Chapter 7

Summary and Conclusions
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Recently atmospheric research established the role of stratosphere in the climate variability and weather changes. The upper troposphere and lower stratosphere regions are very sensitive to the climate changes compared to other layers of the atmosphere. Even though these two layers have entirely different characteristics, the interaction between them cannot be neglected when we study the climate change. There is exchange of mass, energy and momentum takes place by the process of stratosphere-troposphere interactions. Atmospheric waves originating in the dynamically active troposphere and radiatively strong stratosphere play the major role in the stratosphere-troposphere interaction. The ozone in the stratosphere also play a role in the radiative balance between the earth and atmosphere system and it protect the life on the earth from harmful ultra violet radiations.

In the present study we made an attempt to understand the characteristics of the upper troposphere and lower stratosphere over the Asian summer monsoon region, more specifically over the Indian subcontinent. Mainly we had taken three important atmospheric parameters such as zonal wind, temperature and ozone over the UT/LS of the Asian summer monsoon region. We made a detailed study of its interannual variability and characteristics of these parameters during the Indian summer monsoon period. Monthly values of zonal wind and temperature from the NCEP/NCAR reanalysis for the period 1960-2002 are used for the present study. Also the daily overpass total ozone data for the 12 Indian stations (from low latitude to high latitudes) from the TOMS Nimbus 7 satellite for the period 1979 to 1992 (14 years) were also used to understand the total ozone variation over the Indian region. The major outcomes of the present study are presented as follows.

The zonal wind in the upper troposphere and lower stratosphere over the Asian summer monsoon region shows that the major interannual variability in the lower stratospheric zonal wind is QBO with a varying periodicity from 26 to
32 months. The amplitude and period of the QBO vary over the Asian summer monsoon region. The approximate duration of easterly and westerly phases of QBO are 14 and 13 months respectively with a QBO periodicity of 27 months over the Asian summer monsoon region. The phase transition of QBO over the Indian region revealed that the westerly to easterly transition generally occur during the month of May and easterly to westerly transition in January. Also noted that there exist a link between the stratospheric zonal wind variability (QBO phases) and Indian summer monsoon. If QBO phases in the stratosphere is easterly or weak westerly then the respective monsoon is found to be DRY or below Normal. On the other hand, if the phase is westerly or weak easterly the respective Indian summer monsoon is noted as a WET year. This connection of stratospheric QBO phases and Indian summer monsoon gives more insight in to the long-term predictions of Indian summer monsoon rainfall.

Wavelet analysis and EOF methods are the two advanced statistical techniques used in the present study to explore more information of the zonal wind that from the smaller scale to higher scale variability over the Asian summer monsoon region. Both the techniques show that the QBO periodicities are dominant in stratospheric levels. But some years its amplitude and periodicity have greater variations. The above oscillation in the zonal wind is significant above 95% confidence level. The EOF methods give the spatial pattern of the parameter and how it varies over the monsoon region with time. Here also the dominant variability over the summer monsoon region is QBO periodicity, which contributes more than 70% to the total variability in the stratosphere. The spatial pattern of the QBO mode shows a monopole and annual oscillations shows a dipole pattern over the Asian summer monsoon region. The annual oscillation changes its sign between north and south in the alternate levels of the stratosphere. The QBO mode gives way to the annual oscillation at 50 hPa level and contribute above 50 percentage to the total variability in zonal wind. From the analysis it is found that the QBO mode is contributing greater
percentage in the stratospheric levels and annul mode is contributing significantly in the upper tropospheric levels.

A peculiar characteristics of the zonal wind is observed in the DRY and WET years of Indian summer monsoon over the UT/LS of the tropical atmosphere. The zonal wind in the equatorial upper troposphere and lower stratosphere exhibit opposite wind anomalies during the DRY and WET years of Indian summer monsoon period (JJAS). In DRY years, upper troposphere zonal wind (tropical easterly jet over the south Asia) have westerly anomalies and lower stratosphere have easterly anomalies. In WET years, the anomalies are opposite. We named this upper troposphere and lower stratosphere wind systems in the tropical region during the DRY and WET years of Indian summer monsoon season as “UT/LS dipole”. The intensity of the dipole is found to be well correlated with the Indian summer monsoon rainfall. Another interesting fact noted is the weakening of the stratospheric easterly and tropical easterly jet during the period of study 1960-1998. It is found that the Hadley circulation during the WET years of Indian summer monsoon is stronger than the DRY years. The wind direction in the UT/LS of DRY and WET years show entirely opposite characteristics.

The interannual variability of temperature for different stratospheric and tropospheric levels over the Asian summer monsoon region have been studied. The 10.7 cm solar radio flux is used to find the modulation of temperature with the 11-year solar cycle. We used the Morlet wavelet and EOF analysis to study the major oscillations present in the temperature and its percentage of contribution to the total variability over the Asian summer monsoon region. The two major oscillations in the temperature are the quasi-biennial oscillation (26-32 months) and 11-year solar cycle (132-136 months) in the UT/LS region. These oscillations are significant at above 95% level of confidence. Abrupt variations in the UT/LS temperature during the period of study prior and after 1977 are noticed. These changes in the temperature may be due to the decadal
variability (11-year solar cycle) and the climate fluctuation, which occur prior and after 1977.

A QBO periodicity in temperature in the upper troposphere is noted at level 200 hPa. It is observed that there exit an 11-year solar cycle in temperature in the UT/LS levels at 200 hPa and 10 hPa. The temperature at 200 hPa shows an in-phase relation with the solar flux and at 10 hPa shows an out-of-phase relation. The QBO mode in the temperature oscillation is greater than the 11-year cycle. The QBO mode contributes more percentage of variability to the stratospheric temperature whereas the 11-year mode contributes more to the tropospheric temperature variability. We computed the temperature trend over the Asian summer monsoon region for three periods (1969-1978, 1979-1988 and 1989-1998). It is found that there is a cooling trend in the stratospheric levels and which extends up to the upper tropospheric levels.

An attempt has been made to understand the total ozone characteristics and its interannual variability over 12 Indian stations spread from south latitudes to north latitudes. It is noticed that total ozone is maximum during the monsoon period (JJAS) for all the stations except the stations (Srinagar and New Delhi) at northern latitudes. There are two significant interannual oscillations present in total ozone over these stations are observed. One is with a periodicity varying from 16-18 months and the other is with a QBO periodicity varying from 26-32 months. Both these oscillations in the total ozone are significant at 95% level of confidence. Another finding is that total ozone is high during DRY years of Indian summer monsoon than the WET years. Using factor analysis we classified these stations into two groups with the same nature of total ozone variability at these stations. All the central Indian stations fall in the first group with a first factor as the primary loading. There are four stations (two northern stations (Srinagar & Delhi) and two southern stations (Chennai and Bangalore) come under the second group with the second factor as the primary loading. This implies that the total ozone variations over these stations are not fully
latitudinal depended. The correlation between the total ozone and solar flux shows high correlation for the north Indian station compared to south stations.

7.2 Scope for the future study

In the present study we explored the interannual variability of zonal wind, temperature and total ozone over the UT/LS of Asian monsoon region. It is found that the upper troposphere and lower stratosphere contribute significantly to monsoon variability and climate changes. It is also observed that there exists a link between the stratospheric QBO and Indian summer monsoon. So more research work on these aspects will be needed for a better understanding of the physical mechanism responsible for the stratosphere-troposphere interaction. From the results obtained from the present study, a suitable atmospheric model can be developed to study the stratosphere–troposphere interaction processes. If we understand more about the total ozone variability over the Asian summer monsoon region, it will help us to protect the ozone layer by reducing the increased production of chlorofluorocarbons. The ozone variability is a prime concern now a days because the depletion of ozone in the stratospheric levels lead to the imbalance between earth and atmosphere radiative equilibrium.