A STATISTICAL ANALYSIS OF OZONE VARIATIONS AT THE UPPER TROPOSPHERE AND LOWER STARATOSPHERE IN THE INDIAN REGION

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ABSTRACT: The difference in Upper Troposphere and Lower Stratosphere (UTLS) ozone over the tropical and subtropical Indian regions and simultaneous variations of other parameters like divergence, vertical velocity, cloud cover, temperature and geo-potential are examined to understand the dynamics in ozone concentrations at the UTLS. Annual as well as monsoon time averaged plots are constructed to study inter annual fluctuations of ozone and corresponding changes in temperature. It is found that the divergence, vertical velocity and cloud cover exhibit higher values in tropical region during summer monsoon. This indicates influence of monsoon heating on UTLS ozone in the subtropical Indian region. Further the seasonal variations of UTLS ozone may be ascribed to the lifting of the boundary layer air with low ozone to UTLS heights by monsoon updrafts.

Keywords: Ozone, Inter annual fluctuations, divergence, cloud cover, geo-potential, potential vorticity.

I.INTRODUCTION

The upper troposphere lower stratosphere (UTLS) region is a very important interface for the transport of trace gas constituents from stratosphere to troposphere and in the opposite direction. This region which is associated with the large gradients of various atmospheric parameters such as temperature, ozone, water vapor plays a vital role in dynamics of both stratosphere and troposphere. (Rao et al., 2006). Understanding the dynamical processes and chemical composition of this region is vital to quantify the concentration of tropospheric ozone (Lelieveld and Dentener, 2000; Liang et al., 2008). In the tropical regions UTLS is the location where long lived natural and manmade trace gas species are lifted by deep convection in the upper troposphere and then into the stratosphere using the tropical tropopause layer. Hence this deep convection can help to recognize the upward transport of many anthropogenic pollutants into the stratosphere like CFCs that eventually reaches higher latitudes (Murphy and Fahey, 1994).

Ozone variation appears to be determined largely by the zonal variation of vertical convective transport of air from the surface. (Pommereau et al., 2004). It is important to study the composition of the atmosphere at the location where the air enters the stratosphere before it is transported to poles. (Dix et al., 2004). The tropical UTLS is a highly dynamic region dominated by transport and in situ chemical processes. Major aspects controlling the UTLS ozone content are photochemical reactions, stratospheric intrusions, deep convection and in-situ chemistry. (Sembhi and Remedios, 2004).

Seasonal drift in the subtropical jet can in fact change the vertical distribution of ozone and other chemicals (Cuevas et al., 2007). Ozone in the UTLS region has a significant role in global climate by regulating the photochemistry and radiation balance process (Yang, 1995, Chen et al. 2010). The overall variation in total ozone is also found to be correlated with the variation in UTLS ozone. The link between UTLS ozone and temperature is very significant in determining the radiative budget of the stratosphere.

Stratosphere- troposphere exchange through this subtropical tropopause break will ordinarily be inhibited by strong potential vorticity (PV) gradients between the troposphere and stratosphere. The subtropical tropopause is also poorly characterised from a chemical point of view (Folkins and Appenzeller, 1996). The objective of this paper is to identify the differences in UTLS ozone over the tropical and subtropical Indian region. An attempt also has been made to analyze the simultaneous variation of the chemical and thermal tropopause of these two regions.

II.DATA AND METHODOLOGY

Ozone mixing ratio from 1979 to 2018 and concurrent parameters like divergence, cloud cover, vertical velocity, potential vorticity, and temperature and geo-potential height for pressure levels from 300 to 100hPa are obtained from ECMWF Interim dataset. Time pressure plots were constructed for 300 to 100 hPa for divergence and 100-200 hPa for other parameters to study the seasonal and daily variation concurrent with ozone in the UTLS levels. The tropopause height data was retrieved from NCEP reanalysis. Simultaneous seasonal variations of the other parameters were also determined to understand the effect of dynamics in ozone concentrations at the UTLS. Time series of tropopause height were plotted to examine the coincident variations with ozone. Annual as well monsoon time averaged plots were constructed to have knowledge of inter annual variations of ozone and corresponding changes in temperature.

ERA Interim data for two locations, Trivandrum and New Delhi, were taken and analyzed to examine the tropopause variations in the tropical and subtropical Indian region. The World Ozone and Ultraviolet Data Centre (WOUDC) ozone profile measurements have been converted from partial pressures in milli-pascals (which is an absolute unit of ozone measurement) to volume mixing ratio in parts per million volume (which is a relative unit). This is done in order to avoid the effects due to changes incompressibility of the atmosphere. Heights of upper tropospheric ozone minimum for the ozone profiles were determined by finding the altitude of minimum ozone concentration between 400 and 100 hPa. Ozone gradient tropopause is determined by taking the base of the layer in which the ozone increases by 0.1ppmv or more from the layer below.

Lapse rate tropopause is also computed in a similar manner –as the base of the layer in which the lapse rate is more than 2K/km. Cold point tropopause is obtained by taking the altitude of the lowest temperature in the 300 to 70 hPa layer.

III.RESULTS AND DISCUSSION

Seasonal variation of ozone over UTLS region

By analyzing the relation between the total ozone and ozone at each vertical layer it can be observed that UTLS ozone is playing a significant role in total ozone variability. The seasonal variation of ozone in the 100 to 200 hPa for the region from 0°N to 20°N and60°E to 100°E is shown in Fig.1.1. The values vary from 1 x10-7 to 2 x10-7. The 100-125hPa layers show higher ozone levels during summer season. Ozone concentration starts increasing from the middle of April and reaches peak values of the year during July. An increase of about 1.4x10-7 is observed during the summer season compared to the winter season. This increase may be due to the lowering of tropical tropopause during boreal summer.

The time pressure height plot given in Fig.1.2 shows the seasonal variation of 100-200hPa ozone mixing ratios for the region from 20 to 40°N.The overall ozone amount is higher than that of the tropical region with values ranging from 1 to 7x10-7. Here ozone values are more during winter season. Higher concentrations of ozone are observed during January to April. The highest values are observed during February. The increase in the ozone can be closely linked to tropopause heights. Thus it can be deduced that the ozone concentrations at the tropical tropopause region is dominated by the lowering of tropopause region during summer. This is caused by the increase in the depth of the stratosphere due to increasing temperature during the summer season. But in the subtropical Indian region the upward transport of boundary layer air with low ozone amounts by convection is the dominating mechanism in determining the near tropopause concentration of ozone.

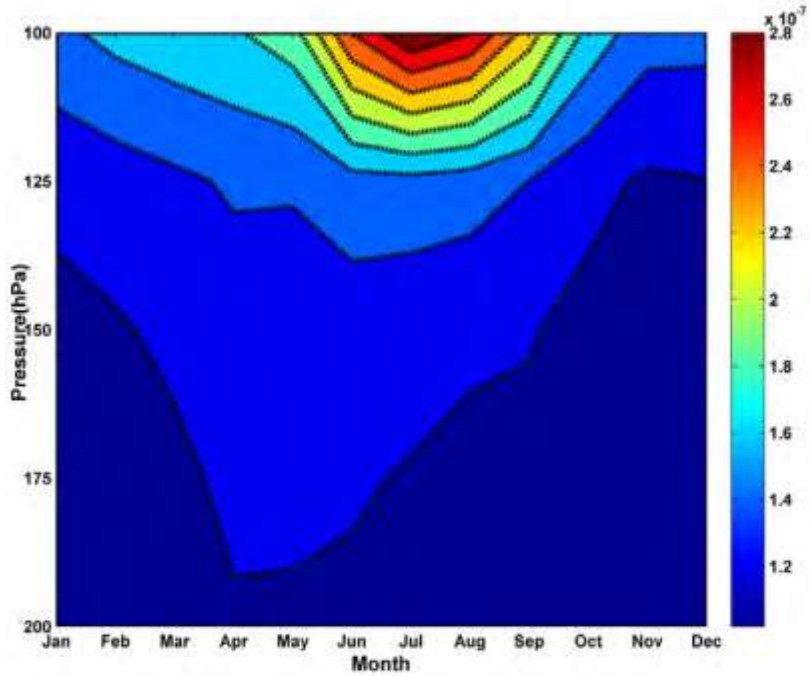


Fig.1.1.Seasonal variation of ozone mixing ratio (kg/kg) in 100- 200 hPa layer for 0°N to 20°Nand 60°E to 100°N.

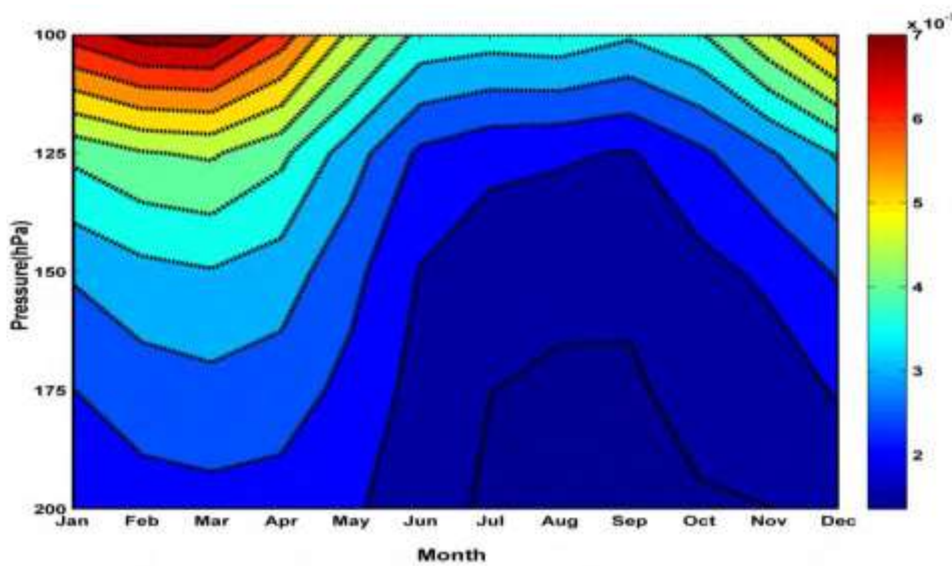


Fig .1.2. Seasonal variation of ozone mixing ratios (kg/kg)in 100-200 hPa layer for 20°N to 40°N and 60°E to 100°N.

Daily variations of UTLS ozone averaged from 1979-2018 at the tropical station-Trivandrum (Figure 1.3) and subtropical station-New Delhi (Figure 1.4) were also analyzed to have a better understanding of the variations. Comparing the diurnal ozone mixing ratios of Trivandrum and New Delhi the increase of ozone in the 100-125 hPa layers occur in summer for Trivandrum and in winter for New Delhi. The summer time increase over Trivandrum appears to be more organized. New Delhi is not showing similar increase during summer time. The winter time increase over New Delhi appears to be taking place as individual events of varying intensity and depth.

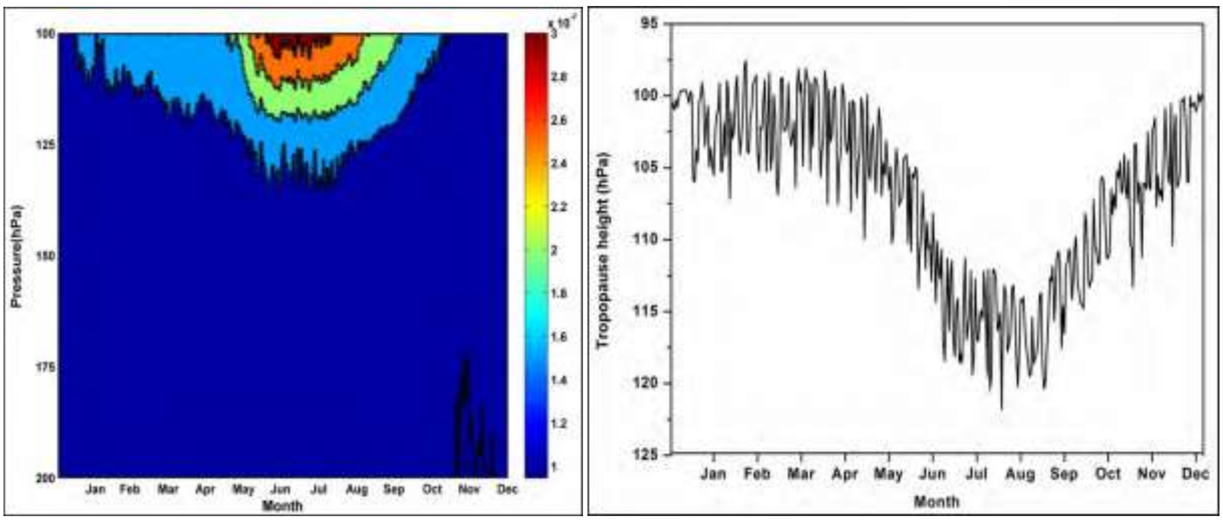


Fig .1.3. Seasonal variation of (a) ozone mass mixing ratio in 100-200 hPa layer and (b)tropopause height for Trivandrum (8.48°N,76.95°E).

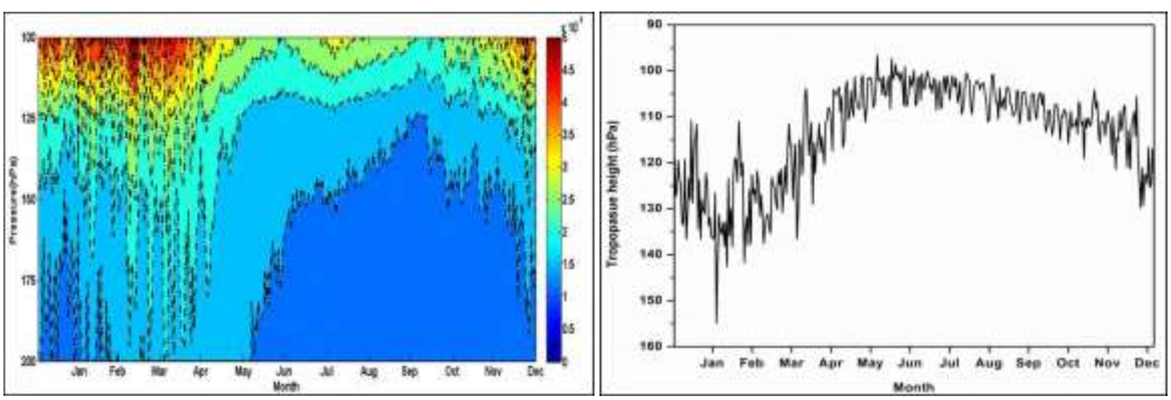


Fig .1.4. Seasonal variation of (a) ozone mass mixing ratio in 100-200 hPa layer and (b)tropopause height for New Delhi (28.3°N, 77.1°E)

The increases in ozone mixing ratio during winter can happen due to the passage of upper tropospheric troughs from middle latitudes during northern hemispheric winter (Singh,1979). The upper tropospheric westerlies of mid latitudes shift southward during northern hemispheric winter. These waves develop into large amplitude north-south oriented troughs that can penetrate deep into South Asia (Sathyamoorthy, 2001). The passage of this upper tropospheric troughs causes the lowering of tropopause height and hence an increase of ozone concentrations in the UTLS region. The effect on tropopause by the passage of a trough or ridge is demonstrated in Fig.1.5.The decrease of UTLS ozone over New Delhi (Fig.1.4) during summer can be due to convection during summer monsoon and vertical transport can be attributed to gravity waves. (Pierce and Grant, 1998). It is established the deep convection plays a major role in the vertical transport of chemical species from the lower troposphere to the upper troposphere (Wanand Prinn, 2000; Mari et al. 2003; DeCaria et al., 2005). From both the figures it is evident that the ozone mixing ratios are increasing with the tropopause heights

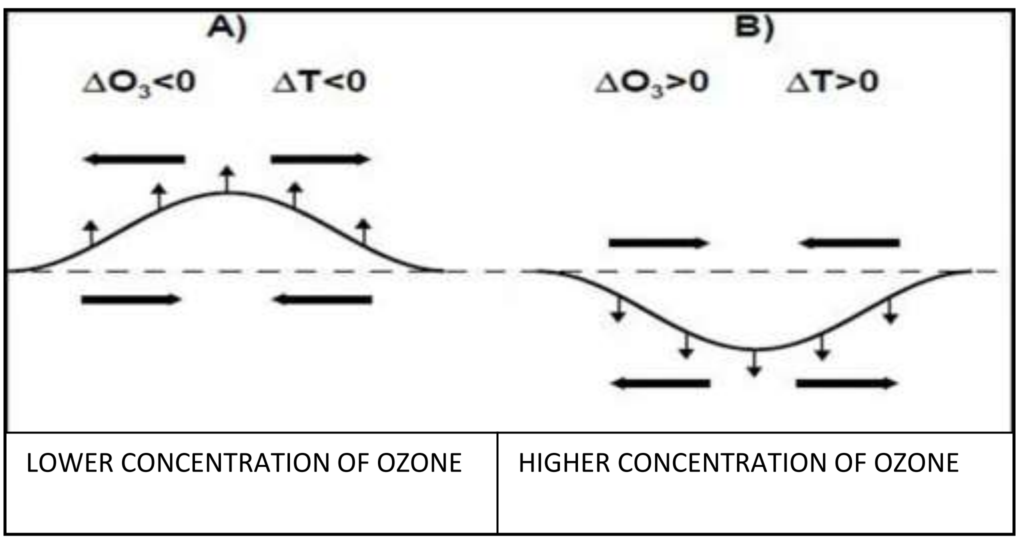


Fig. 1.5 Schematic picture showing changes in ozone and temperature associated with the passage of (a) a ridge and (b) a trough.

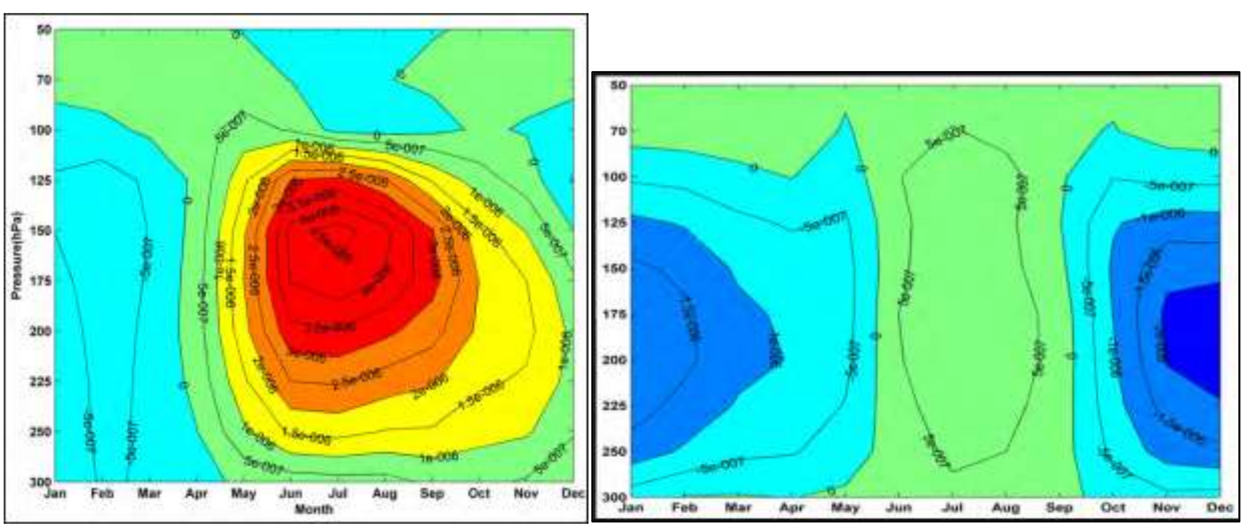
In order to inspect the role and nature of circulation in the ozone distribution over various seasons, various parameters that represent the circulation pattern over the region were examined. Fig.1.6.(a) shows the divergence of the layers from 300 to 50 hPa for 0°N to20°N. The maximum observed at 125 to 200 hPa region can be due to upper level divergence associated with monsoon circulation. The region above 100 hPa during summer season shows a slight negative value of divergence i.e. convergence in the region and the time of ozone increase occurs. But for fig.1.6.

(b) (20-40°N) the entire depth of the region shows slight positive values of divergence, this divergence points to the circulation that uplifts the air (or tropopause and hence ozone upwards).

Figures.1.6(c) and (d). represent the seasonal climatological distribution of cloud cover over the Indian region from 0 to 20°N and 20 to 40°N. Cloud cover is expressed in the 0 to 1range with zero representing no cloud and 1 representing full cloud cover. The tropical Indian region exhibits a high amount of cloud cover in the 100-200 hPa level compared to the subtropical Indian region. Cloud cover is full during the monsoon season. From figures 1.2 and 1.4 it is observed that the seasonal decrease of ozone in the monsoon season occurs at a time where the full cloud cover occurs in the Subtropical Indian region. However over the tropics the ozone variations in UTLS is not showing any concurrence with cloud cover.

Meteorological parameters at the UTLS region

Climatological variation of vertical velocity for both the tropical and subtropical region is represented in Figure 1.7. (a) and (b) Negative values of vertical velocity denotes ascent whereas the positive values indicates descent. Elevated values of negative vertical velocity can be observed from spring to autumn season over the tropical region. These are the periods of the equinoxes and summer solstice for northern hemisphere. Minor positive values of vertical velocity denoting descent and hence the ozone increase can be observed during June to September near 100 hPa over a very small area in tropical Indian region.



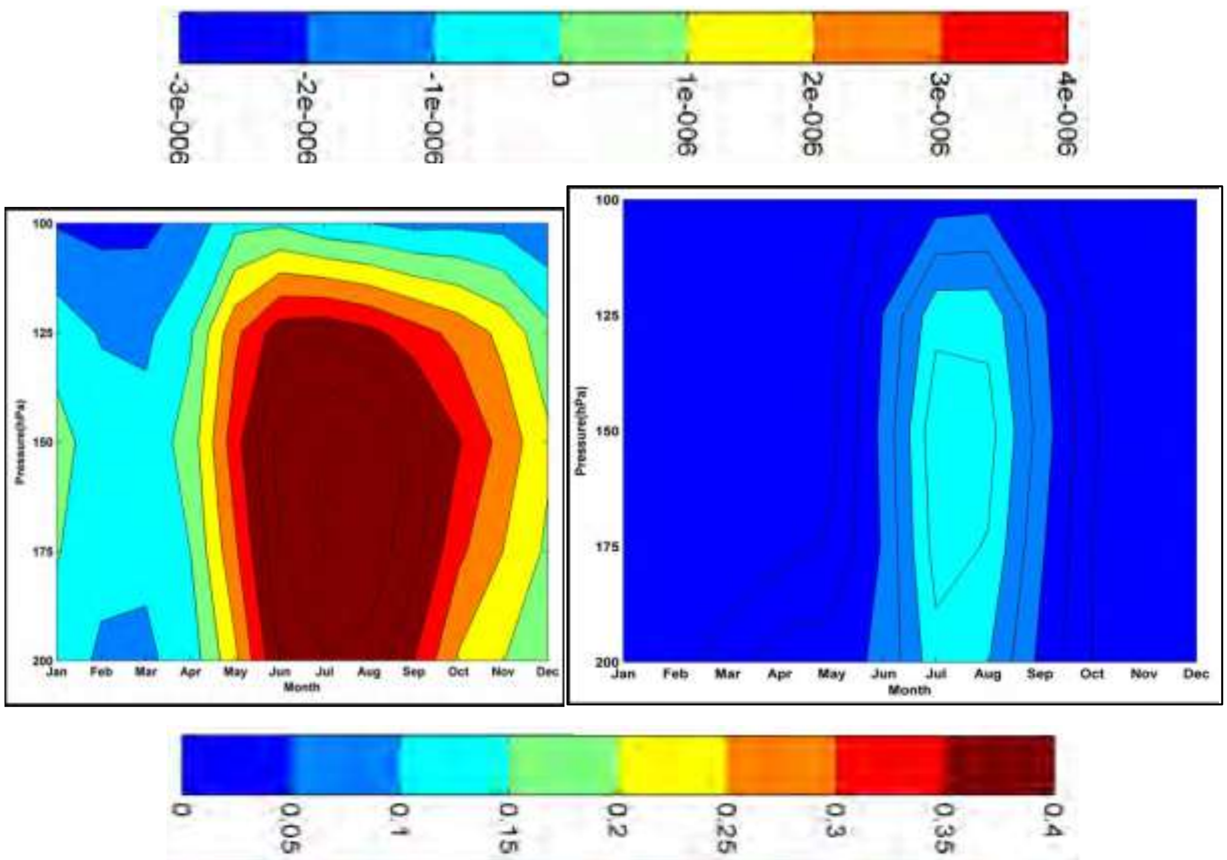


Fig.1.6. Seasonal variation of Divergence (s-1) for 300 to 50 hPa (top) for 0 to 20°N (a) and 20 to40°N(b) and cloud cover 200 to 100 hPa (bottom) for 0 to 20°N(c) and 20 to 40°N(d).

For the subtropical region peak values of vertical velocity occurs only during monsoon season in the UTLS region. Highest values (blue color) of vertical velocity crosses more heights compared to that of the tropical region. This occurs during the peak monsoon months. Descending of air can be observed throughout other season in the same areas of high ozone. This reflects the occurrence of stratospheric intrusion during winter and spring months.

(a) 0-20 °N (b) 20-40 °N

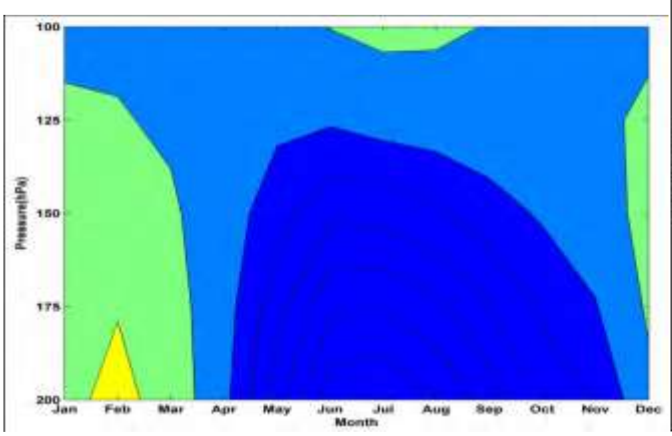
(c) 0-20 °N

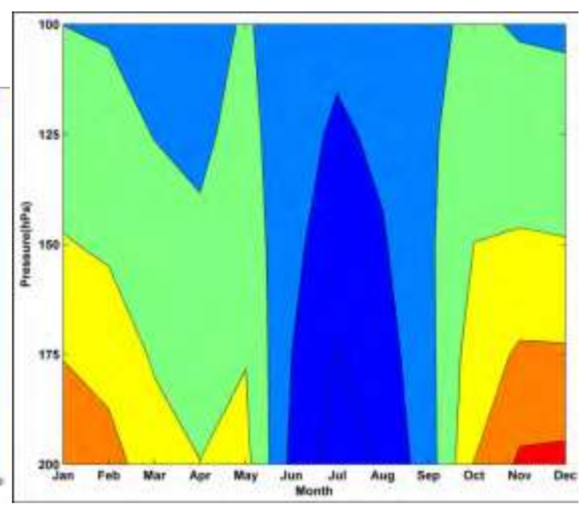
(d) 20-40 °N

Potential vorticity of both the tropical and subtropical region are given in Figures 1.7.(c)and (d). Values of potential vorticity can be used to distinguish between the air of stratospheric and tropospheric origin. Dynamical tropopause is considered as the atmospheric layer that coincides with 2 PVU (Potential Vorticity Unit- 1 PVU=10−6Kkg−1 m2 s−1). Ozone mixing ratios together with its maps can give information about the dynamical processes leading to ozone variations (Hoskins, 1995). The structure of variations for both the latitude regions reflects the variation of the tropopause height. Values as high as 6.5 PVU can be observed in the region between 100 and 125 hPa during winter and spring.

Seasonal variation of temperature from 200-100 hPa is depicted in Figures 1.8 (a) and (b).In the tropical upper troposphere from 200-125 hPa there is very little seasonal variation in the temperature. But there is a noticeable increase in the 125-100 hPa layer from June to September. This is similar in magnitude and span with the seasonal ozone variations observed during summer season over the same region (Fig.1.1 and 1.3). The slight increase in temperature observed from March to October near 200 hPa has no correlation with the ozone variations.

As shown in the fig. 1.8 area seasonal fluctuations of temperature are comparatively high. The 125-100 hPa layer shows lower values of ozone from March to November with the lowest values from June to September which the time of seasonal decrease of ozone over the region. Also higher temperatures can be seen at the time of ozone increase over the subtropical region. From the two figures it can be seen that seasonal high temperature exists in the 100-125 hPa region at the time of seasonal increase of ozone in0-20°N Indian region. Also a seasonal low temperature prevails at the time of ozone decrease in the 20-40°N region. Geo-potential of both the latitude regions is given in figure 1.8. (c) and (d). Seasonal fluctuation seems to be nil for the tropical region. In the subtropical region downward movement of geo-potential surfaces can be observed at the time ozone decrease in the upper tropospheric region.





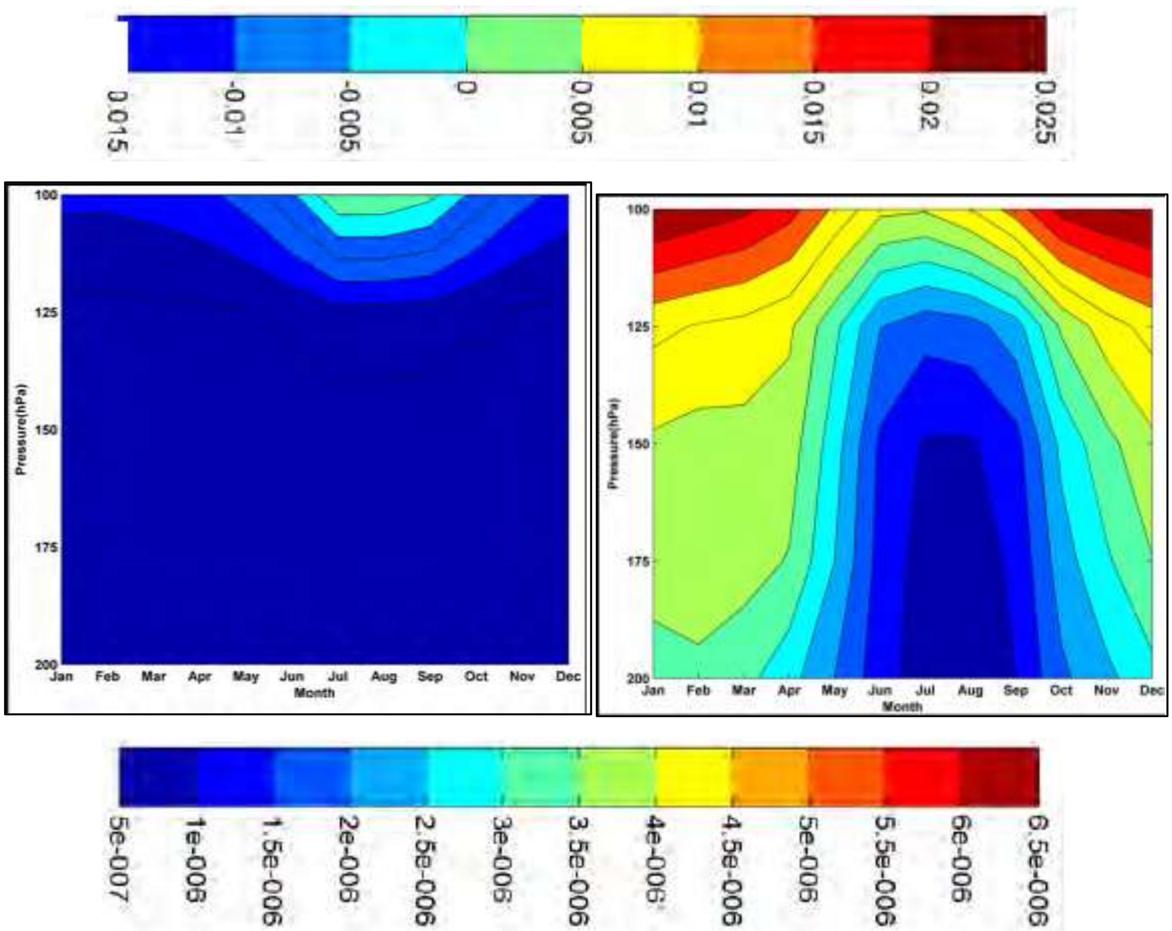
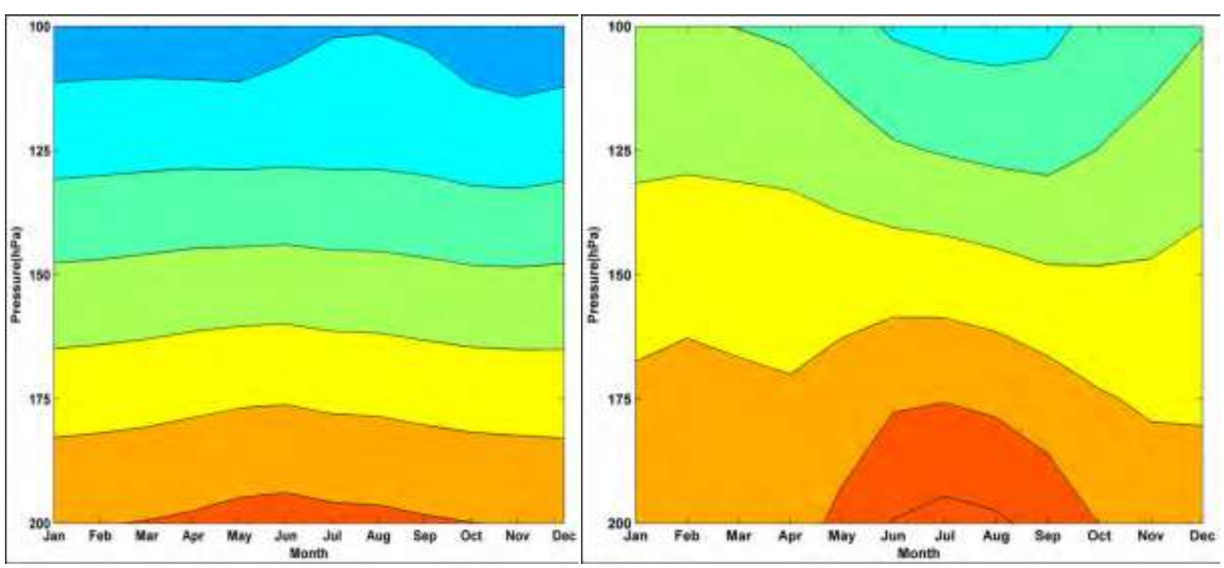


Fig.1.7. Seasonal variation of vertical velocity (Pa s-1)(top) and potential vorticity(K m2 kg^{-1} s^{-1}) (bottom) for the pressure levels from 200 to 100 hPa for the latitude region (a and c) 0 to 20°N and (b and d)20 to 40°N and longitude 60 to 100°E.



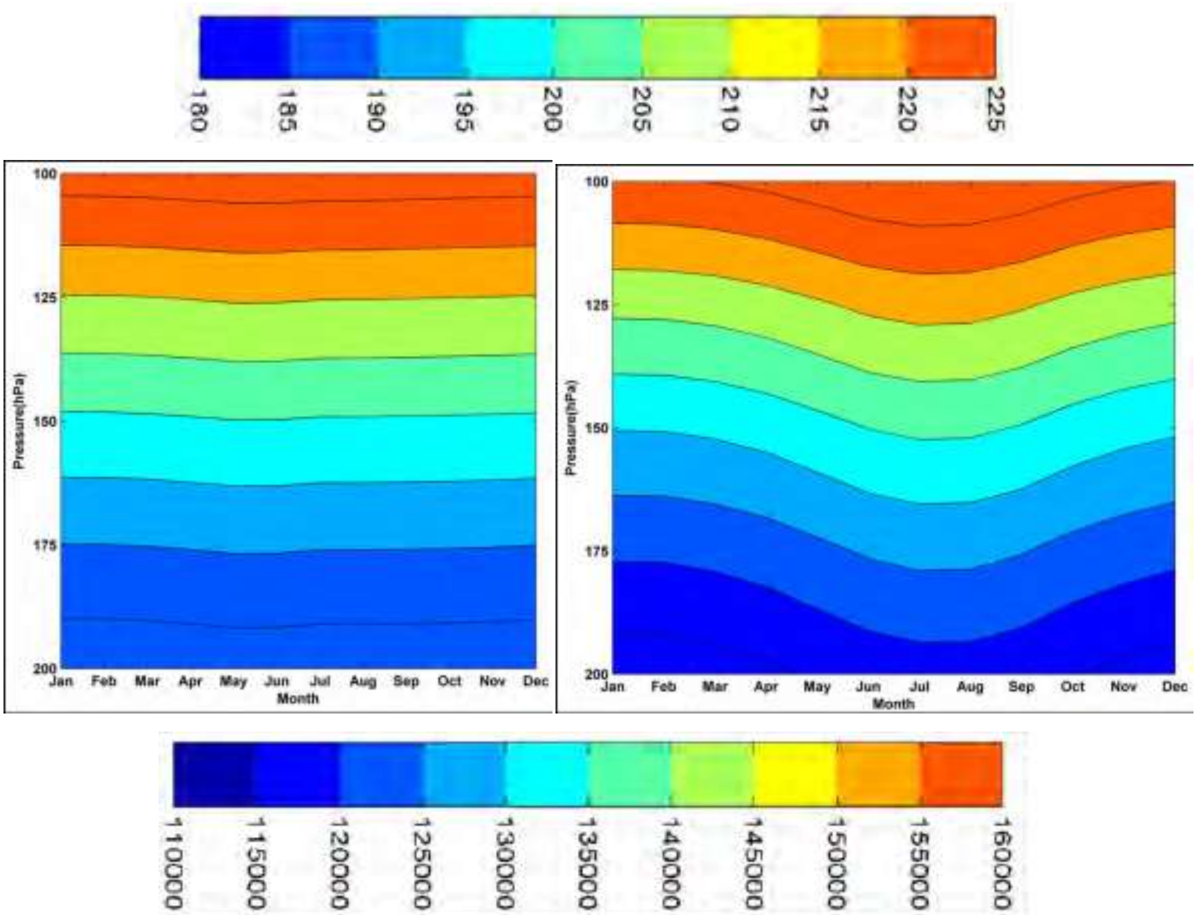


Fig.1.8. Seasonal variation of temperature (K) (top) and geo-potential height (m2 s-2) (bottom) for the pressure levels from 200 to 100 hPa for the latitude region (a and c) 0 to 20°N and (b and d)20 to 40°N and longitude 60 to 100°E.

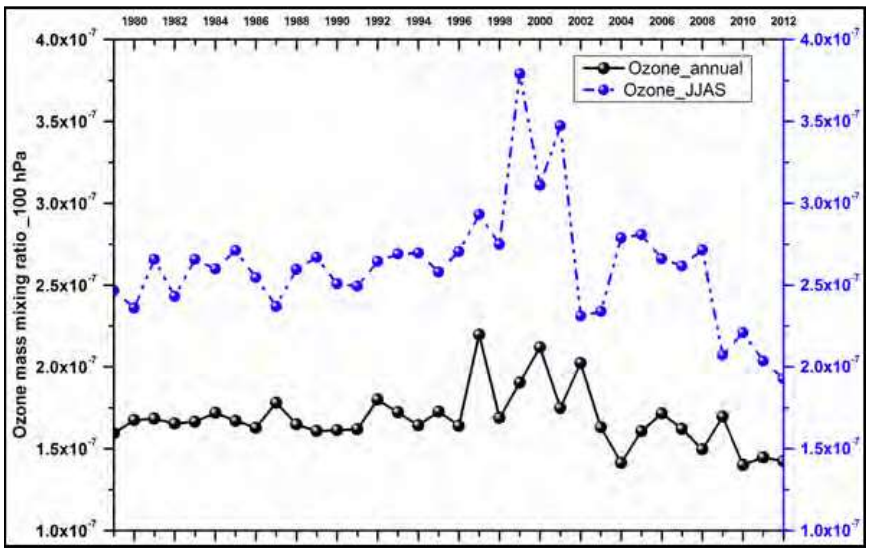
Near tropopause ozone variation at the tropical and subtropical region

To know the effect of monsoon on ozone in near tropopause inter annual variations of 100hPa ozone data for the tropical Indian region and subtropical region are studied from annual and monsoon averages. And we are represented in fig 1.9.

From the fig 1.9(a) it can be seen that the average monsoon time ozone amount is higher than annual average in the tropical near tropopause region. During monsoon region the amplitude of inter annual fluctuations are found to be large. Maximum amplitude of inter annual fluctuations of annual average values vary from 1.5×10-7 to2.25×10-7 kg/kg and that of monsoon average is from 2×10-7 to3.75×10-7kg/kg. It can be also noticed that the variations during 1998 to 2002 is large with peak values in 1999 and 2001.

In subtropical region the annual average of ozone are higher than that of monsoon average as can be seen from fig.1.9 (b). For subtropical region and annual average varies between 5×10-7 to 8.5×10-7kg/kg and monsoon average is from 2.5×10-7 to 5×10-7kg/kg.

The large variations in the tropical region may be the effect of large variations of 100hPa ozone in summer season during the same period as similar to fig1.8. However in the subtropical region the higher annual average of ozone clearly indicates the absence or less influence of summer season variation on the total ozone values in the near tropopause region. Influence of wave activity on winter time ozone concentration may be the reason for the comparatively less influence of summer time ozone values on the annual average.



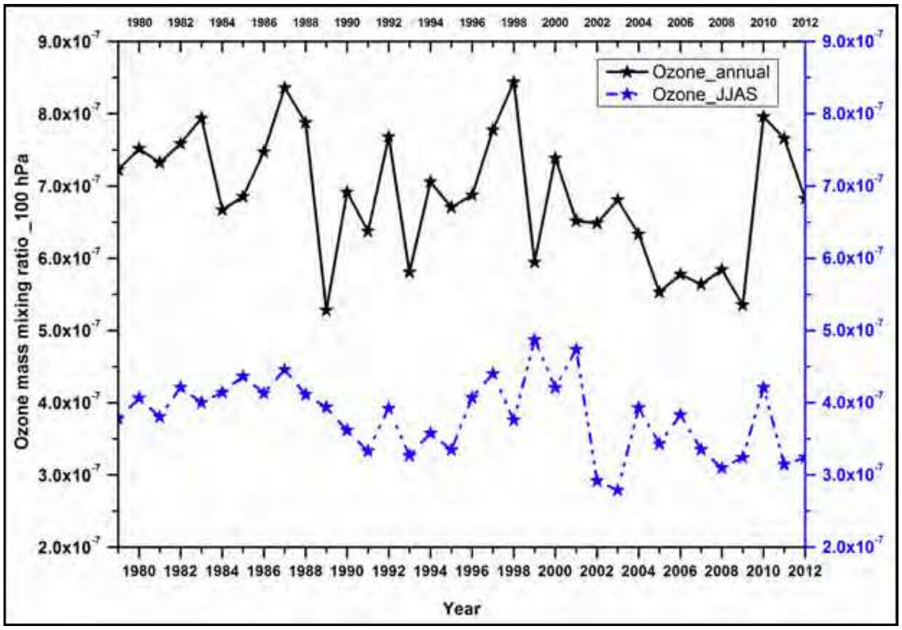


Fig.1.9. Inter annual variation of near tropopause (100 hPa) ozone over (a) tropical and (b) subtropical region. Solid black lines indicate annual average and dashed blue lines indicate monsoon season average.

IV.CONCLUSIONS

From the analysis of seasonal variations and diurnal variations of UTLS ozone at tropical and subtropical (Trivandrum and New Delhi) Indian regions following conclusions can be drawn.

The seasonal variation of ozone is in accordance with the variation of tropopause height for both regions. In summer the tropical region is showing an increase of ozone near the 100hPa during which lowering of tropopause occurs. Also analysis of inter annual fluctuations in the tropical near tropopause region can be notice that the variations during 1998 to 2002 is large with peak values in 1999 to 2001.

Over the subtropical region the ozone is showing lowest values in the entire 200-100hPa. A sharp over shooting of low ozone values in the tropopause and above is visible in the peak monsoon months.

During winter season increase of UTLS ozone occurs sporadically. This can be attributed to the passage of upper tropospheric troughs from middle latitudes over the region which causes the lowering of the tropopause and more intrusion of ozone in the upper tropospheric region.

Various other parameters like divergence, vertical velocity, cloud cover, temperature, geo-potential and potential vorticity over the UTLS region are analyzed. Divergence, vertical velocity and cloud cover are found to have higher values in tropical region during summer and monsoons. In subtropical region it is observed that the variations of ozone are closely following the structure of variations of these parameters, even though the variations are small. This shows the high influence of monsoon heating on UTLS ozone in the subtropical Indian region. Thus the influence of monsoon heating on UTLS ozone is more in the subtropical Indian region. Also the seasonal decrease can be ascribed to the lifting boundary layer air with low ozone to UTLS heights by monsoon updrafts. On the tropical UTLS ozone no significant variations in geo-potential are observed. It is as observed that the seasonal variations of potential vorticity are closely following that of UTLS ozone.

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