

Abnormal behavior of total ozone over Indian region during 1991-98

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सार – भारत के चार स्टेशनों नई दिल्ली (28°उ.), वाराणसी (24°उ.), पुणे (18°उ.) और कोडाइकनाल (10°उ.) में 1981 से 1998 तक के 18 वर्षों की अवधि में डॉबसन स्पेक्ट्रोफोटोमीटर से प्राप्त किए गए मासिक औसत ओजोन का उपयोग करते हुए भारत के ऊपर कुल कॉलम ओजोन की परिवर्तनशीलता का अध्ययन किया गया है। इस शोध पत्र में ओजोन की परिवर्तनशीलता अर्द्धवार्षिक दोलन, सौर चक्र और ज्वालामुखी विस्फोट (1982 के एल चीकोन, 1991 के माउंट पाइनाट्यूबो) जैसी वायुमंडलीय घटनाओं के प्रभाव का पता लगाया गया है। इस विश्लेषण के परिणामों से यह ज्ञात होता है कि उष्णकटिबंधीय क्षेत्रों में ओजोन की परिवर्तनशीलता प्रायः निम्नसमतापमंडल और सौर चक्र की क्षेत्रीय पवन में भूमध्यरेखीय अर्द्धवार्षिक दोलन के कारण होती है। 1981 से 1990 के दौरान कुल ओजोन में वर्ष प्रति वर्ष अधिक परिवर्तनशीलता नहीं पाई गई है जबकि 1991 से 1998 की अवधि के दौरान वर्ष प्रति वर्ष अधिक परिवर्तनशीलता देखी गई है। 1991 से 1993 की अवधि में कुल ओजोन कम हो गई और बाद में पुनः अधिक होने लगी। 1981 से 1998 की अवधि में परिकलित की गई सकारात्मक ओजोन असामान्यताएं 1981 से 1990 की अवधि की सकारात्मक असामान्यताएं की अवधि की सकारात्मक असामान्यताएं और 1991 से 1998 अवधि की नकारात्मक असामान्यताएं दर्शाती हैं। यद्यपि 1981 से 1990 और 1991 से 1998 की दो विभिन्न अवधियों में अर्द्धवार्षिक दोलन और सौर चक्र के योगदान लगभग समान है किंतु फिर भी बाद की अवधि में कुल ओजोन की राशि थोड़ी कम है। निम्न ओजोन राशियों के कारण संभवतः माउंट पाइनाट्यूबो में ज्वालामुखी विस्फोटन हुआ।

ABSTRACT. The total column ozone variation over India has been studied using monthly mean ozone for the period of 18 years from 1981 to 1998, which were collected with Dobson Spectrophotometer at four Indian stations, New Delhi (28° N), Varanasi (24° N), Pune (18° N), and Kodaikanal (10° N). The effect of atmospheric phenomena like Quasi Biennial Oscillation (QBO), solar cycle and volcanic eruptions (El Chichon of 1982, Mt. Pinatubo of 1991) on ozone variations has also been explored in this paper. The results of the analysis has shown that the ozone variations in the tropical region seem to have mostly caused by the equatorial QBO in zonal wind at lower stratosphere and solar cycle. During the period 1981-90, there is no much year to year variability in total ozone, whereas during the period 1991-98, much variability is observed between year to year. The total ozone is decreased from 1991 to 1993 and later started recovering. The ozone anomalies calculated for the period 1981-98 showed positive anomaly for the period 1981-90 and negative anomaly for the period 1991-98. Though the contribution of QBO and solar cycle to total ozone for the two different periods of 1981-90 and 1991-98 is almost same, the total ozone amounts for the later period are lower. These lower ozone amounts may be attributed to the Mt. Pinatubo volcanic eruption.

Key words – Quasi-Biennial Oscillation, Solar cycle, Volcanic eruption, Ozone variation, Dobson Spectrophotometer, TOMS.

1. Introduction

The ozone plays a significant role in the chemistry of the Earth's atmosphere, even though it is a minor species in terms of abundance. The ozone concentrations are rather variable, but the mixing ratio with respect to the entire atmosphere is a few tenths of a part per million. The importance of atmospheric ozone has been recognized for more than sixty years and it is apparent now that the stratospheric ozone concentration has been declining

during recent years (WMO, 1998). Considerable measurements based on both space and ground indicates that ozone is decreasing even in the subtropical latitudes also. This is a region for concern, because these are the regions where ozone concentrations are naturally low and further decrease in this ozone layer will expose life (highly populated) to high risks due to UV rays. Comprehensive studies of the Total Ozone Mapping Spectrometer (TOMS) data for 14 years, analyzed in detail for the behavior of ozone layer over different

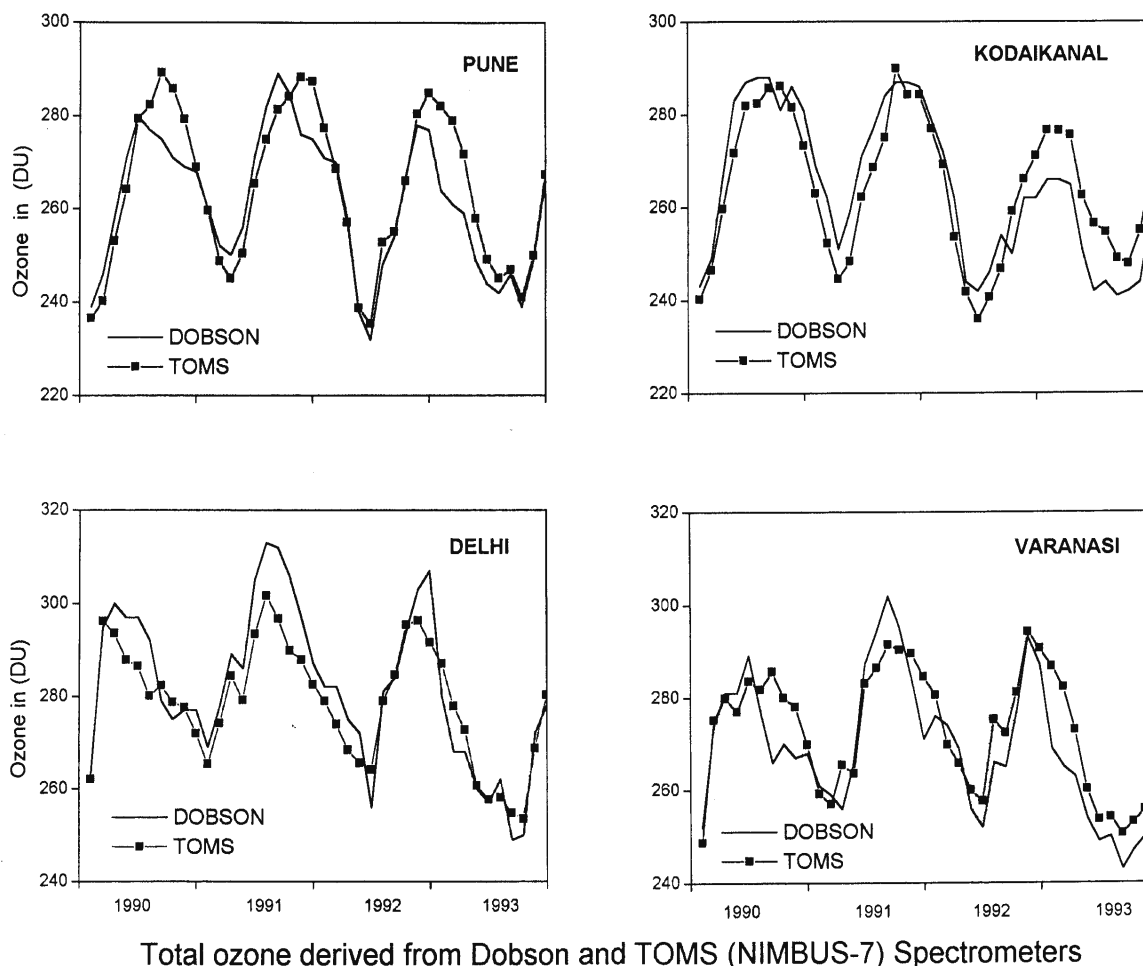


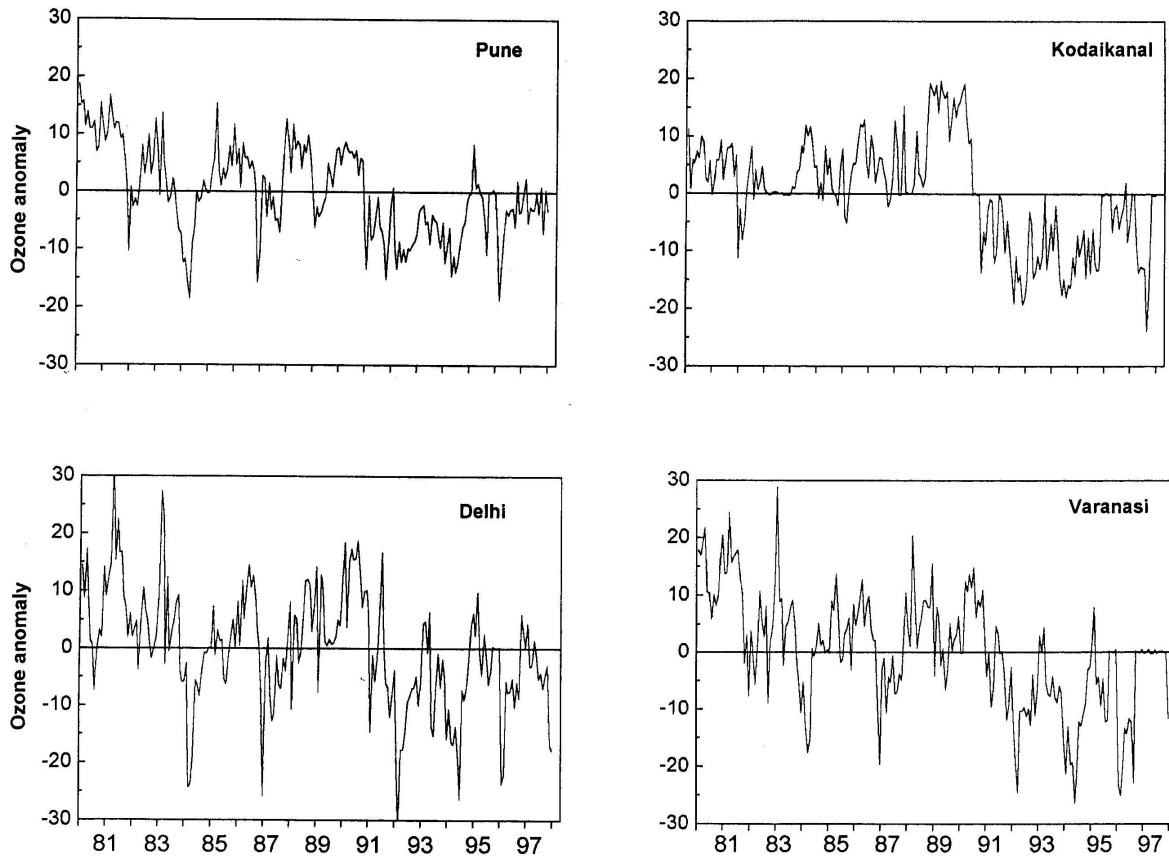
Fig. 1. Comparison of Dobson and TOMS total ozone data

latitudes and regions (Herman *et al.*, 1993 ; Randel and Cobb, 1994). Mt. Pinatubo eruption which took place in June 1991 has injected a large amount of volcanic material into the stratosphere. An estimated amount of 12 to 15 megatons of SO_2 has been injected by Pinatubo and is rated as the strongest eruption of the century (Jayaraman *et al.*, 1995). Solomon *et al.*, (1996) noted that the occurrence of two major volcanic eruptions nine years apart during each of the last two declining phases in solar activity could lead to some confusion in separating volcanic and solar effects on ozone. This may not strongly influence trend estimates for the long time records, but may have implications for isolation for the solar cycle in the short observational record.

Chandra (1993) has analyzed ozone data collected by NIMBUS 7 - TOMS and NOAA/11 Solar Back-scatter Ultra Violet (SBUV)/2 Spectrometers and reported that the decrease in total ozone in the tropics may not be more than 2-4 % after Pinatubo eruption. Similar decreases in TOMS total ozone in the tropics are also reported by

Schoeberl *et al.*, (1993). Grant (1992) have estimated a relatively larger decrease in ozone content in the tropics from the analysis of ozone profiles from the ECC sondes obtained at Brazzaville, Congo (4° S , 15° E) and Ascension Island (6° N , 14° W). The global satellite ozone records since 1979 show evidence for a decadal oscillation of total ozone with maximum amplitude ($\sim 2\%$) at low latitudes (Hood and McCormack, 1992; Chandra and McPeters, 1994; Hood, 1997).

Climatologically, the column abundances of ozone is lowest over the tropics (Salby and Callaghan, 1993) due to which these regions experience larger fluxes of solar UV radiation. This fact underlines the need for continuous monitoring and analysis of ozone levels in the tropical and sub tropical regions, especially the long term trends and fluctuations. India is a second largest population country in the world. A very few studies are available on long term variations of total ozone over Indian stations (Mani and Sreedharan, 1973; Tiwari, 1992; Kundu and Jain, 1993). Hence the ozone variations over



Monthly Ozone anomaly from January 1981 to December 1998

Fig. 2. Monthly total ozone anomalies for the period 1981-98

four Indian stations for the last two decades (*i.e.* 1981-98) are explained with QBO in lower stratospheric zonal wind, solar cycle and volcanic eruptions of El Chichon, 1982 and Mt. Pinatubo, 1991 in this paper.

2. Data analysis

The daily total ozone data for four Indian stations *i.e.* New Delhi, Varanasi, Pune and Kodaikanal have been collected from Ozone Data for the World (ODW) for the period January 1981 to December 1998. Data is obtained from Dobson Spectrophotometer. The measurements of ozone with Dobson Spectrophotometer are carried out by India Meteorological Department. The calibration of all the Dobson instruments is checked on a monthly basis using mercury and standard lamps. The standard Dobson instrument (#112) for this region is located at the India Meteorological Department, New Delhi. Comparison of this standard instrument with all other Dobson instruments are performed once every 4 - 5 years under identical sky conditions. In addition to this data and standard lamps of standard instrument are circulated to all the stations and

compared with the respective instrument once every 1 or 2 years. The standard instrument (#112) participates regularly in the international comparison of ozone. The error in the Dobson ozone values is estimated less than five. The last inter-comparison was made at Tsukuba, Japan from February 26 to March 26, 1996 (Peshin *et al.*, 1998). The initial inter-comparison data confirms that the existing ozone data derived from the instrument No. 112 is accurate. This instrument is used to calibrate other Dobson instruments in the IMD network. Therefore, it confirms that the existing data at various IMD stations meet the international standards of reliability.

Monthly zonal wind data at 30 hPa and 50 hPa for the equatorial station Singapore (1° N, 103° E) and sunspot number data have been utilized to study the effect of QBO and solar cycle on ozone variations.

The Dobson ozone data collected for the period 1990 to 1993 over four Indian stations is compared with TOMS (Total Ozone Mapping Spectrometer) ozone data published by NASA and is shown in Fig. 1. The two

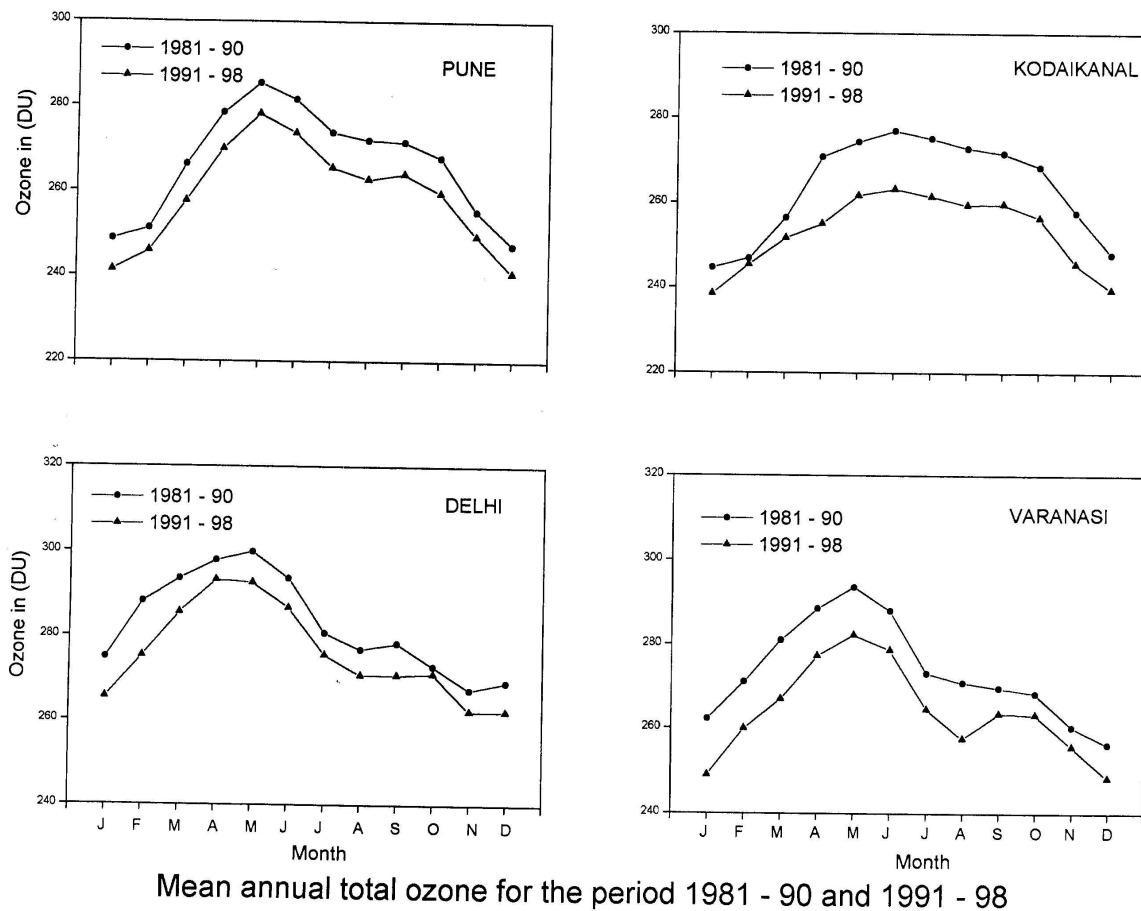


Fig. 3. Mean annual total ozone for two different periods viz., 1981-90 and 1991-98

ozone data sets are in good agreement. It is observed that the average difference between two data sets is not more than $\pm 3\%$. Thus the data utilized for the present study is quite reliable.

The daily ozone data for the period of 18 years (1981-98) is utilized to work out the monthly means of ozone for four stations mentioned above. These monthly ozone values were used to study the ozone variations. To remove seasonal changes, the average total ozone for each month has been calculated by considering 18 years total ozone for the same month and this average ozone value is subtracted from the corresponding month of the years. Annual means of ozone were also calculated by utilizing the same data.

3. Results and discussion

The variations in total column ozone have been studied by several research workers (Chandra and McPeters, 1994; Grant, 1992; Randel and Cobb, 1994). In the present study an attempt has been made to study

ozone variations over the Indian region. It is seen from the data that the ozone variations during the period 1981-90 are more or less same and there is no specific ozone trend either decreasing or increasing during this decade. However results are interesting from the period 1991 onwards as ozone values decreased up to 1993 and thereafter started recovering. The ozone anomalies for the period 1981 to 1998 are shown in Fig. 2. The ozone anomalies are positive for the decade 1981-90 and negative for the period 1991-98. Thus it can be said that ozone values for the period 1991-98 are lower than those of 1981-90. This feature is seen in Fig. 3 in which mean annual total ozone for the two periods mentioned above is plotted for comparison.

The ozone variations in the tropics are mainly controlled by QBO in lower stratospheric wind and solar cycle. Inter-annual variability in tropical ozone is dominated by an approximate 2-year cycle, which is closely linked with the QBO in zonal wind and temperature in the tropical stratosphere. A strong QBO component in ozone is also observed at extra-tropical

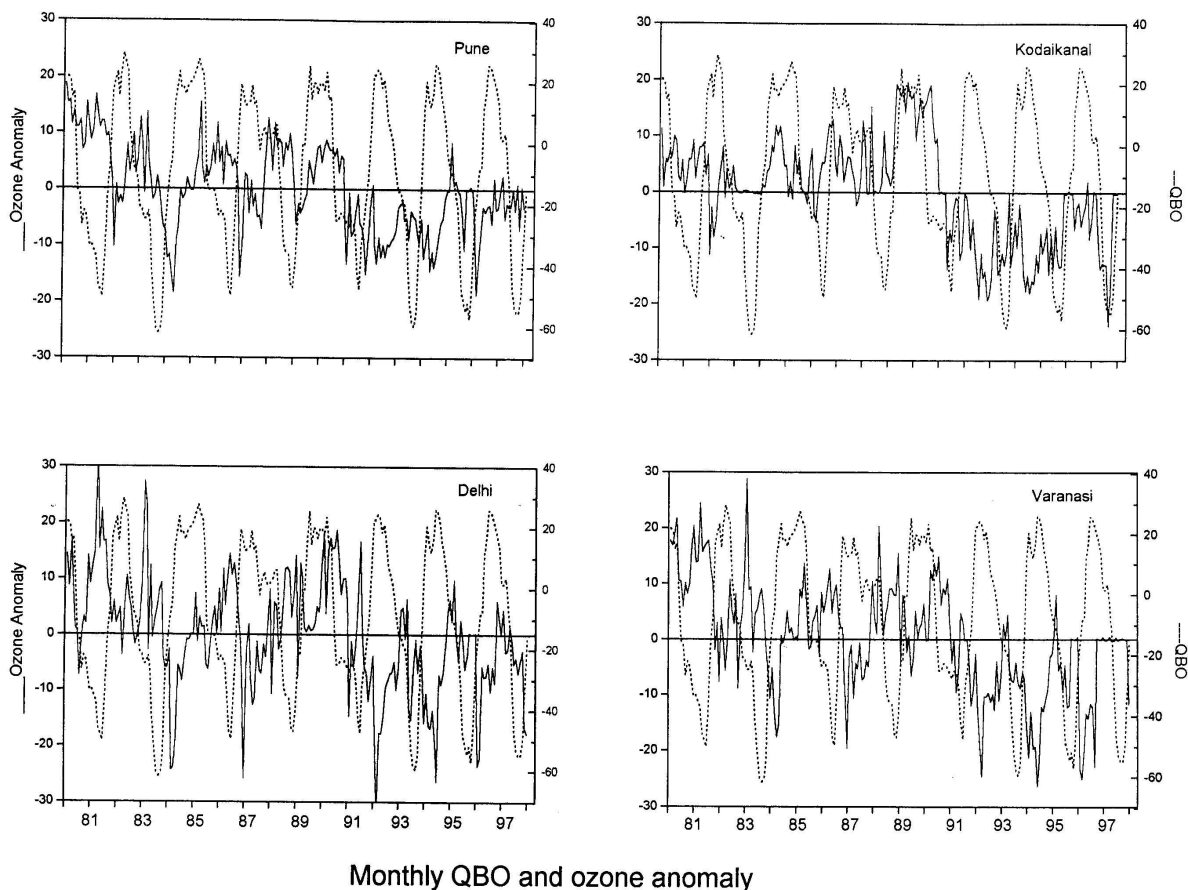


Fig. 4. Monthly total ozone anomalies and QBO (mean zonal wind of 30 and 50 hPa for Singapore)

latitudes in both hemispheres. Analysis of long term records of global satellite data from TOMS have clearly documented characteristics of the global QBO in column ozone (Bowman, 1989; Lait *et al.*, 1989; Chandra and Stolarski, 1991; Randel and Cobb, 1994). The main results of these analyses show: (i) Column ozone variations near the equator ($\leq 10^\circ$ latitude), approximately in phase with equatorial zonal winds near 30 hPa, and (ii) extra-tropical anomalies over approximately $15^\circ - 60^\circ$ latitude in each hemisphere, approximately out of phase with the tropical signal. The amplitude of the column ozone QBO anomalies is of the order 2-4% of the mean ozone amount. In the present study, Singapore averaged winds of 30 and 50 hPa are considered for QBO and plotted in Fig. 4 along with ozone anomalies for the period of 1981 to 1998 for four Indian stations. It is seen from the figure that ozone at Kodaikanal show in phase relation with QBO up to 1991 and thereafter this relation is not seen apparently. Ozone at remaining stations also show in phase relation with some phase lag upto 1991 and thereafter this relation is not seen apparently. As per Schoeberl *et al.*, (1993), equatorial total ozone normally follows the phase of the QBO in lower stratospheric equatorial winds. During the

easterly phase, ozone amounts are lower while during the westerly phase the amounts are higher as a result of the secondary circulation associated with the QBO. They have concluded that the ozone decrease in the tropics following the Pinatubo eruption amounts to a 5-6% decrease over climatology of easterly phase QBO years.

Changes in solar ultraviolet spectral irradiance directly modify the production of ozone in the upper stratosphere (Brasseur, 1993), and hence it is reasonable to expect a solar cycle variation in ozone amounts. Analysis of ground-based records extending over three to six decades indicate the existence of a decadal time scale variation of total ozone that is approximately in phase with the solar cycle (Angell, 1989; Zerefos *et al.*, 1997). The solar cycle along with the ozone anomalies is shown in Fig. 5. Two solar minima occurred in 1985, 1996 and solar maximum occurred in 1991. Ozone at all four stations show in phase relation with solar maximum but do not show in phase relation in declining phase of solar cycle (solar minima). Thus ozone variations after 1991 cannot be explained only with the QBO and solar cycle and it becomes essential to include the effect of volcanic

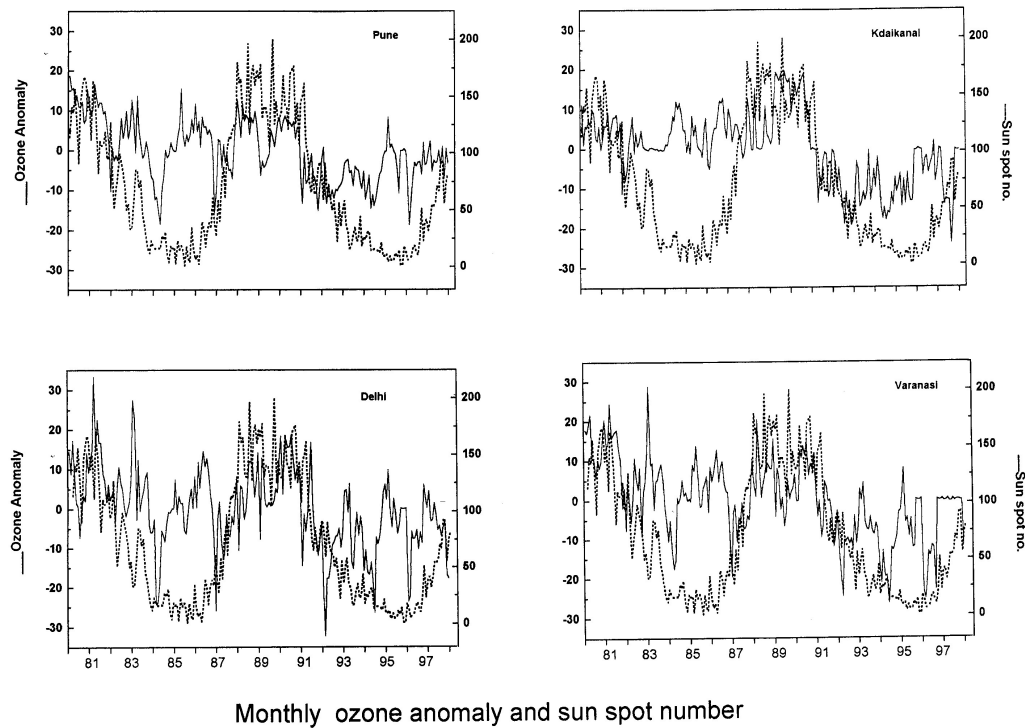


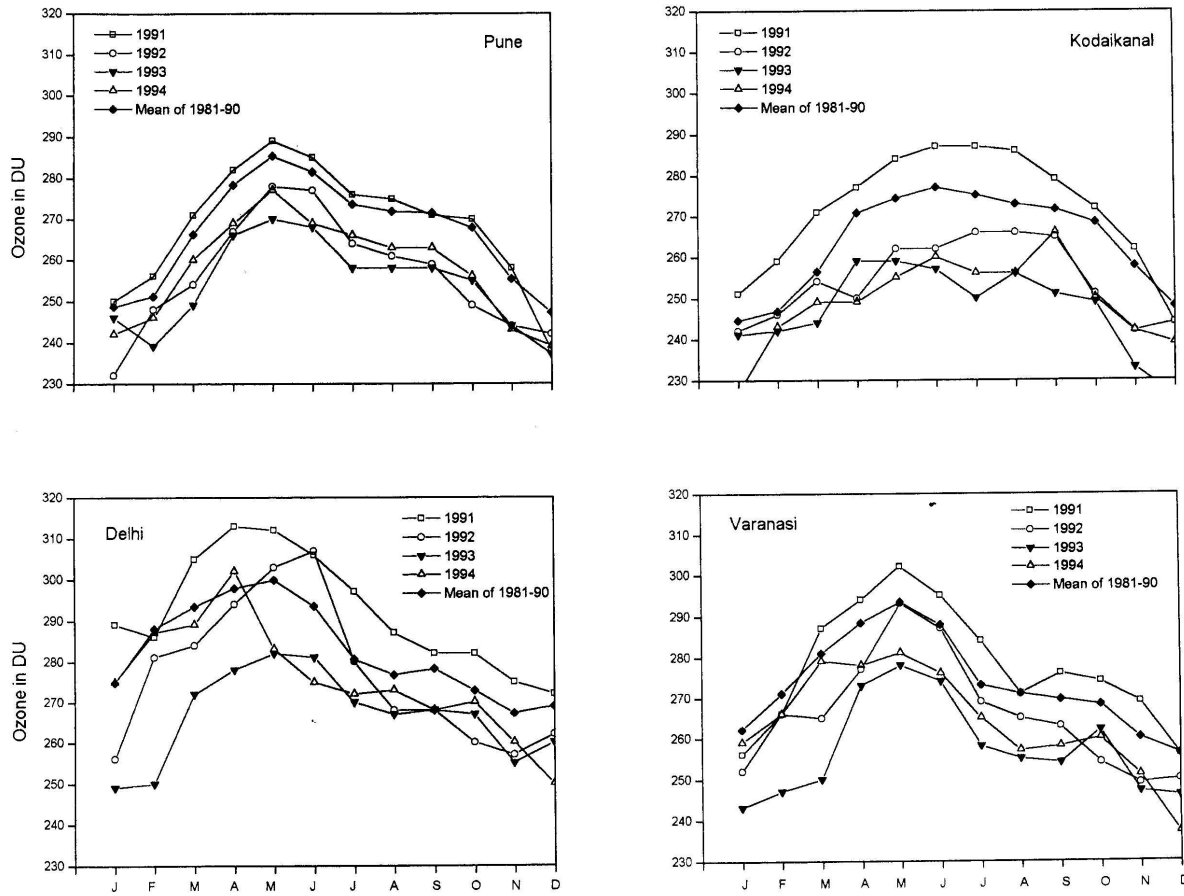
Fig. 5. Monthly total ozone anomalies and sunspot number

aerosols produced by Mt. Pinatubo eruption. In the present study ozone anomalies which are negative after 1991 may be the combined effect of the Pinatubo eruption and declining phase of solar cycle. Further it is seen from Fig. 4 that during 1983 ozone minima was observed for all stations and this may be attributed to El Chichon eruption of April, 1982. The Mt. Pinatubo injected larger amounts of volcanic material into the stratosphere than El Chichon. Thus the effect of Mt. Pinatubo eruption was seen for longer period as compared to El Chichon eruption. The ozone minima are observed during 1992-93, 1994-95 and 1996. The ozone minima occurred during 1994-95 and 1996 may be the effect of solar minima however the ozone minimum during 1992-93 might have caused by Mt. Pinatubo eruption.

Earlier studies made to estimate the effects of Mt. Pinatubo eruption on ozone showed ozone reduction of about 5% at mid-latitudes (Zerefos *et al.*, 1994; Coffey, 1996) and about 2% in the tropics (Angell, 1997a). The chemical ozone destruction is less effective in the tropics, but lifting of low ozone concentration layers with aerosol cloud (Kinne *et al.*, 1992) causes a fast decrease in ozone mixing ratio in the low latitudes. The aerosols produced by heterogeneous chemistry reactions are responsible for changing the solar radiation fields in ways that also contribute to reduce ozone (Michelangeli *et al.*, 1989). For Mt. Pinatubo, the maximum aerosol optical depth

measured was 0.5 (Stowe *et al.*, 1992). It could have accounted for a large fraction of the observed tropical ozone changes in ozone (Grant, 1992). The radiation perturbations induced by the aerosols is an important depletion mechanism for ozone at least at tropical latitudes where the optical thickness of volcanic particles has remained sufficiently high for several months after the eruption (Pitari and Rizi, 1993). In fact low latitude stratosphere is the production factory of ozone from where ozone is transported towards the higher latitudes, hence it becomes necessary to study the factors which affect the ozone production rate. In the tropics the ozone decrease is less than the 2% following all three eruptions of Agung, 1963; El Chichon, 1982 and Mt. Pinatubo, 1991 (Angell, 1997b). Ozone-sonde measurements at Hilo, Hawaii (20° N), after the eruption of Pinatubo, are compared to measurements made there from 1985 to 1990 in order to investigate possible volcanic effects. The general nature of O₃ anomalies in 1991-92 can be summarized as lower than normal ozone below about 25 km and higher than normal ozone above. The net result was that total ozone was somewhat lower than average and, during late 1992 was as low as recorded in 1982, following the eruption of El Chichon (Hofmann *et al.*, 1993).

Mean annual ozone for the period 1981-90 and annual ozone for the individual years 1991 to 1994 are plotted in Fig. 6. It is seen from the figure that ozone



Monthly ozone for the years 1991-94

Fig. 6. Mean of monthly ozone for the period 1981-90 and monthly ozone for individual years, 1991 to 1994

values during 1991 are more than average ozone for 1981-90, however ozone values for the years 1992, 1993 and 1994 are lower than average ozone. It can be said that ozone values started decreasing from 1992, reached to minimum during 1993 due to Mt. Pinatubo eruption and then started recovering from 1994.

Mean yearly total ozone for the four Indian stations is averaged for the period 1981-98 to represent the yearly mean ozone over the Indian region. The deviations of yearly ozone from the 18 years mean ozone have been calculated. The percentage deviations computed from yearly deviations are shown in Fig. 7. This figure also shows that ozone deviations are more negative during 1992-93.

4. Conclusions

The highlights of the above study are as follows :

(i) The ozone anomalies are positive for the period 1981-90 and negative for the period 1991- 98.

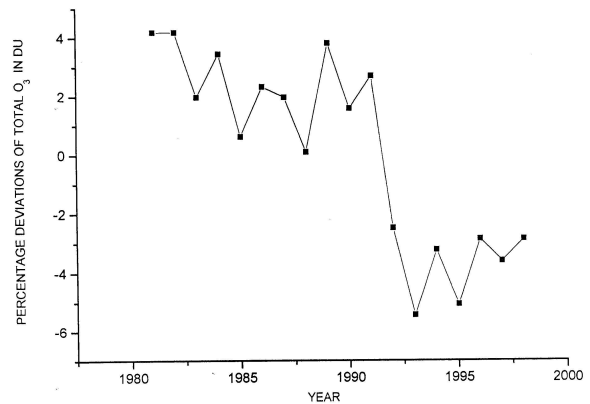


Fig. 7. Percentage deviations of average yearly ozone over Indian region

(ii) Mean annual ozone amounts for the period 1991-98 are lower than those of 1981-90.

(iii) The contribution of QBO and solar cycle to total ozone for the two different periods of 1981-90 and

1991-98 is almost same. But the total ozone amounts for the later period are lower. These lower amounts may be attributed to the Mt. Pinatubo volcanic eruption.

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