

Compilation of ozonesonde observation over Schirmacher oasis east Antarctic from 1999-2007

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सार – भारत मौसम विज्ञान विभाग द्वारा भारतीय इलेक्ट्रो-केमिकल ओजोनसॉंदे की मदद से एंटार्कटिका पर भारत के दूसरे स्टेशन मैत्री (70.7 डिग्री द., 11.7 डिग्री पू.) से ओजोन स्थिति (प्रोफाइल) का नियमित माप किया जा रहा है। वायुमंडल के उदग्र स्तंभ में ओजोन के घनत्व की गणना पूरे वर्ष में लिए गए साप्ताहिक ओजोन साउन्डिंग से की जाती है। वायुमंडलीय ओजोन की उदग्र स्थिति (प्रोफाइल और ओजोन छिद्र (होल) की विशेषताओं का अध्ययन करने के लिए सितंबर-अक्टूबर माह के दौरान बहुत बार परिज्ञप्तियाँ (साउन्डिंग) ली गई हैं। इस शोध पत्र में सतह से 10 हेक्टा पा. के बीच ओजोन और तापमान के मासिक एवं वार्षिक औसत में विविधता की गणना एवं विश्लेषण वर्ष 1999 से 2007 की अवधि में लिए ओजोनसॉंदे आरोहणों से किया गया है। इस अध्ययन से पता चला है कि ओजोन छिद्र के संबंध में गहन अवक्षय अक्टूबर में और अल्प परन्तु महत्वपूर्ण अवक्षय सितंबर माह में हुआ है। अक्टूबर में लगभग 250 एवं 20 हे.पा. के बीच सबसे सुस्पष्ट अवक्षय हुआ है जिसमें अधिकतम स्थानीय ओजोन के स्तर में 70 हे.पा. और 10 हे. पा. के स्तरों पर और सितम्बर में 70 हे. पा. पर गिरावट देखी गई। भिन्न-भिन्न दाब स्तरों के लिए ओजोन का तापमान के साथ सहसंबंध से नई जानकारियों और ओजोन परिवर्तन में विस्तार का पता चला है। पूरे वर्ष में 300 से 50 हे. पा. के बीच न्यूनतम वार्षिक औसत तापमान -55 डिग्री से -63 डिग्री सेंटीग्रेड तक बदलता है। अगस्त और सितम्बर के महीनों में 70 हे. पा. तथा 100 हे. पा. स्तरों पर तापमान का -80 डिग्री सेंटीग्रेड से कम होना एवं अक्टूबर माह में 70 हे. पा. तथा 100 हे. पा. स्तरों पर लगभग -70 डिग्री सेंटीग्रेड से कम होने की स्थिति को अक्टूबर माह में ओजोन अवक्षय के संकेतक के रूप में माना जा सकता है।

ABSTRACT. Regular ozone profile measurement over Antarctica has been made by India Meteorological Department over Indian second station Maitri (70.7° S, 11.7° E) with the help of Indian electro-chemical ozonesonde. Ozone density in the vertical column of the atmosphere is computed with weekly ozone soundings taken throughout the year. During the month of September- October more frequent soundings were taken to study vertical profile of atmospheric ozone and features of ozone hole. The mean monthly and yearly variation of ozone and temperature from surface to 10 hPa has been computed and analyzed from the ozonesonde ascents for the period 1999 to 2007. The study has shown profound depletion in October and lesser but substantial depletion in September, in association with the ozone hole. Depletion is most pronounced between about 250 and 20 hPa in October, with maximum local ozone losses near 70 hPa & 100 hPa levels and in September at 70 hPa. Ozone correlations with temperature for several pressure levels have revealed new insights into the causes and extent of ozone change. Lowest annual mean temperature varies from -55 to -63 °C between 300 to 50 hPa in all the year. The temperature less than -80 °C in months of August & September at 70 hPa & 100 hPa levels and about -70 °C in month of October at 70 hPa & 100 hPa levels can be attributed as an indicator of ozone depletion in months of October.

Key words – Antarctic ozone hole, Schirmacher oasis, Seasonal variation, Tropospheric ozone climatology, Vertical distribution Ozone, Dobson spectrophotometer, Standard instrument, Inter-comparison.

1. Introduction

Ozone is a gas that naturally occurs and is minor constituent of our earth's atmosphere. In troposphere about 10% of atmospheric ozone is found and remaining 90% of ozone is found in stratosphere. The large amount of ozone in stratosphere which lies at the top is referred as ozone layer. It is continuously formed at altitude above

30 km from the photo dissociation of molecular oxygen by solar radiation. Its maximum concentration is localized at an altitude of 20-27 km in stratosphere.

The stratospheric ozone layer plays a vital role in the earth system through its absorption of ultraviolet light from the Sun. While scientific interest in ozone began more than a century ago, its systematic global monitoring

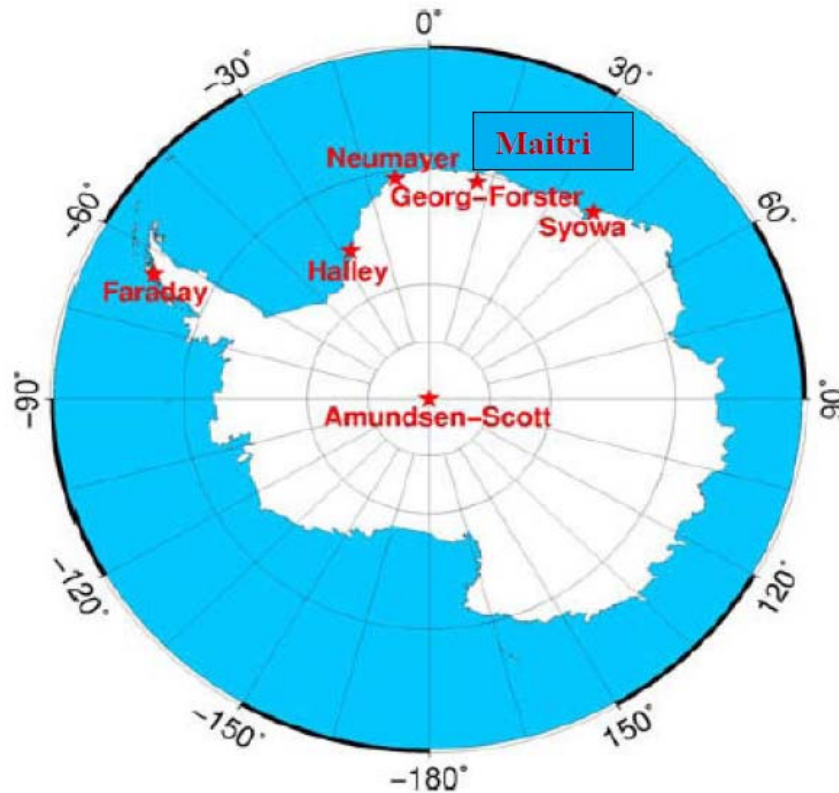


Fig. 1. Location of Maitri and Georg-Forster Station and all other Antarctic stations equipped with ozonesonde measurements

at sites worldwide traces to the International Geophysical Year in 1957-1958, an international effort that also helped foster construction and year-round use of Antarctic research stations beginning in the late 1950s and early 1960s. In the mid-1980s, an unprecedented change in October Antarctic ozone was documented using both total ozone and Ozonesonde instruments [Farman *et al.* (1985); Chubachi (1984)]. The change has been observed over Antarctica in every spring since late 1970. The ozone column abundance is reduced inside the polar vortex. At Halley station in East Antarctica the monthly mean ozone column in October was 300 DU in 1960 which has been reduced to around 150 DU in 1990 (WMO/UNEP1991). The trend in vertical ozone column shows near total disappearance of ozone from 12 to 20 km altitude in spring (September-October). This dramatic phenomenon was quickly dubbed the “ozone hole”. Since the discovery of the ozone hole, its nature and character has been probed by a powerful combination of ground-based, balloon-borne and satellite observations that have comprehensively documented the changes in ozone and other chemicals [Solomon (1999); Stolarski *et al.* (1991); WMO/UNEP (2003)]. While total ozone observations are the cornerstone documenting the historic depletion of the

ozone layer, only the Ozonesonde can reveal the full temporal and vertical structure of the ozone changes.

The nineteenth session of Scientific Committee on Antarctic Research (SCAR) meeting held at San Diego, USA, in June 1986 and World Meteorological Organization Executive Committee Working Group on Antarctic Meteorology meeting held at Geneva in September 1986, made recommendations for joint international effort for ozone observation programme for the characterization of ozone-depletion trend over the sub-continent and to understand physical, chemical and/or dynamical processes which cause the phenomena. Several countries of the world including India have since extended their active support in the programme. India Meteorological Department (IMD) foreseeing the importance of ozone monitoring over Antarctica, took up the venture during its Second Scientific Expedition in the year 1982-83 during which Ozonesonde ascents were attempted to obtain the vertical profile of ozone at the temporary Indian station, Dakshin Gangotri (69° S, 12° E) (Sreedharan *et al.*, 1986). During third expedition, a permanent scientific station “Dakshin Gangotri” (69° 59' 23" S, 11° 56' 26" E) was established in Lazarev

TABLE 1
Number of ozonesonde observations over Schirmacher oasis during 1999-2007

Month	Year									Total observations
	1999	2000	2001	2002	2003	2004	2005	2006	2007	
January	2	2	2	1	4	0	2	2	0	15
February	1	2	1	2	3	0	1	0	1	11
March	2	2	2	2	2	0	2	0	2	14
April	1	2	1	3	2	0	0	0	1	10
May	0	2	2	1	1	0	2	0	0	8
June	0	0	0	1	2	0	1	0	0	4
July	0	1	2	1	2	0	0	0	0	6
August	0	0	0	3	0	0	0	0	1	4
September	2	1	0	3	3	0	0	1	2	12
October	4	5	0	5	2	0	2	1	1	20
November	3	3	0	4	2	0	3	1	1	17
December	5	4	1	2	2	0	4	2	2	22
Total	20	24	11	28	25	0	17	7	11	143

Sea area of Queen's Maud Land and functioned there till 1989. Thereafter second Indian Antarctic Station, Maitri (70° 45' 57" S, 11° 44' 09" E) was established in 1989 in the Schirmacher Oasis of East Antarctica. IMD made elaborate arrangements at "Dakshin Gangotri" to join the international efforts for Antarctica Ozone-Hole Investigation Programme which commenced in 1986 (Faruqui *et al.*, 1988). Regular measurement of ozone at the Indian Antarctic Station, Dakshin Gangotri started in 1987 (Kopper and Nagrath, 1991; Sreedharan *et al.*, 1989).

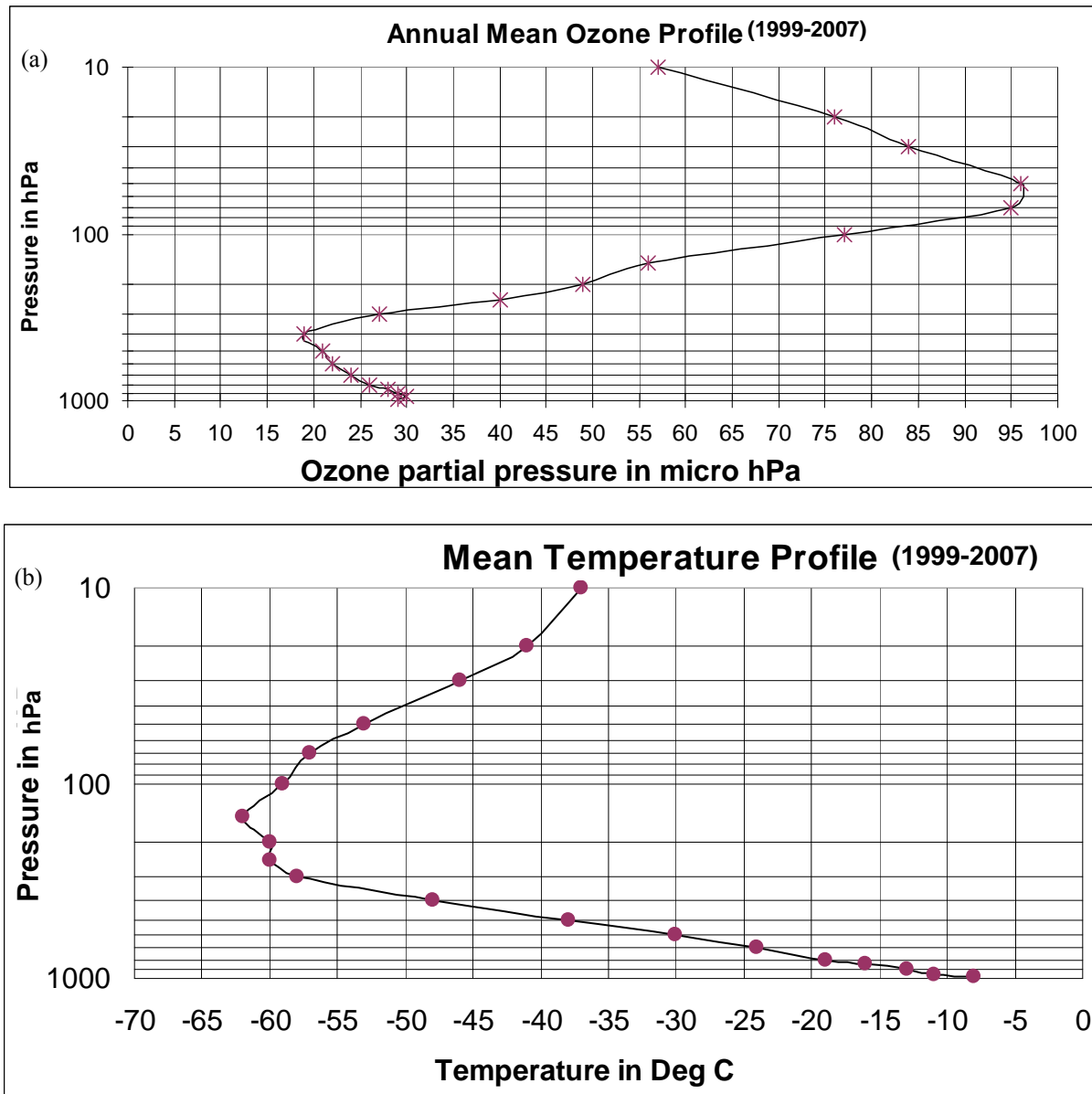
The balloon-borne soundings were also performed by Georg-Forster Station (70° 46' S, 11° 41' E) at the upper air sounding facility of the neighbouring station Novolazarevskaya, just 2 km from Maitri station. The vertical ozone distribution at Georg-Forster-Station, Schirmacher Oasis and its surroundings from 1985 until 1992 has been studied by Gernandt (1987 & 1995); Gernandt *et al.* (1989). Ozonesonde profiles (after correction for total ozone) which have crossed 20 hPa level at Dakshin Gangotri and Maitri from 1987 to 1993 have been analysed and ozone hole structure has been studied in detail by Tiwari (1999). Ozonesonde observations from Syowa and the South Pole over more than 40 years (1966 to 2004) has been described and intercompared by Solomon *et al.* (2005). Regular ozone profile measurement over Antarctica has been made by India Meteorological Department since 1987 at Dakshin

Gangotri till 1989. The regular measurement of ozone continued over Indian second station Maitri (70.7° S, 11.7° E) with the help of Indian electro-chemical ozonesonde (Sreedharan, 1968). Weekly ozone soundings are taken throughout the year and during the month of September-October more frequent soundings are taken to keep a close watch on fast depletion of atmospheric ozone. Ozone density in the vertical column of the atmosphere is calculated with the help of weekly ozonesonde ascents.

The detailed study of year to year observations has been carried out by many scientists on ozonesonde data of Maitri [Peshin *et al.*, 1996 & 1997; Sreedharan *et al.*, 1993]. In this paper ozone climatology based on available ozone soundings of Maitri between 1999 and 2007 has been analyzed and discussed.

2. Data and methodology

The measurement of ozone at the Indian Antarctic Station, Dakshin Gangotri started in 1987 and continued at Maitri since 1990 with help of Indian electrochemical ozonesonde on regular basis. The ozonesonde ascent has been taken once in a week throughout the year but during month of September and October more frequent sounding is taken to keep a close watch on fast depletion on atmospheric ozone. The vertical ozone profile of the atmosphere over Schirmacher Oasis in east Antarctica has



Figs. 2(a&b). Vertical distribution of (a) Mean ozone and (b) Mean temperature over Schirmacher Oasis for 1999-2007

been calculated with the help of weekly ozonesonde ascents. The nuhPaer of ozonesonde observatory is not uniformly distributed in Antarctica (Fig. 1). The data of ozonesonde ascent at Maitri has been checked and scrutinized at National Ozone Centre (NOC), India Meteorological Department, New Delhi. Those ozonesonde ascents have been rejected which have not reached at higher level. The authors have collected data from the National Ozone Centre. The data for the year 2004 was not available at NOC as the ascent has either not reached at higher levels or it has been rejected. The

ozonesonde data for each ascent has been picked up for all standard isobaric levels from surface to 10 hPa. If the value for standard levels is not available then nearest value (plus minus 10-15 hPa) has been taken as standard levels. The vertical profile of ozone in micro hPa and temperature in deg C of total mean value for the period of 1999-2007 has been computed. The mean monthly and yearly variation of ozone and temperature has been computed from these data. The monthly mean vertical distribution of ozone and temperature from 300 hPa to 10 hPa has been analysed.

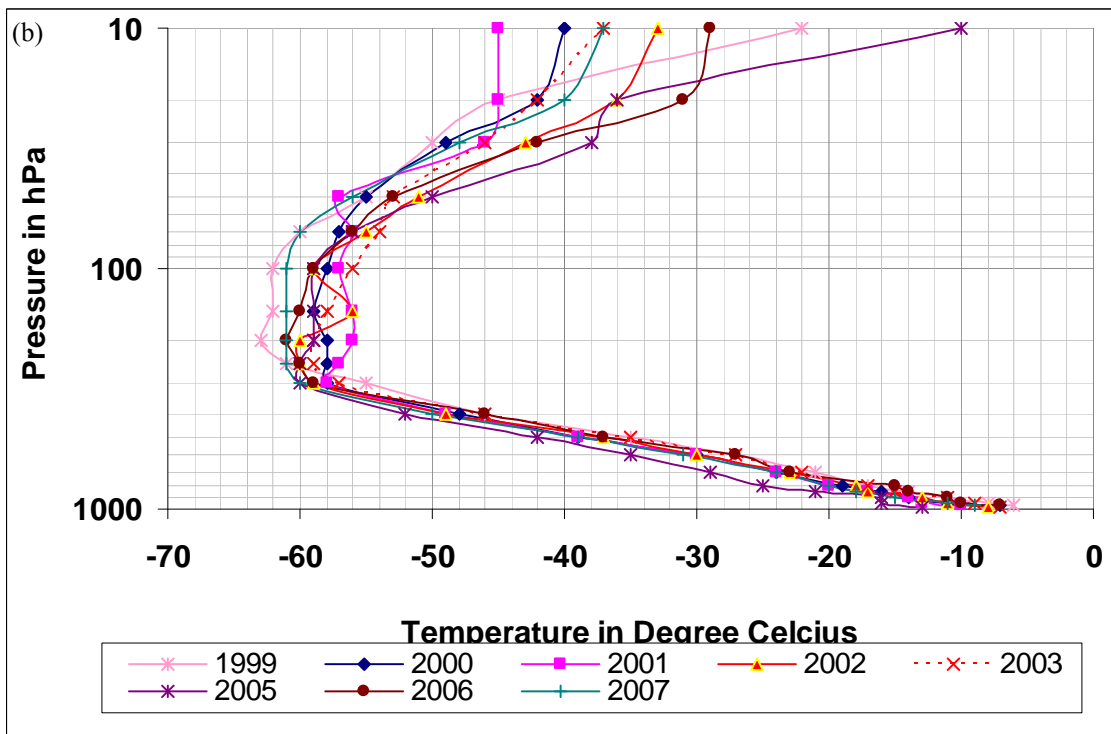
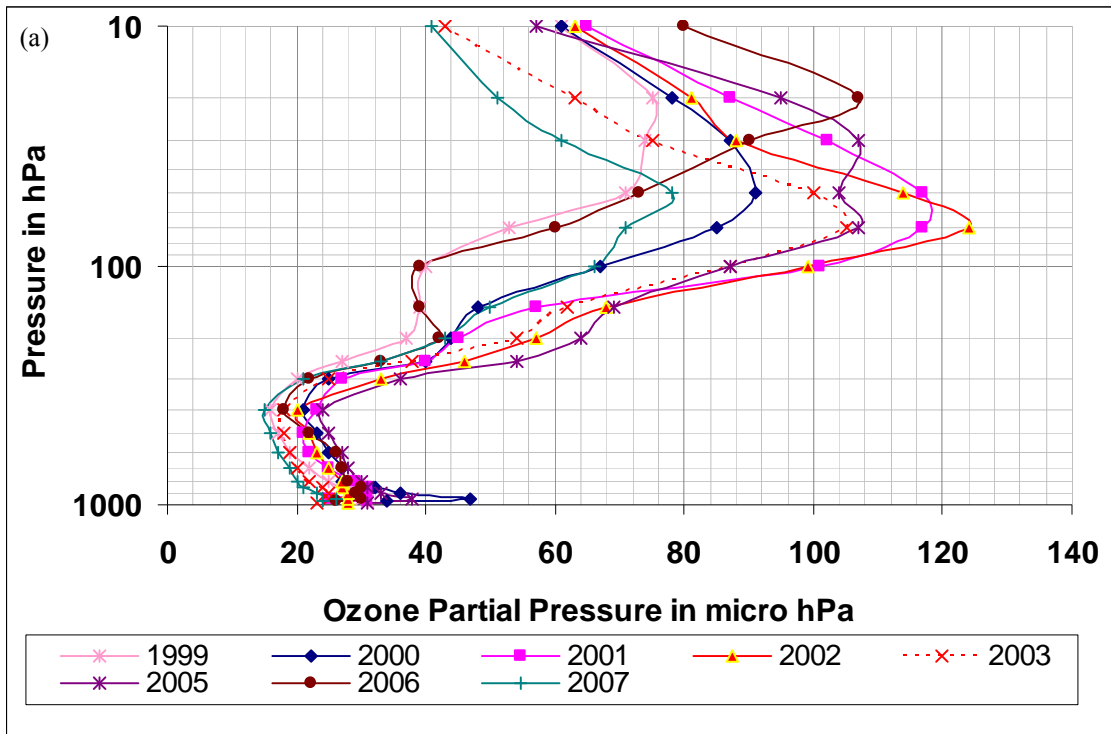


Fig. 3(a&b). Vertical distribution of (a) ozone and (b) Annual mean temperature over Schirmacher Oasis for the years 1999-2007

3. Result and discussion

The study of ozone hole phenomena has been carried out by analyzing ozone data and the mean vertical distribution of ozone concentration for the period of study has been computed and discussed in Section 3.1. The annual mean vertical distribution and its variation have been discussed in Section 3.2. The monthly mean vertical distribution of ozone and its variation have been discussed in Section 3.3. and conclusion has been given in Section 4.

3.1. Mean Vertical distribution of Ozone and Temperature

The number of ascent (observation) taken at Maitri has been shown in Table 1. This shows that during winter season fewer ascents have been taken whereas during summer the number of observation are more and then followed by spring season. The abrupt rise in wind speed and frequent blizzard is one of the reasons for lesser ascents during winter. The variation of mean ozone during the period 1999-2007 has been shown in Figs. 2(a&b). The highest (96-95 micro hPa) value of ozone concentration has been found between the 70-50 hPa levels and lowest (19 micro hPa) value of ozone concentration has been observed on 400 hPa. The ozone concentration gradually falls above 50 hPa level. The ozone increased sharply from 300 hPa whereas below 400 hPa level the gradual increase has been observed during the period of study. This shows that core of maximum ozone concentration occurs between 100-20 hPa levels and the total concentration of ozone layer has been observed between 300 hPa to 20 hPa levels during the period of study. The highest temperature was observed over the surface and then it falls upto 150 hPa level thereafter it increases slowly. The highest concentration of ozone was found at 50 hPa level whereas the lowest temperature was at 150 hPa level.

3.2. Vertical distribution of annual mean ozone and temperature

The annual mean variation of ozone and temperature has been shown in Figs. 3(a&b). This shows that lowest annual mean ozone was observed at 400 hPa level in all the years except 2001. In 2001 lowest annual mean ozone has been observed at 500 hPa level. The lowest annual mean ozone varies from 16 to 24 micro hPa in all the year. The sharp rise of ozone above 300 hPa has been observed in all the years except 2006 and in the year 2006 ozone increases sharply above 100 hPa whereas below 400 hPa level the gradual increase was observed in all the years. The peak value of maximum ozone varies between 70-20 hPa in different years. The highest value of ozone concentration of 124 micro hPa was observed in the year

2002 followed by 117 micro hPa in 2001, 107 micro hPa in 2006 & 2005, 105 micro hPa in 2003, 91 micro hPa in 2000, 78 micro hPa in 2007 and 75 micro hPa in 1999 was observed during the period of study. This shows that Peak value of maximum ozone varies between 75 to 124 micro hPa during the period of study. This further indicated that ozone depletion was more in 1999 and 2007. The lowest annual mean temperature varies from -55 to -63 °C between 300 to 50 hPa in all the years. The sharp fall in temperature above 400 hPa has been observed in all the years during period of study. It has been found that lowest temperature was observed in year 1999 followed by 2007 also these were the years when lowest annual mean ozone value was obtained. This suggests that stratospheric temperature plays major role in depletion of stratospheric ozone.

3.3. Vertical distribution of mean monthly ozone and temperature

The mean monthly vertical distribution of ozone and temperature between surface to 10 hPa level for the month of January to May has been shown in Fig. 4 (a) and for the month of July to December in Fig. 4 (b). The ozone value in month of June was found higher side at all levels because the ozonsonde observation has been normalized against the total ozone value obtained from Brewer spectrophotometer observation taken by focusing on Moon the value thus obtained is not accurate and shows abnormally high values. Therefore mean profile of the month of June has been excluded in the section. In general it has been observed that the ozone value is lesser at all levels in the month of September & October. The monthly variation between surface to 300 hPa in all months does not show large variations. It has been observed that at 300 hPa the lowest ozone concentration of 16 micro hPa was recorded in the month of August followed by September and October. From November to July it was in the range of 25 to 32 micro hPa except in April when it was 19 micro hPa. The concentration of ozone increases in all the month at 250 hPa in the range of 24 to 57 micro hPa though it was lowest in August followed by September & October and same pattern has been observed in all the months at 200 and 150 hPa.

The vertical profile indicates that maximum ozone occurs between 100 to 50 hPa levels from January to August and it reduces abruptly in October, thereafter it starts recovering in November and December. The drastic fall has been observed in the month of September, October and November at 100 hPa level. The lowest ozone was observed in the month of September and October at 100 hPa, 70 hPa & 50 hPa levels and it was higher above 50 hPa levels. The study of vertical profile indicates that maximum ozone value varies from month to

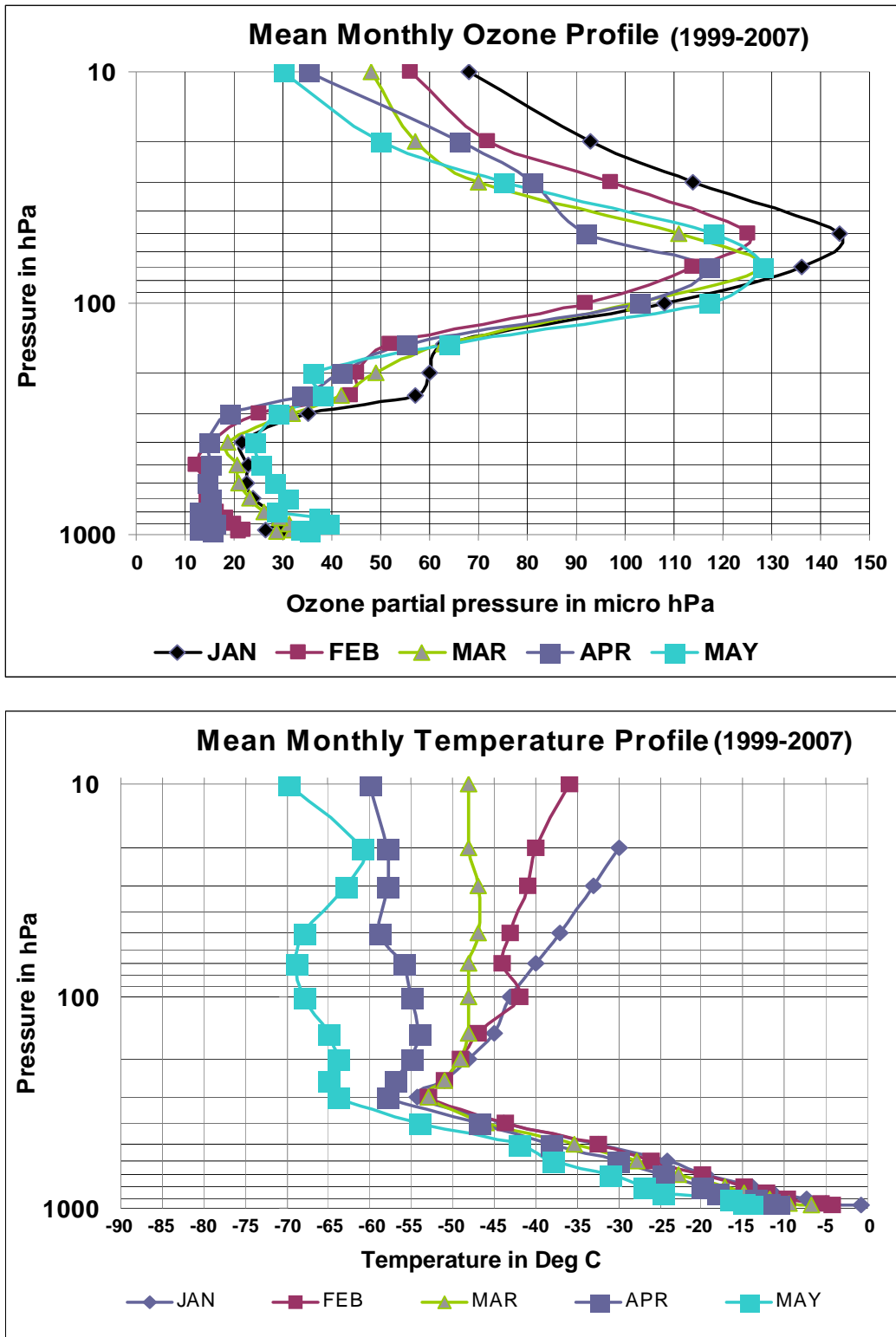


Fig.4(a). Vertical distribution of Mean Monthly (Jan-May) ozone and temperature in upper troposphere and stratosphere over Schirmacher Oasis during the period 1999-2007

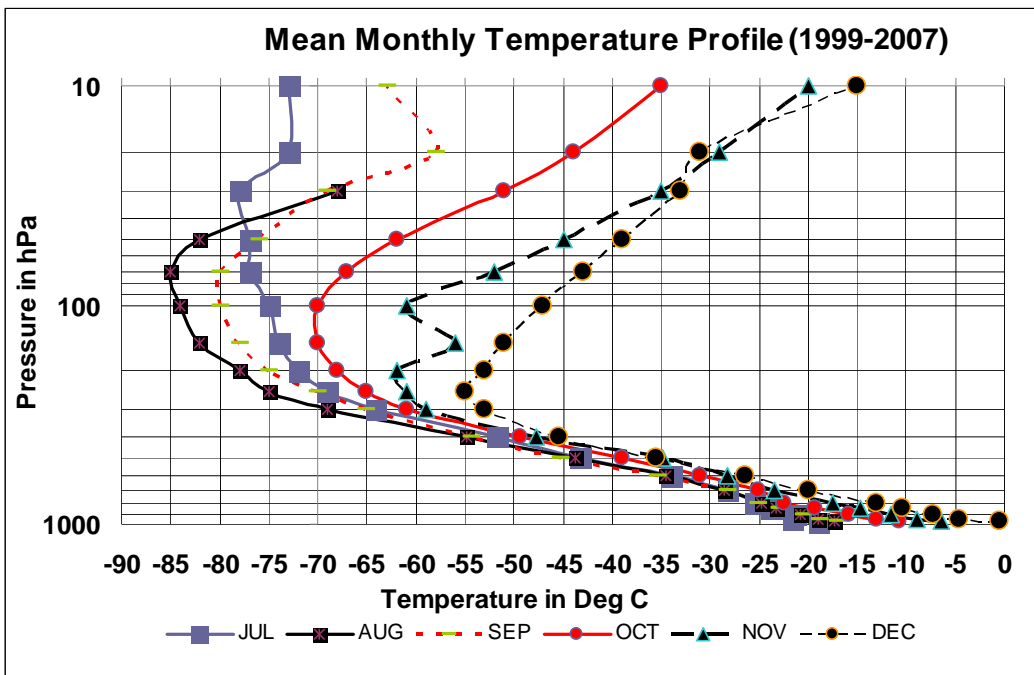
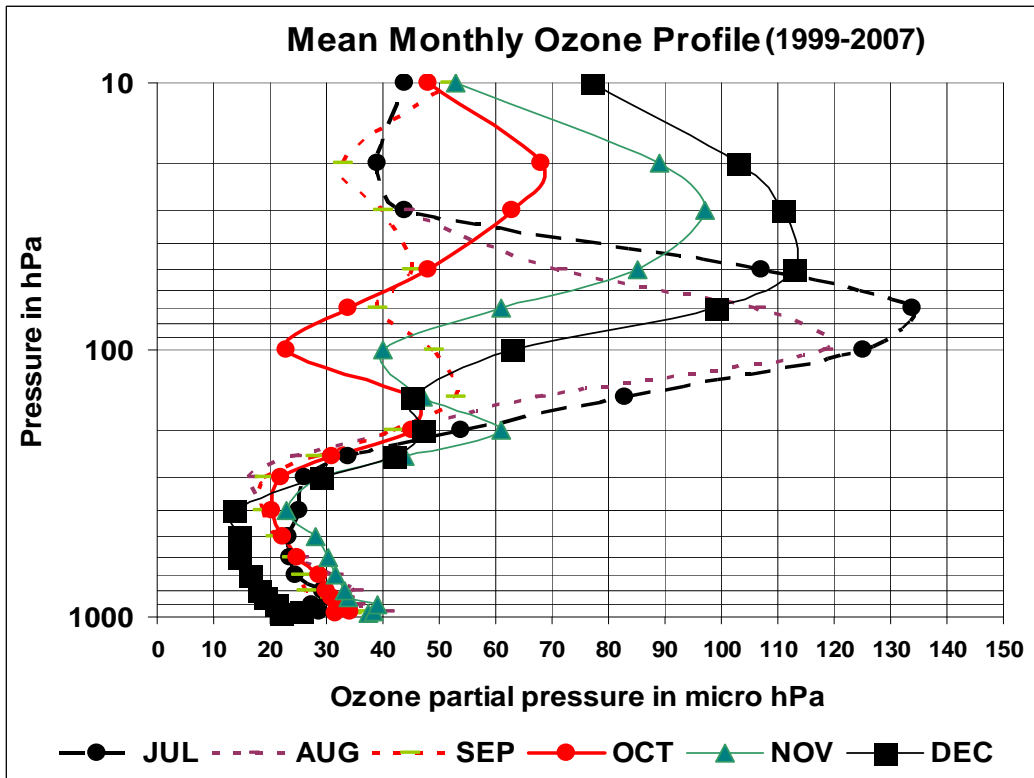


Fig.4(b). Vertical distribution of Mean Monthly (Jul-Dec) ozone and temperature in upper troposphere and stratosphere over Schirmacher Oasis during the period 1999-2007

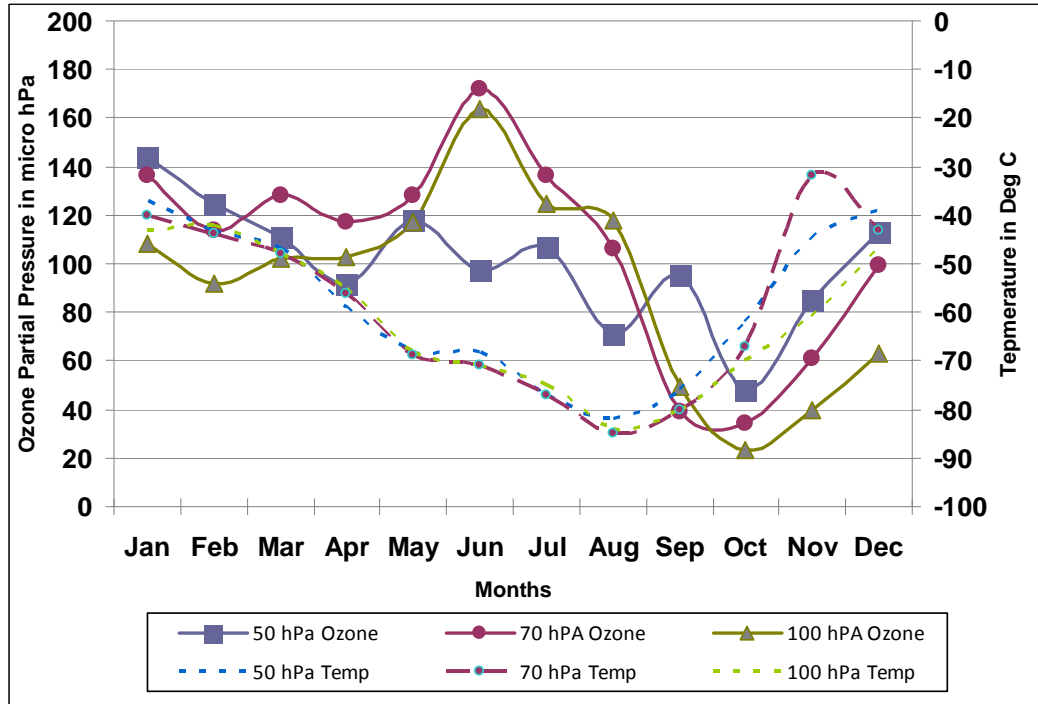


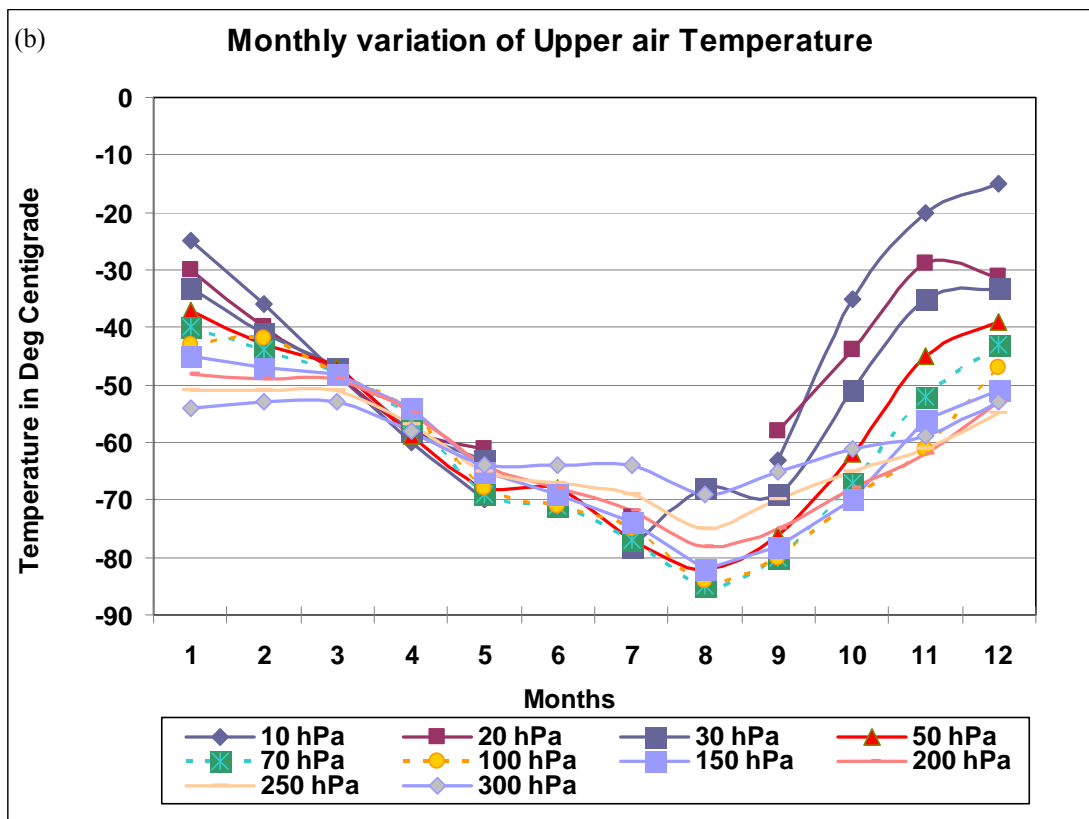
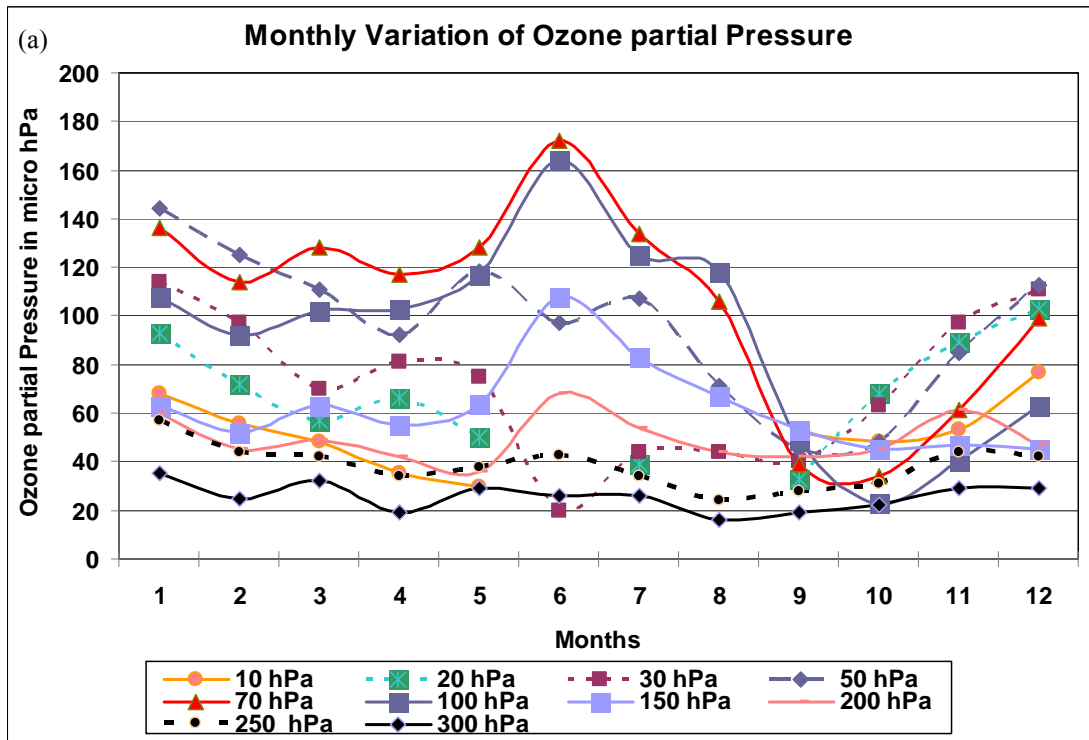
Fig. 5. Mean Monthly distribution of ozone & temperature (°C) in stratosphere (50, 70 & 100 hPa) over Schirmacher Oasis during 1999-2007

month and year to year. Except for the month of August the maximum ozone is observed between 70 and 50 hPa. In the month of August it was observed 118 micro hPa at 100 hPa. The quantitatively mean maximum concentration of ozone was observed at 50 hPa in month of January 144 micro hPa, and February 125 micro hPa. At 70 hPa in March 128 micro hPa, April 117 micro hPa, May 128 micro hPa, June 172 micro hPa, and July 134 micro hPa was observed. The ozone depletes abruptly to its lowest value of 23 micro hPa in month of October at 100 hPa.

The study of temperature profile indicates that no large variation has been observed up to 300 hPa and mean tropopause is observed around 200 hPa. Level of lowest temperature increases from January to August and lowest temperature is observed in the month of August between 70 hPa and 100 hPa. Warming of lower stratosphere starts in the month of September and warms rapidly till October and zone of lowest temperature descends between 100 and 200 hPa. The lowest temperature -85 °C was recorded in month of August. This shows that well ahead of ozone depletion temperature fall to the lowest and the lowest ozone was recorded in month of October when the temperature was in increasing with slow rate. From November temperature increases rapidly.

In general it has been observed that the upper air temperature starts falling from May to September attaining lowest in August up to 50 hPa and from October to April it shows rising trend in all levels. The observations showed that during polar night the lowest temperature was recorded. The temperature during May to September decreases from 300 hPa to 50 hPa and then it starts increasing above 50 hPa levels. The lowest temperature -85 °C was recorded in month of August at 70 hPa level. The temperature in August falls below -80 °C from 150 hPa to 50 hPa levels and in September temperature falls up to -80 °C at 100 and 70 hPa levels.

In order to study the temperature dependence of ozone depletion monthly mean values for the levels 100, 70 and 50 hPa have been plotted in the same charts as indicated in Fig. 5. Temperature and ozone partial pressure at all standard levels has been shown in Figs. 6(a&b). The values for month of June also have been taken for the sake of continuity although the values for May and June appear to be high due to normalization of ozone ascents with Brewer total ozone values observed through Moon observations. The maximum depletion of ozone was observed in month of October at 70 hPa & 100 hPa levels and in September at 70 hPa level as shown



Figs. 6(a&b). Mean Monthly distribution of (a) ozone partial pressure (micro hPa) and (b) temperature (°C) in upper troposphere and stratosphere over Schirmacher Oasis during 1999-2007

in Fig. 5. The sharp depletion from 118 to 49 micro hPa of ozone has been observed in September and then in October at 100 hPa level from 121 micro hPa it depleted to 23 micro hPa. The depletion of ozone was almost 100 micro hPa from the value of ozone in July and August at 100 hPa level. Similar depletion pattern has been observed at 70 hPa level in month of September and October. The depletion of ozone has also been observed in month of September and October at 50 hPa level but the rate of depletion is very less. Ozone starts increasing from the month of November in all levels. The depletion of ozone in month of September and October at 50 hPa to 100 hPa is significantly related with the temperature at these levels in months of August. The temperature of the order of -85°C has been observed in months of August at 70 hPa & 100 hPa levels. It slightly increases to -80°C in month of September and about -70°C in month of October at 70 hPa & 100 hPa levels. The temperature falls below -80°C in months of August at 150 hPa level have also been observed.

4. Conclusion

The ozonesonde observations taken at Maitri, Antarctica, during 1999 to 2007 have shown profound depletion in ozone partial pressure in the month of October and lesser but substantial depletion in September. Depletion is most pronounced between about 250 and 20 hPa in October, with maximum local ozone losses near 70 hPa & 100 hPa levels and in September at 70 hPa. In these altitudes temperature-dependent polar stratospheric chemistry involving chlorine is most effective for depleting ozone, our observations also support it. The data also suggest that ozone-depleted air is transported down to altitudes close to the tropopause on a timescale of a few months. The lowest annual mean ozone was observed at 400 hPa level and it varies from 16 to 24 micro hPa in all the years. The maximum ozone lies between 70-20 hPa. During the period of study its value varied between 75 to 124 micro hPa in all the years.

The effects of changes in ozone depletion due to variations in temperature are also apparent from year-to-year and from sounding-to-sounding. Lowest annual mean temperature varies from -55 to -63°C between 300 to 50 hPa in all the year. While the springtime stratosphere of 2002 was especially warm and the ozone could not be depleted much of that. The years 2001, 2003 and 2005 has also been characterized by warmer temperatures and less ozone loss whereas the ozone depletion was more in 1999 and 2007 as the lowest temperature was observed in 1999 and 2007. This show that fall of temperature is one of the reasons of ozone depletion. The ozone depleted abruptly

to its lowest value (23 micro hPa) in month of October and the lowest temperature -85°C was recorded in month of August which shows that well ahead of ozone depletion temperature falls to the lowest. The temperature less than -80°C in months of August & September at 70 hPa & 100 hPa levels and about -70°C in month of October at 70 hPa & 100 hPa levels can be attributed as an indicator of ozone depletion in months of October.

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