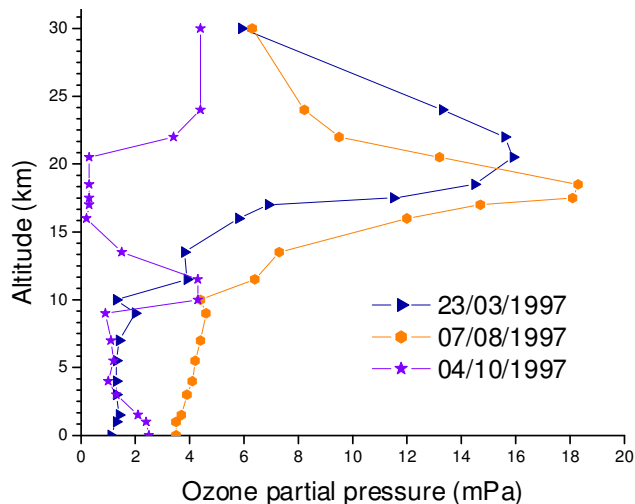


Fig. 3: Comparison between ozone levels at Maitri during the year 1997 for the months March, August and October (Source of data: India Meteorological department).

It is observed that the ozone peak is higher during March (summer), but its altitude decreases in August (winter). This may be because during winter as the air begins to cool, ozone rich air grows denser and sinks to lower altitudes, resulting in a lowering of the ozone peak. The October profile indicates that ozone has almost disappeared from about 16-21 km altitude range which would be where the polar stratospheric clouds that enhance ozone destruction are mostly located.

4. Long term trend of total ozone column (TOC):

The variability in the TOC at Maitri has been studied by several Indian scientists by using satellite and ground based observations (Tripathi and Jain; 2000; Singh and Sharma, 2008). However, it may be noted that these studies are either restricted to coordinated campaigns or encompasses data measured over a continuous period of time, which is much before and after the implementation of the Montreal Protocol, and therefore cannot delineate the real effects of the Protocol. Since the implementation of Montreal Protocol entered into force from January 1989, the entire period of available data set is separated into two segments: 1979-1988 (before the implementation of Montreal Protocol) and 1989 - 2001 (after the implementation of Montreal Protocol) with a view to study the impact of Montreal protocol and other factors on ozone levels. The linear trend of monthly mean TOC from 1979-1988 and 1989-2001 at Maitri is plotted in Fig. 4.

The monthly mean TOC at Maitri exhibits a small decreasing trend of 0.331 DU yr^{-1} for the period 1979-1988. Thereafter, during the period from 1989-2001, the depletion in ozone levels is observed to slow down and a decreasing trend of $0.2015 \text{ DU yr}^{-1}$ is observed. The observed weakening in ozone trends is $+0.1295 \text{ DU yr}^{-1}$.

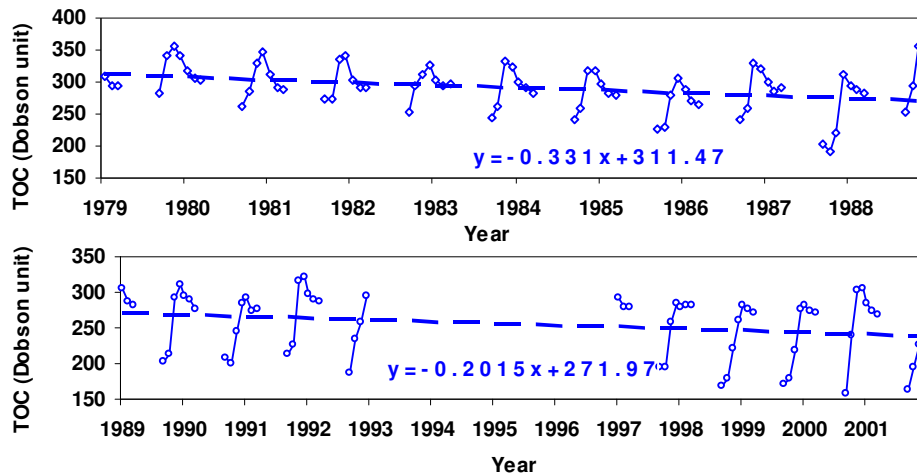


Fig. 4: Trend of TOC (DU) at Maitri for the period 1979-1988 and 1989-2001 (Source of data: Nimbus- 7 TOMS and Earth Probe TOMS)

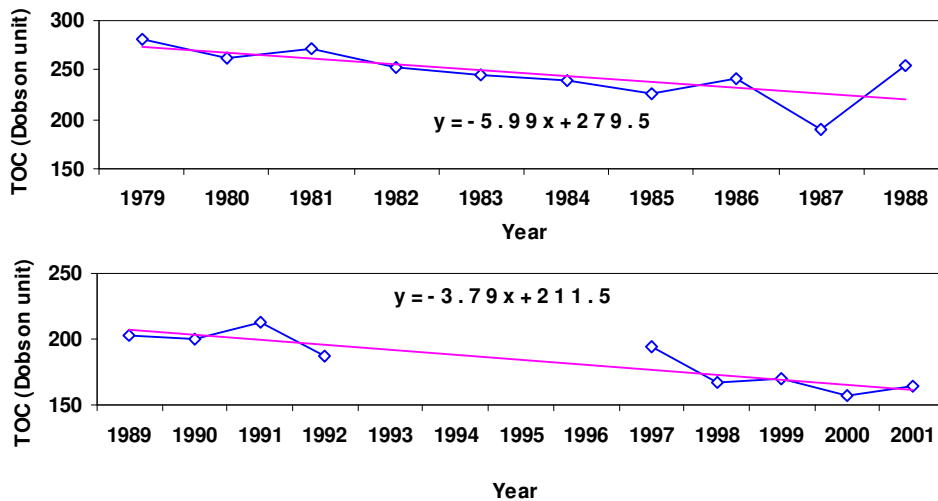


Fig. 5: Trend of minimum TOC (DU) at Maitri for the period 1979 - 1988 and 1989-2001 (Source of data: Nimbus - 7 TOMS and Earth Probe TOMS).

Similarly, the minimum TOC during ozone hole period at Maitri (Fig. 5) exhibits a sharp decreasing trend of 5.99 DU yr^{-1} for the period 1979-1988. Thereafter during the period from 1989-2001, the depletion in ozone levels is observed to slow down and a decreasing trend of 3.79 DU yr^{-1} is observed. This indicates that although the ozone hole grew deeper during the period from 1979-2001, and the ozone depletion inside the vortex was increasing, a weakening in the ozone hole trend of the order $+ 2.20 \text{ DU yr}^{-1}$ was observed to occur during the period from 1989-2001 compared to 1979-1988. The recovery in ozone levels was small because, since the life time CFC's in the stratosphere varies from a few years to hundreds of years, although the world had reduced or eliminated the use of many of these gases, their impact from the past may be affecting the ozone layer during the period from 1989-2001. Thus, it may take several more years before we may observe a reasonable recovery in TOC at Maitri. The change in the slope observed between the two epochs indicates the possible contribution of Montreal Protocol, because apart from changes in stratospheric ozone concentration due to

catalytic reactions in the stratosphere involving CFC'S, other natural factors and climatological processes such as photochemical balance, transport of ozone by winds and meteorological conditions in the stratosphere could also influence the recovery in ozone levels (Jain *et al.*, 2008; Ganguly and Iyer, 2009).

Conclusions

The trend, diurnal and seasonal variation of ozone at the Indian Antarctic station Maitri has been examined using satellite and ground based data. TOC at Maitri exhibits a clear seasonal variation, which is found to be maximum in January and minimum in September/October while the surface ozone does not exhibit any significant diurnal variation. The monthly mean TOC and the minimum TOC observed during the ozone hole period at Maitri exhibits a weakening in the ozone trend during the period from 1989-2001 compared to 1979-1988. It is argued that it is difficult to attribute the weakening in the ozone trend entirely to the success of Montreal protocol, due to the influence of a large number of natural and anthropogenic factors on the ozone chemistry.

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