6.1 Introduction

Total ozone distribution in the Northern Hemisphere exhibits wide range of temporal and spatial variability. Large-scale ozone anomalies of interannual timescales caused by APW were documented in the previous chapter. It is well known that the total column ozone undergoes substantial short-term fluctuations, which correlate closely to the passage of synoptic weather systems (Dobson et al., 1929). Later Reed (1950) showed that these fluctuations were part of the synoptic scale regions of depleted ozone which were advected under the influence of tropospheric dynamics and exhibited growth and decay on a time scale of a few days. These transient regions of strongly depleted total ozone were referred as *Ozone mini-holes* (Newman, et al., 1988; Mc Kenna et al., 1989). Ozone mini-holes are formed by the horizontal advection of ozone-poor airmass from tropical region to the extratropics and ascent across the tropopause region resulting in divergence of ozone-rich stratospheric air out of the column (James et al., 1997; James et al., 2000). In the region of ozone mini-holes, total ozone amounts may fall by over 100 DU in a couple of days. Petzoldt et al., (1994) and Petzoldt (1999) have shown case studies of exceptionally deep mini-ozone holes that occurred over northern Europe during stratospheric warming. Ozone mini-hole events frequently appear in the Northern Hemispheric mid and high latitudes.

In tropics and mid-latitudes, synoptic scale ozone-rich regions are associated with synoptic scale weather systems. These ozone-rich regions form due to the advection of ozone-rich airmass from higher latitudes to lower latitudes and lowering of tropopause over synoptic scale wave troughs. They also exhibit growth and decay over a few days.

Number of synoptic scale total ozone anomaly events caused by meteorological disturbances is low in the tropics compared to the extratropics. Because of this reason, fewer studies have been made about such ozone variabilites in the tropics especially in Asia. On occasions, remnants of extratropical cyclones and upper tropospheric troughs/ridges, reach tropical Asia (even very close to equator). One such long wave is seen as Upper Tropospheric Trough (UTT) in zonal westerly winds during winter season in tropical Asia and another one as Upper Tropospheric Blocking High and Trough (UTBHT) pattern in summer. Although their circulation characteristics and associated rainfall activity have been studied in detail, relatively less importance has been paid to the total ozone variations associated with them. Since these two waves are present around the tropopause level, they are expected to generate large ozone anomalies by variations of the stratospheric depth also. These waves are also expected to exchange ozone between tropical upper troposphere and extratropical lower stratosphere, *via* tropopause break as noticed by Mani et al., (1973). Aim of the present work is to highlight the total ozone variations caused by these two upper tropospheric long waves over Asia. A few well-developed cases of these two events have been considered randomly for this study. Circulation features of these two types of long waves have been analysed using NCEP/NCAR reanalysis data. Total ozone variations have been studied using satellite measured total ozone data.

6.2. Data

Daily streamline maps of 200 hPa are obtained from NCEP/NCAR reanalysis data for winter (January and February) and summer (July and August) months to identify the presence of UTTs and UTBHTs. Monthly mean temperature at 17 levels with same horizontal resolution as for wind of 1982-94 period has been taken from NCEP/NCAR reanalysis data to obtain the climatology of the vertical distribution of temperature and the location of tropopause break.

TOMS version-7 (onboard Nimbus-7 satellite) data set has been used to study the variations in total ozone associated with these upper tropospheric long waves over Asia. Details regarding the break periods in Indian Summer Monsoon have been taken from De et al., (1998).

6. 3. The Characteristics of upper tropospheric long waves over Indian subcontinent and associated ozone variations

6. 3. 1 Winter-time westerly Upper Tropospheric Troughs (UTT)

During northern hemispheric winter, upper tropospheric waves of zonal westerly flow in the middle latitudes take more southerly location. On occasions these waves develop into large amplitude north-south oriented troughs that penetrate deep into south Asia. Occasionally some of these troughs extend even upto near equatorial latitudes in winter season. Under the influence of overlying UTTs, lower tropospheric low-pressure systems form, intensify and move eastwards. Indian meteorologists refer to these eastward moving lower tropospheric circulation features as *western disturbances* to differentiate them from the main westward moving tropical disturbances over this region. The western disturbance tracks reach the southern most position in January and February months. Singh (1963), Dutta and Gupta (1967) and Singh (1979) brought out the close relation existing between the UTTs and the formation, intensification and movement of the lower tropospheric disturbances. Singh (1979) made a detailed case study of vertical structure of a UTT and its interaction with lower troposphere over the Indian region.

Generally the UTTs occur in between 500 hpa and 100 hPa levels and persist for less than a week during winter months over south Asia. UTTs are followed by cold polar jet stream from north. Singh (1979) noticed that the northerly polar jet associated with the UTT becomes more prominent at 200 hPa than the Subtropical Jet stream (STJ) and the later rose to 150 hPa from 200 hPa. He showed that the wind speed in the northerly polar jet is 100 - 165 knots for the December 1974 – January 1975 case. A case study of a UTT is also reported by Joseph (1967).

6. 3. 2 Summer-time Upper Tropospheric Blocking Highs and Trough (UTBTH)

In summer season, the Inter Tropical Convergence Zone moves as far as 30° N in July over south Asia and is accompanied by strong cross equatorial lower tropospheric wind flow from southern hemisphere in the form of Indian summer monsoon. At the same time, the polar front shifts to its northern most position far away from Indian region. India gets about 80% of its annual rainfall during the summer monsoon season (June to September). Indian summer monsoon rainfall (ISMR) activity shows strong intraseasonal variability. Summer monsoon season is characterized by active and break periods. In active period, the whole Indian subcontinent experiences widespread rainfall. During break periods, rainfall activity abruptly weakens over India and dry weather prevails over most parts of India. The low-pressure monsoon trough in the lower troposphere shifts from its normal position over central India to foothills of Himalayas in the north. Break periods are identified by the weakening of rainfall activity, shift in the position of monsoon trough, departure in the surface pressure, changes in wind direction, and the presence of upper tropospheric trough over India.

It is well known that during break periods (or simply breaks) upper tropospheric westerly troughs in midlatitudes penetrate deep into the south Asian region (Ramaswamy, 1962). Raman et al., (1980) found that the breaks were associated with stagnant upper tropospheric blocking ridge over the east Asia along ~ 100°E, extending from 35°N to 70°N. Raman and Rao (1981) presented a model for the evolution of blocking highs one over East Asia and another over West Asia with a deep wave trough in between during prolonged break monsoon situations.

Details about the breaks in Indian summer monsoon activity has been provided by both De et al., (1998) and Webster et al., (1995). For the present study the break periods listed by De et al., (1998) has been used. They identified 193 break days (33 break spells) during 1968-97 (30 years) period. Breaks appear once or twice in most of the years during summer monsoon season (one in 17 years, 2 in 8 years and zero in 5 years in the above 30 year period). Duration of the break period is highly variable. It varies from few days to a few weeks (20 days in 1979). Once break period comes to an end, widespread rainfall activity gets restored over whole of India again. Breaks that occurred during 1988-97 (ten year) period taken from De et al., (1998) has been presented in Table. 6. 1

Year	No of Breaks	Period	No of Break Days
1988	2	5-8 July, 13-15 August	4, 3
1989	2	10-12 July, 29-31 July	3, 3
1990	2	8-10 July, 27-31 July	3, 5
1991	1	3-9 September	7
1992	-	-	-
1993	1	19-21 July	3
1994	-	-	-
1995	1	12-15 August	4
1996	1	1-5 July	5
1997	-	-	-

Table 6.1 Breaks during 1988-1997 (De et al., 1998)

Daily 200 hPa streamlines obtained from NCEP/NCAR reanalysis wind data have been used to study the circulation characteristics of the UTBTH situation during break periods in ISMR activity. In fig. 6.1, the composite picture of the 200 hPa streamlines corresponding to one of the longest breaks that appeared during 1968-97 period is presented. It started on 17 July 1972 and ended around 3 August 1972 in the middle of the summer monsoon season. This represents the typical upper tropospheric circulation during break monsoon condition with two upper tropospheric ridges, one over East Asia and another over West Asia and a deep trough intruding into south Asia. Detailed examination of the streamline charts corresponding to these break days shows the presence of cut-off low in the trough region on individual days (not seen in composite). The blocking

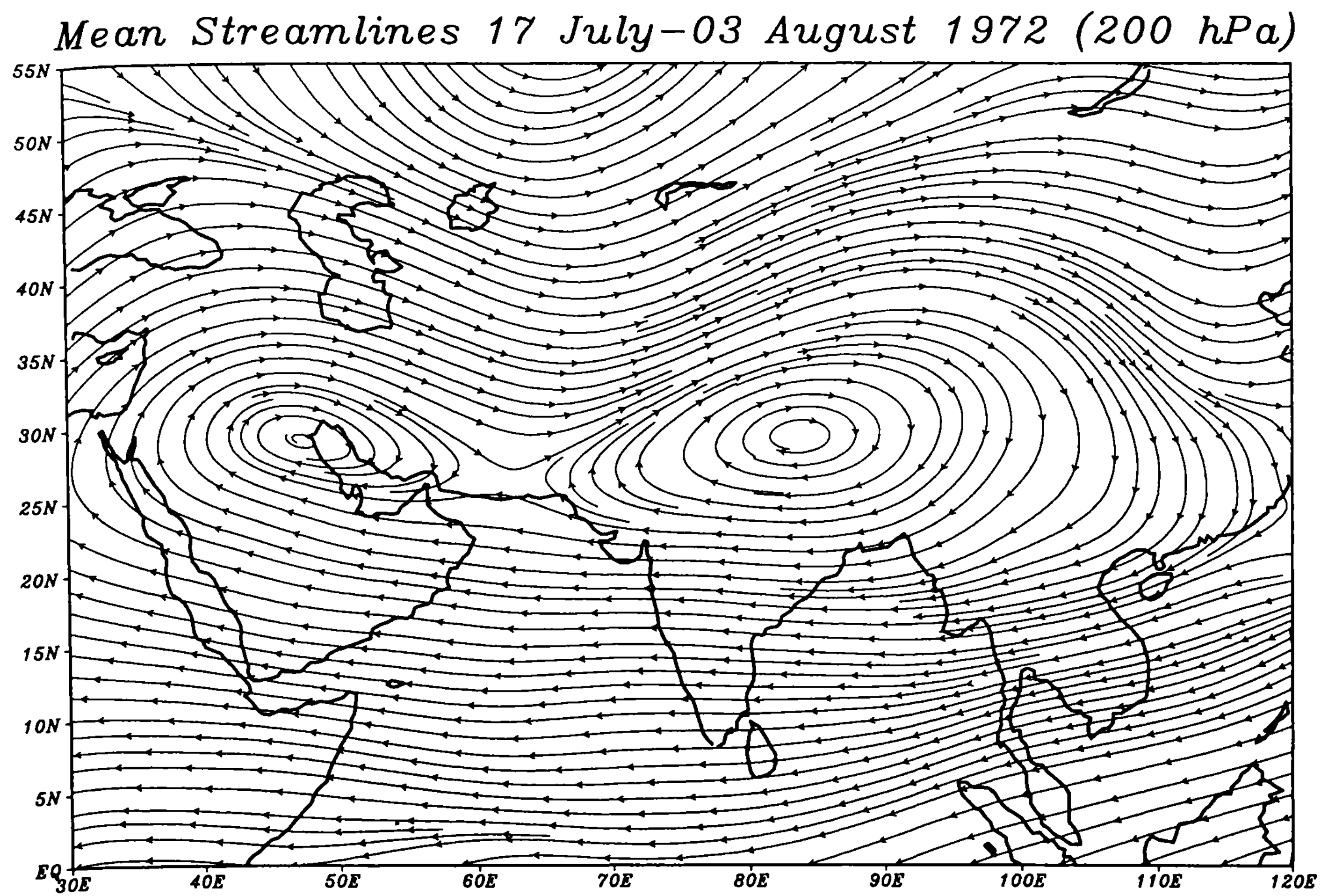


Fig. 6.1 Mean 200 hPa streamlines for the 17 July – 3 August 1972 break period in Indian summer monsoon.

pairs prefer to occur in the same latitude belt and the most favoured latitude for their centers is around 30° N, the east one generally appear over Eastern Tibet and the west one somewhere from Egypt to Iran at 200 hPa. Once the break condition ends and active monsoon condition get established over the Indian region, the Tibetan high shifts westwards. This stationary UTBHT condition persists during break periods in the Indian summer monsoon season over Asia. This wave pattern is similar to the Asia Pacific wave of May reported by Joseph and Srinivasan (1999).

6. 3.3 Upper tropospheric long waves and total ozone variations

In fig. 6.2, the meridional cross-section through India of the 13 year (1982-94) mean temperature averaged over Indian longitudes (50°-100° E) is presented for January-February (winter) and July-August (summer) months. A break is seen between tropical and extratropical tropopauses in these figures. The zone of westerly winds and the break region are at more northern latitudes during the summer season. The 14 year (1979-92) mean January-February and July-August total ozone distribution for the Northern Hemisphere (0°-55°N) are presented in fig. 6.3. The total ozone increases from the equator towards the pole. Gradient of the total ozone is relatively more in the 25°-45° N latitude belt in January-February and 35°-50° N latitudes in July-August. Total ozone variations are negligible in lower latitudes upto 20° N in both the seasons. At about 200 hPa level (~ 12 km altitude) where these two waves are present in large amplitude, steep meridional ozone gradient exist (see fig. 5.8) between tropical upper troposphere and extratropical lower stratosphere and mutual exchange is possible between these two regions due to the presence of tropopause break there. The northwesterly flow to the west of the trough in these two cases is

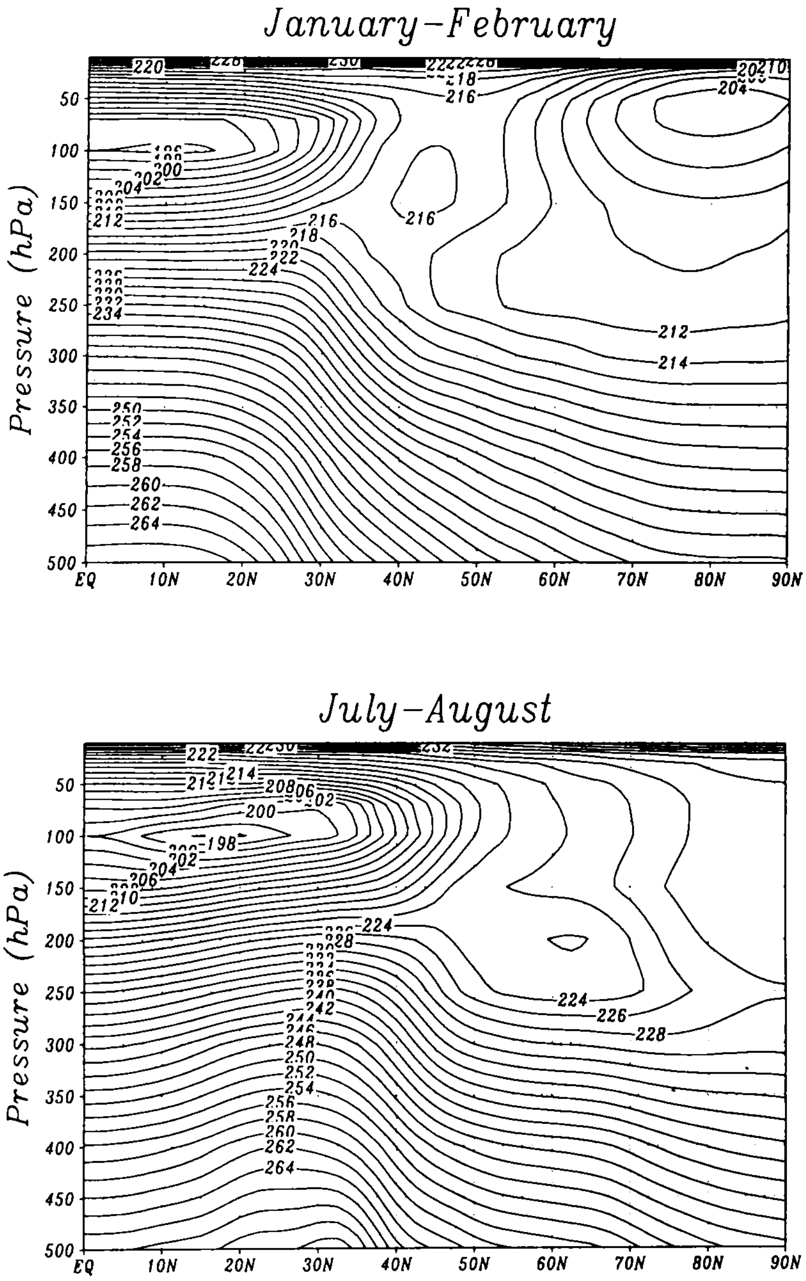


Fig. 6.2. 13 year (1982-94) climatology of the latitude – height distribution of temperature (°K) for January – February (winter) and July – August (summer) months averaged between 50° E and 100° E longitudes. Contour interval is 2°K.

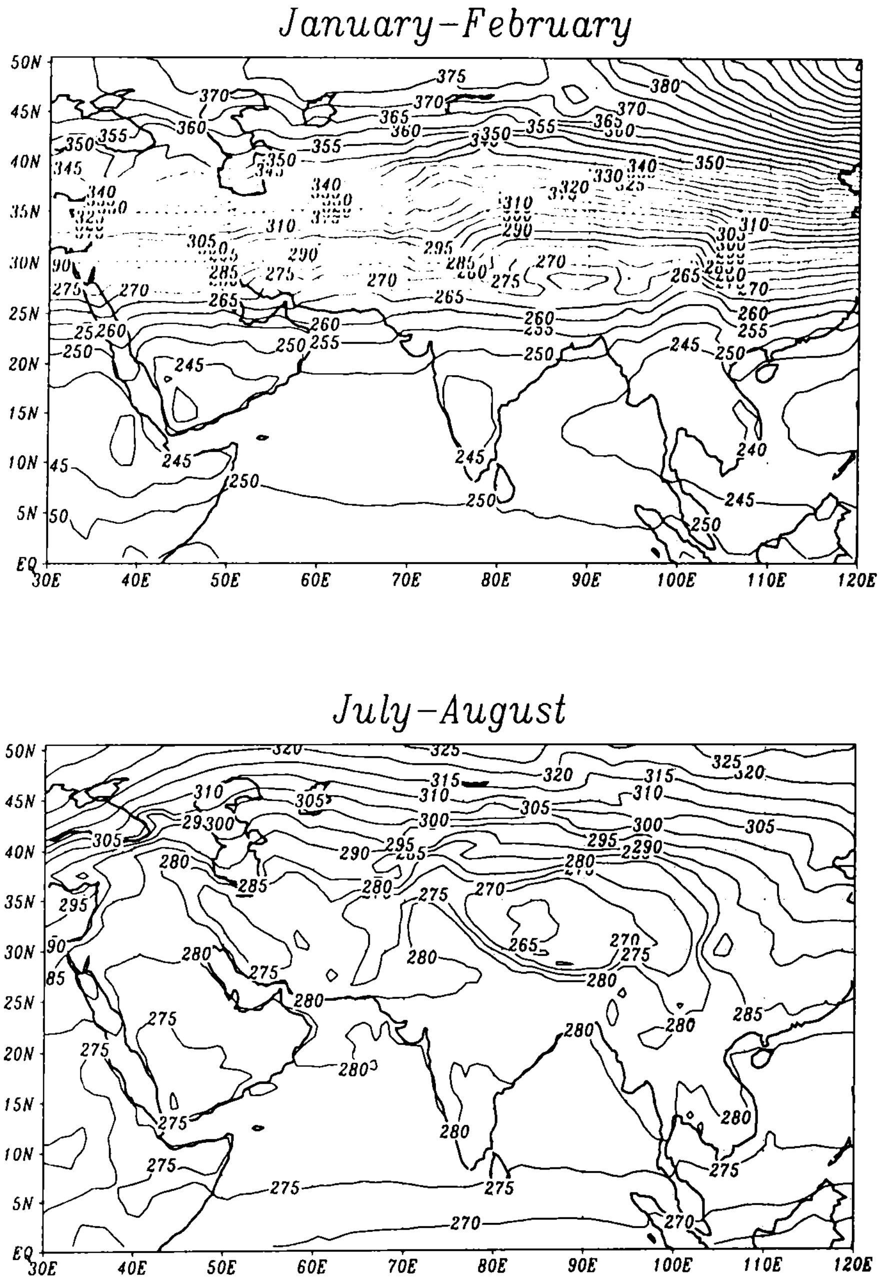


Fig. 6.3 . Climatological (1979-92) distribution of total ozone (Dobson Units) over Asia for January-February (winter) and July-August (summer). Contour intercal is 5 DU.

likely to transport ozone-rich extratropical lower stratospheric airmass into the tropical troposphere over south Asia and increase the total ozone content over this region. In the east of the trough and to the west of the blocking high, the existing southwesterly airflow is expected to transport ozone-poor tropical tropospheric air to the extratropical lower stratosphere.

More importantly a trough in upper troposphere lowers the tropopause, thereby enhancing the stratospheric column and hence the total ozone column. On the other hand, ridge decreases the stratospheric column and hence the total ozone amount. Thus by the transport of ozone rich airmass from higher latitudes and the increase in stratospheric column, total ozone increases over the trough region. Conversely by the transport of ozone poor airmass from low latitudes and the decrease in stratospheric column, total ozone decrease over the ridge region. In the present work, attempt has been made to study the total ozone variations associated with these waves over Asia using satellite measured total ozone.

6. 4. Case studies

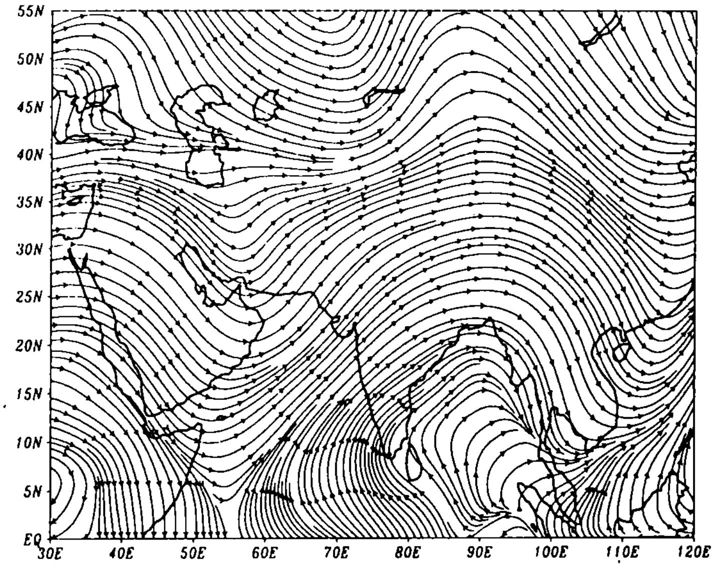
6.4.1 Winter season

Case studies of 2 UTTs are presented in this section. The troughs in these cases are at different longitudes, over south Asia and these UTTs moved very slowly eastwards. These typical cases with deep troughs extending across the tropopause region were chosen from the period 1979 to 1992. In general, this large amplitude slow moving waves that penetrate deep into tropical Asia is expected to cause synoptic scale ozone variations for few days like in midlatitudes. But the presence of near uniform total ozone distribution (also in the upper troposphere, see fig. 6.3) and the increase in the height of the tropopause towards the equator in tropics are expected to make the situation slightly different.

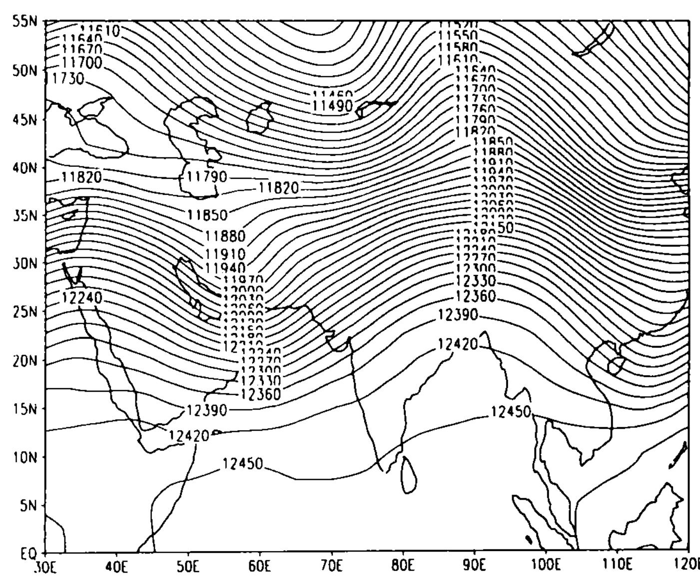
6.4.1.1 January 01-04, 1988 UTT (55° E Longitude)

In the 200 hPa streamline chart, this UTT is seen in the form of a deep cyclonic flow over Caspian sea, Arabian peninsula and Arabian sea on 1 January. The north-south extent of the trough is between 55°N and 5°N latitudes during 1-2 January. The northern portion of the trough moved east and the southern portion remained practically stationary. A well-developed ridge is seen east of the trough at 90°E at this level. The trough weakened after 4 January.

In fig. 6.4, the 200 hPa streamlines at 1200 UTC, geopotential height of 200 hPa at 1200 UTC and Total Ozone Anomaly (TOA) for 3 January 1988 are presented. Anomalies are the deviations from January and February climatological total ozone values. The TOA plot shows the signatures of changes in circulation and tropopause height associated with the upper tropospheric trough/ridge. An area of positive TOA is seen over Saudi Arabia, Iraq and Iran regions. The southward extent of this anomalous region is seen upto 20° N latitude. Maximum TOA over this region is 60 DU, which is about 25% more than the January – February climatological mean over this region. The magnitude of total ozone variability in this case is comparable with those of extratropical ones. Though the cyclonic trough is seen southwards upto 5° N, positive TOA pattern is limited north of 20° N latitude and no signatures of ozone variation is seen beyond this latitude. The uniform ozone distribution

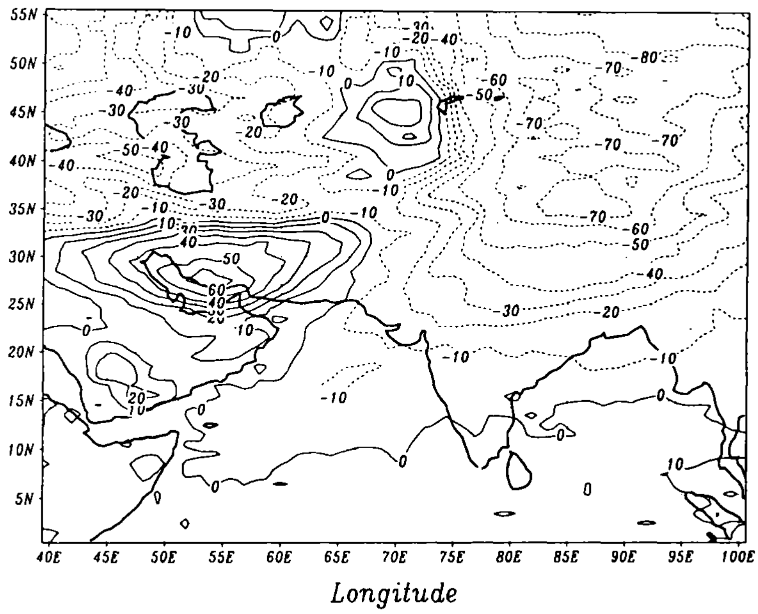


(a)



(b)

Fig. 6.4 a) 200 hPa streamlines at 1200 UTC for 3 January 1988 b) Geopotential height (gpm) of 200 hPa at 1200 UTC for 3 January 1988 (Contour interval is 30 gpm) and c) Total ozone anomaly from January-February climatology (Contour interval is 10 DU) in Dobson units for 3 January 1988.



(c)

Fig. 6.4 (Continued)

encountered by the airmass once it reaches 20° N latitude from north and the increase in the tropopause height towards equator may be the cause for the insignificant TOA in the tropical region.

An area of negative TOA is seen east of 85° E longitude and north of 20° N latitude in the region of southwesterly flow west of the ridge and east of the UTT. As suggested earlier, the ozone-poor air transport from tropical upper troposphere to the ozone rich extratropical lower stratosphere and the decrease in stratospheric column may be the cause for this low total ozone over this region. It is seen that both the positive and negative anomalies are elongated in the east-west direction. This may be due to the strong zonal component of the wind that moves the meridionally transported ozone to the east.

6.4.1.2 February 24-28, 1992 UTT (90°E Longitude)

In the 200 hPa streamline chart, trough is seen over India, *Bangladesh regions on 24 February, intensified during 25-27 February* and weakened afterwards. The trough has shown slow eastward movement and is seen over Indo-China on 28 February. A ridge is seen west of the trough in the same level. In fig. 6.5, 1200 UTC streamline charts at 200 hPa and TOA for 26 February are presented. Area of positive TOA is seen over Bangladesh-Indian region over the trough. The values of the maximum TOA in this case reached as high as 100 DU and the area of positive anomaly is seen upto 15° N latitude. An area of negative TOA with values of 50 DU below the climatological values is seen over a large area in the field of the southeasterly flow west of the ridgeline, which transports ozone-poor air from the tropics.

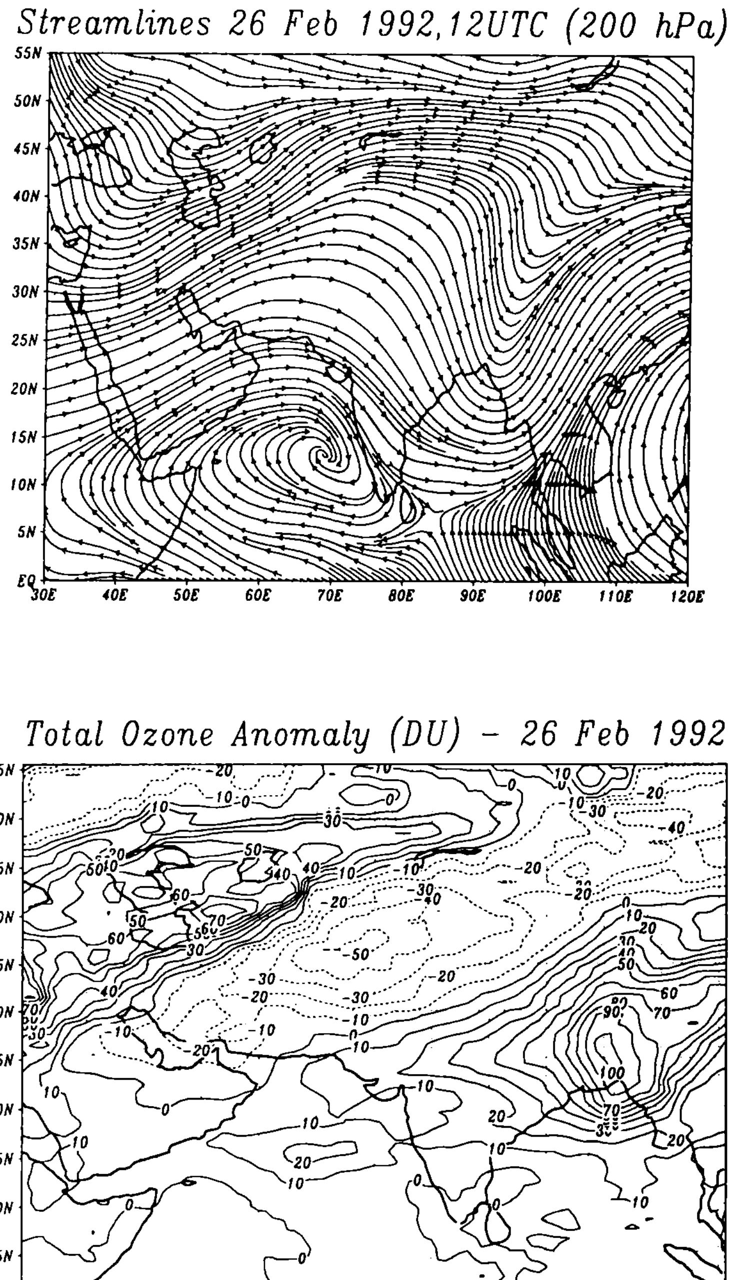


Fig. 6.5 Same as fig. 6.4 (without geopotential height), but for 26 February 1992.

These two cases of UTT show the occurrence of large ozone anomalies in association with the phase of the upper tropospheric waves over tropical Asia.

6.4.2 Summer season

From the 33 break situations listed by De et al., (1998) during 1968-97 period, 2 cases that occurred during the mid-summer monsoon season (July, August) have been selected from the 1979-92 period (TOMS data from Nimbus-7 satellite were available only during this period) to find the ozone variations associated with the UTBTH seen in the upper troposphere during break monsoon period. Daily 200 hPa streamline chart obtained from u, v fields has been analysed to study the circulation features during these two breaks over south Asia. These breaks are characterized by two blocking highs, one over eastern Tibet and another over west Asia accompanied by a trough in between them at 200 hPa level. In these cases, the distance between the blocking highs is relatively small for 1981 case compared to 1987 case. If the blocking highs are relatively much apart, the trough in between them is likely to penetrate deep into tropical latitudes. This is clear from the existence of well-developed trough in between the blocking highs in 1987. On individual days, the trough in this year penetrated deep into the tropical latitudes and a cut-off low formed in the trough region. Generally UTBHT are stationary and we have presented composites for each case.

The mean 200 hPa streamline chart, and composite TOA (deviations from July climatology) for the first break (26 July - 31 July, 1981) are shown in fig. 6.6. The mean 200 hPa streamline chart, mean 200 hPa

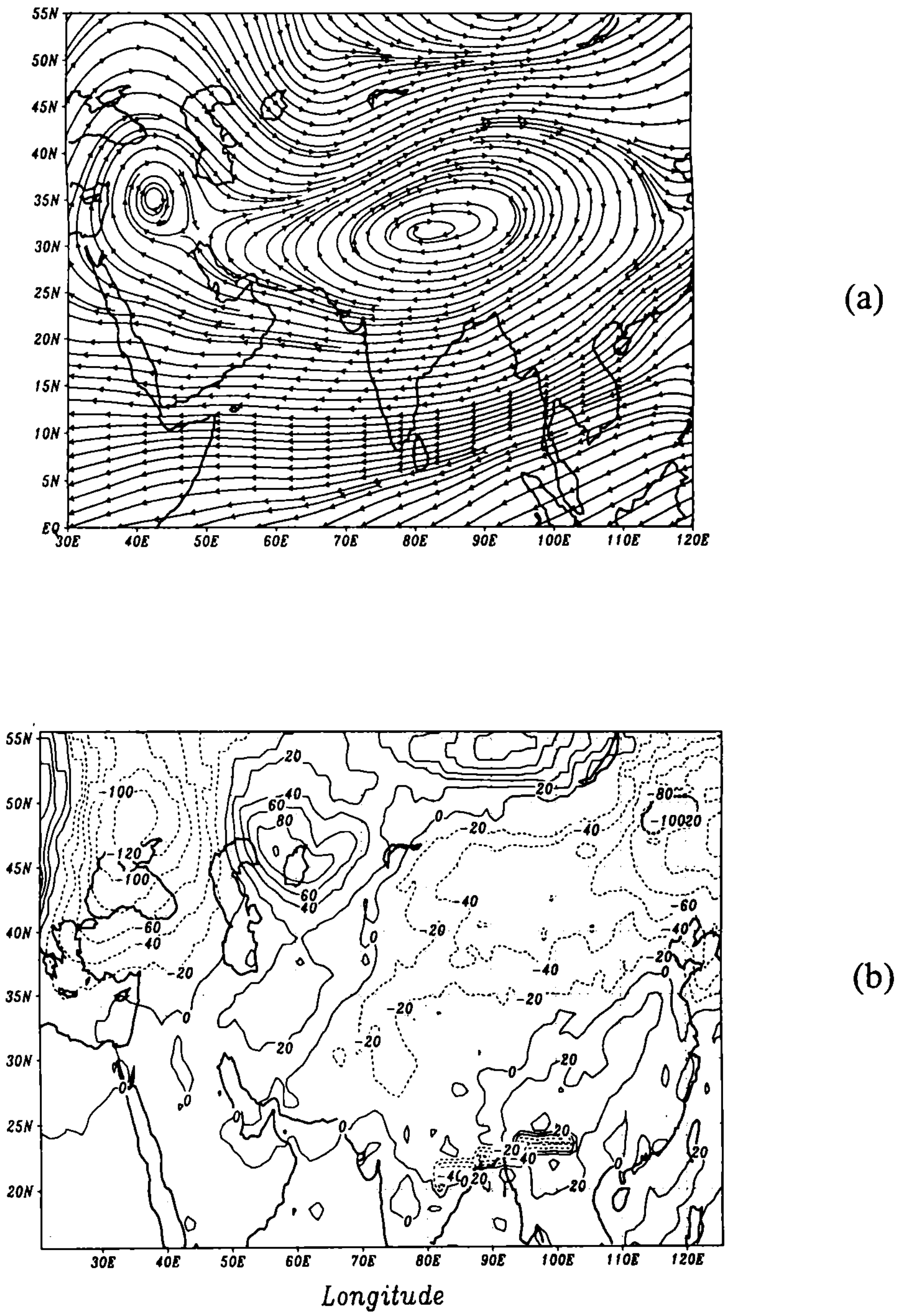
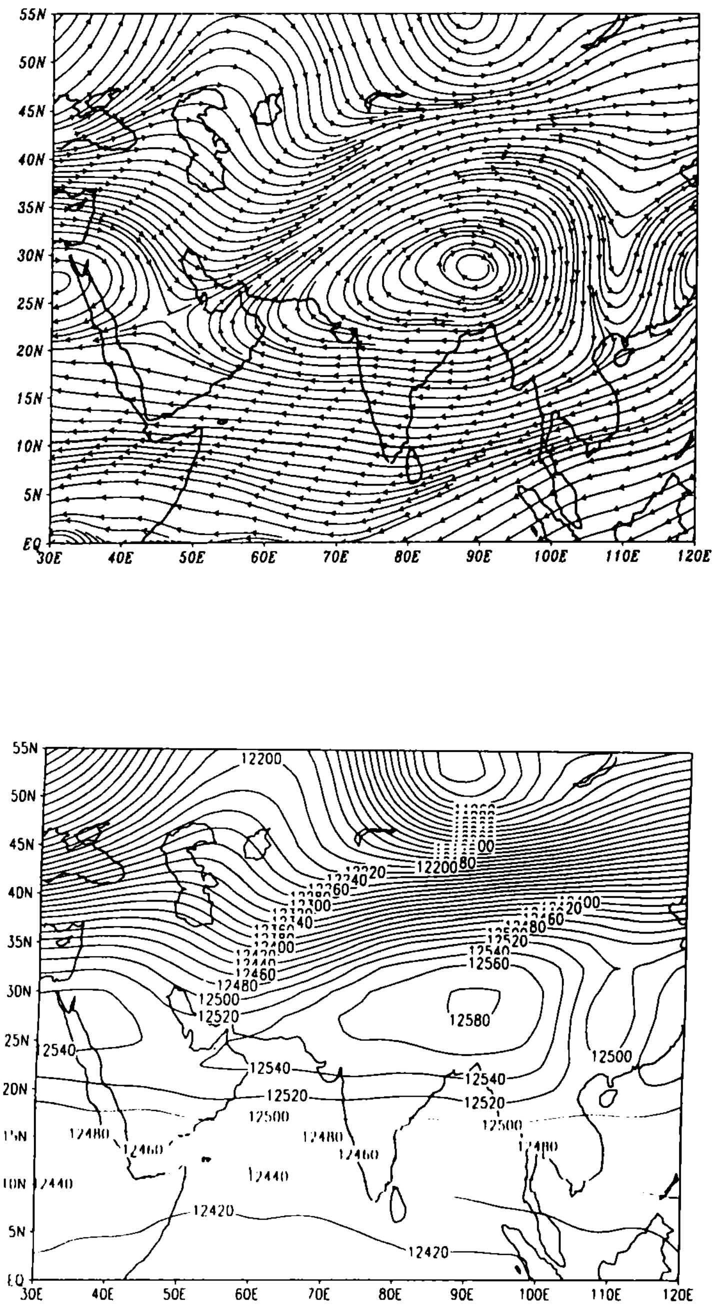


Fig. 6.6. a) Mean 200 hPa streamlines for the break in Indian summer monsoon during 26-31 July 1981, and b) Mean total ozone anomaly from July climatology for 26 – 29 July 1981 (Contour interval is 20 DU). [Ozone data was missing for some days over Bangladesh, Myanmar regions].

geopotential height for the second break (28 July - 1 August, 1987) and mean total ozone anomaly from July climatology for 28 July - 31 July 1987 are presented in fig. 6.7. To avoid major gaps in the total ozone data, TOA anomaly is computed for the days when adequate data coverage is available. Large amount of ozone variations taking place caused by the wind flow associated with blocking high and trough and variations in stratospheric column is reflected in these plots. Important feature seen in these figures are the large total ozone increase in the trough regions and decrease in ridge regions. The magnitude of ozone variations is comparatively more than the UTT case. Although the 1981 break is seen during 26-31 July period, the TOA composite is computed only for 26-29 July due to the large ozone data gaps present during the remaining two days.

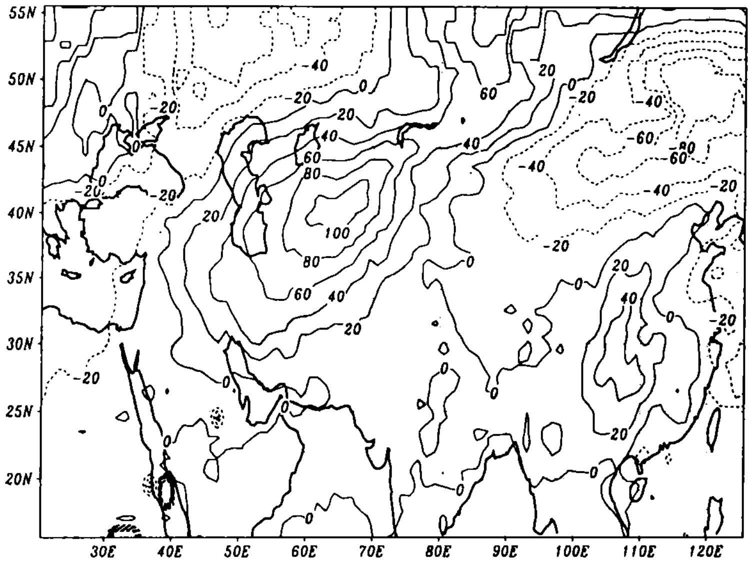
The 1981 ozone anomaly chart shows two areas of pronounced negative TOA associated with the western blocking highs over a region north of Black sea and an area of positive TOA along the trough east of Caspian sea. The maximum value of positive TOA reached as high as 100 DU and negative TOA reached as low as –120 DU, which is about 30% more, and 35% less than the July climatology respectively. The 1987 case also showed large areas of positive and negative TOA. Eastward tilt in the trough from south and its southward extension is reflected well in the positive anomaly pattern. The maximum positive TOA has reached upto 100 DU and negative values upto –80 DU, which is about 35% more, and 25% less than the July climatology. Unlike the UTTs, the UTBHT are stationary in their position. In prolonged break periods, the negative TOA over ridge may increase the ground level UV-B radiation considerably due to the presence of sun near Tropic of cancer.



(a)

(b)

Fig. 6.7 a)Mean 200 hPa streamlines for the break in Indian summer monsoon during 28 July – 1 August 1987, b) Mean 200 hPa geopotential height (gpm) for 28 July – 1 August (Contour interval 20 gpm) and c) Mean total ozone anomaly from July climatology for 28 – 31 July 1987 (Contour interval is 20 DU). (No data areas are marked by stippling). [Ozone data was missing for some days over Red Sea].



(c)

Fig. 6.7 (Continued)

The UTT moves eastward with time generally with very slow speed. It produces total ozone variations even in the tropical latitudes. The UTBHT is stationary over Asia for several days. The magnitudes of TOA generated by UTBHT are relatively more than that of UTT. The UTBHT produces TOA over latitudes north of India. The intense anomalies associated with UTBHT are possibly because of the stationary nature of UTBHT. The large negative TOA anomalies associated with UTBHT pose severe health threat to the people of central Asia by the presence of overhead Sun in summer and possible increase in surface UVB radiation than that of UTT.

6.5 Summary

Ozone perturbations caused by two upper tropospheric long waves in winter and two upper tropospheric blocking high and trough of summer seasons over south and central Asia were presented. The wintertime UTT and the ridges following and preceding it occasionally penetrate deep into south Asia on synoptic time scales and create positive and negative TOA over these areas. Values of TOA reached upto ± 25-35 % during this condition over south Asia.

In summer season, UTBHT situation develops over south Asia during the break periods in the Indian summer monsoon. This situation persists for a few days to a few weeks and creates negative and positive TOA over south and central Asia. Positive TOA reaches values of the order of 100 DU and negative TOA upto −140 DU depending upon the strengths of the blocking highs and troughs. The negative TOA reached even 50% less than the long-term mean in some areas during these episodes and created a sort of *mini ozone hole* like situation. Negative total ozone perturbations are likely to increase the amount of harmful UV-B radiation reaching the ground considerably in these situations particularly as UTBHT occur during summer with sun over head which increases the solar UV radiation over these areas for a period of few days to weeks. Increased columnar ozone over the trough decreases the ground level of UV radiation over the trough region.