Estimation of Regional Stratospheric Ozone Concerning Pakistan

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Abstract

Total Stratospheric Ozone Dobson Spectrophotometer data of 16 stations around Pakistan and its adjoining area are investigated in the present analysis over the period 1958–2004 except some stations where the data for the said period is missing in-between. The data distribution in terms of the latitude range from 10.20 °N to 42.82 °N and longitude range from 51.35 °N to 91.14 °N. This study investigates the annual Stratospheric Ozone concentration and variation over Pakistan. Further long term trend of Ozone is studied and anomalies from zonal mean total Ozone data- mean of Dobson, Brewer and Filter Ozone data- are interrelated with stations located in the east of Pakistan. The annual Ozone averages in the upper parts of the country vary from 320 DU to 290 DU, in the central parts from 290 to 270 DU and 280 DU to 260 DU in the southern parts of Pakistan for the whole year. The results further reveal declining trend of Stratospheric Ozone in the regions south east as compared to other parts of the country. By fixing Latitude 30±5 °N the Ozone data of Quetta is correlated with Isfahan, New Delhi, and Varanasi (Banaras) showing close qualitative correlation confirming the fact that except slight meridional change, latitudinal variation remains the same.

Keywords: Stratospheric Ozone; Dobson Unit (DU); Chlorofluorocarbon (CFC); Photic zone; Anthropogenic emissions.

Introduction

Stratospheric Ozone is layer of oxygen molecules (O_3); formed in stratosphere, located above 15 to 35 km a.m.s.l where Ordinary O_2 is converted into O_3 by chemical process in the presence of ultraviolet (UV) radiation. It prevents most harmful UV band wavelengths (280–315 nm) to penetrate the Earth's atmosphere. It is suspected that a variety of biological consequences such as increases in skin cancer, cataracts (Dyer, 2005) damage to plants, and reduction of plankton populations in the ocean's photic zone result from the increased UV exposure due to Ozone depletion.

The Antarctic "Ozone Hole" was brought to light to scientific community after a paper was published in Nature 1985 (Farman et al., 1985). The magnitude of the climate-induced Ozone changes in the troposphere remains smaller than the changes produced by enhanced anthropogenic emissions (Brasseur et al., 2005). The observed and projected decreases in Ozone have generated worldwide concern leading to adoption of the Montreal Protocol that bans the production of Chlorofluorocarbons (CFCs) and halons - mainly found in industrial solvents and spray aerosols, insecticides, and also used in foam products, refrigerators, air conditioners and freezers as well as related Ozone depleting chemicals such as increase in atomic Chlorine and Bromine in the Stratosphere. CFCs stay in atmosphere from 50 to 100 years.

The instrument most widely used for measuring thickness of total Ozone layer is Dobson Spectrophotometer designed in 1920s and still in use today. The Dobson instrument, located on ground, measure the solar radiation transmitted through Ozone layer at pair of wavelengths near 300 nm. One wavelength is significantly absorbed by Ozone while the other is attenuated in the instrument by calibrated optical wedge. Another ground based instrument for the measurement of total Ozone column is Filter Ozonometer. Developed in mid 1950s, the instrument encountered multiple systematic errors. However, latter it was improved by implementing narrow band light filters. Besides Brewer spectrophotometer is also used for total Ozone measurement. The retrieval of data scheme is similar to Dobson spectrophotometer. Total Ozone is derived by comparing direct sun signals measured at wavelengths of 306.3, 310.1, 313.5, 316.8 and 320.1 nm. Most of the data used in this paper is that of Dobson spectrophotometer except zonal mean total Ozone data - mean of Dobson, Brewer and Filter Ozone data for the same period (Stolarski et al., 1992).

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The Dobson unit (DU) is a unit of measurement of atmospheric Ozone columnar density. One Dobson unit refers to a layer of Ozone that would be 10 µm thick under standard temperature and pressure (STP). Its unit is measured in millimeter (mm) (McNaught et al., 1997). One DU occupies 2.69*1016 molecules per square centimeter (Schwartz S. E and P. Warneck, 1995). The baseline value of 220 DU is chosen as the starting point for Ozone hole since total Ozone value of less than 220 DU was not found in the historic observation prior to 1979.

Quasi-Biennial Oscillation thoroughly influence transportation of Stratospheric Ozone from tropics to higher latitudes (Rohli, 2011). It is explicit that why DU value increases from tropics to polar region.

Total global Ozone is extensively studied since the inception of Ozone hole particularly in the tropical region having the fact that 38% of global Ozone is located between 25 °S and 25 °N. Bojkov and Fioletov (2006) observed the decline of 3% in average of total global Ozone in the period 1984–1993. Similar observations were made by Gleason and Bhartia et al., (1993) where Ozone amounts were low in a wide range of latitudes in both the northern and southern hemispheres, and the largest decreases were in the regions from 10 °S to 20 °S and 10 °N to 60 °N.

Besides global decrease in total Stratospheric Ozone concentration, similar pattern of studies are also conducted concerning South Asia region. Sahoo and Sarkar et al., (2005) observed the decline trend of Ozone in the northern parts of India. Maida and Rasul (2010) reported the decreasing trend in Stratospheric Ozone over Pakistan for the period 1987-2008 with annual change up to -5.67 DU and monthly decrease found −4.2 DU for the same period.

Methodology

1. Ozone data of Dobson Spectrophotometer for different stations (16 in total) in the region surrounding Pakistan were taken on daily basis from the World Ozone and Ultraviolet Radiation Data Centre (WOUDC). Its monthly averages were calculated. This data set was spatially distributed and graphically represented by using Arc GIS 9.1 technique of spatial analysis tool “Kriging” with output cell size of 0.105826. Its contours were drawn by surface spatial analysis tool of the aforementioned software. Each contour is separated by the interval of 10 DU. The output images are presented in Figure (1) to (6) along with overall variations in data set showed in Table (1).
2. Pakistan is mainly divided into three geographical areas. The Northern Highlands; Indus River plains and Balochistan plateau. Indus River plains further include Pothohar Plateau and plains of Punjab. The monthly data is discussed accordingly.
3. There is only one station available in Pakistan regarding Dobson Spectrophotometer located in Quetta. One station data cannot cater for the whole region of Pakistan. Since the observed Ozone variations in the tropics is dominated by zonal mean vertical motions with relatively large variations in tropics up to 50 °N with marginal mean meridional transport (Randel, 1993). Stations located in the vicinity of Eastern regions of Pakistan i.e. Srinagar, New Delhi, and Mount Abu were selected having latitudes 34.1 °N, 28.65 °N and 24.6 °N respectively for representing latitudinal profile of Pakistan. Quetta, having latitude 30.11 °N, is selected to represent the western parts of Balochistan Plateau and Sindh plains. Data set of Stratospheric Ozone zonal mean value of Dobson, Filter and Brewer with the interval of 5° was obtained from WOUDC. The deviation of the selected stations were deduced and presented in Figure (7), (8), (9) and (10).
4. Similarly, by fixing latitude 30±5°, Stratospheric monthly Ozone data of Isfahan, New Delhi, and Varanasi having latitudes 32.51 °N, 28.65 °N, 25.317 °N respectively were compared with Quetta (Lat: 30.11 °N). The comparison is presented in Figure (11), (12), and (13).

Results and Discussion

The spatial and temporal annual variation, on monthly basis, is drawn in the Figure (1) to (6) respectively. The monthly Stratospheric Ozone shift over Pakistan was studied and analyzed. The maximum value of DU prevails from March to June, 320-300 DU in upper parts to 280 DU in lower parts of the country. However, its value decreases from July i.e. 290-280 DU to 260 DU until December. In the upper parts of Pakistan, DU ranges from 320 to 290 with maximum of 320 DU in the month of January to March. In the central regions of Pakistan Ozone overall value varies from 290 DU in the month of March as its peak and decreases to 270 DU from September to December. Similarly in the lower parts of the country DU value decreases further to 280 DU in the month of February to 260 DU in November and December. The DU value from August to November remains almost same except slight variation of 10 DU throughout the country. Further these empirical values drawn from Figure (1) to (6) are broadly correlated with the whole data set of all the 16 station selected in the environs of Pakistan and depicted in Table (1). The maximum value of 380 DU in the month of February with standard deviation of ±18.16 having mean value of 296 DU for the same month while both DU along with standard deviation decreases in the month September and October. However, as for as Pakistan is concerned maximum Stratospheric Ozone value as drawn from contour lines of Figure (1) to (6) reaches in the month of March. The packing of contours or the deviation of DU increases from mean value in the data set in February and decreases to 11 DU in the months of September and October.

Monthly Analysis

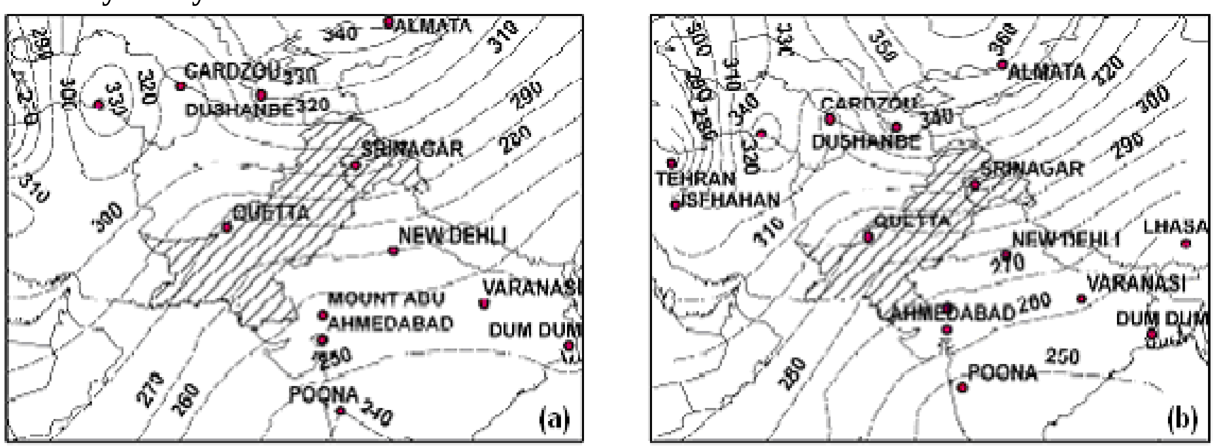

Figure 1: Zonal Flow of Stratospheric Ozone over Pakistan in **(a)** January and **(b)** February. The contour values are in Dobson unit.

In the month of January contour line of 310-300 DU passes over the northern high lands of Pakistan while 300 DU value prevails in Azad Jammu and Kashmir located in the east and FATA region in the west. In plains of Punjab, including Pothohar and upper parts of Balochistan plateau, Stratospheric Ozone lies in the range of 290-280 DU and over the southern parts of Sindh plains its value reduces further to 270. In costal areas of Pakistan 260 DU dominates during the month of January.

The overall variation in Stratospheric Ozone in the month of February is 330-270 DU with northern regions 330 to 310 DU, Punjab Plains up to Balochistan Plateau 300-280 DU and Sindh plains along with coastal areas 270 DU.

In month of March, Figure 2(a), the reduction of Stratospheric Ozone thickness is 10 DU. In upper parts of northern areas DU remains 310 and in Punjab plains 300 DU. However there is an increase of 10 DU, i.e. 280 DU in plains of Sindh and Balochistan plateau as compared with January and February, Figure 1(a) and (b) respectively.

In April, the DU value remains the same in all parts of the country except northern areas where decrease of 10 DU is observed as compared to the first three months of the year.

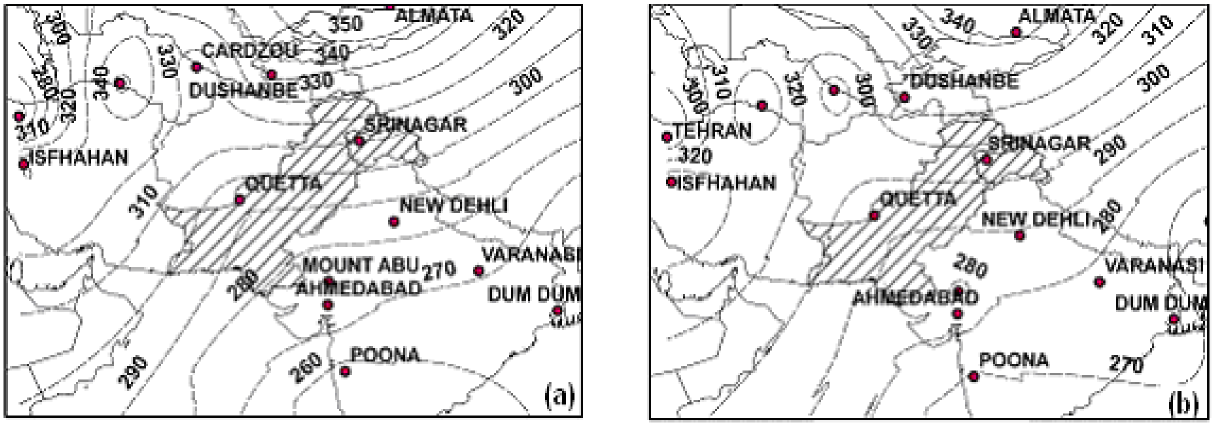

Figure 2: Zonal Flow of Stratospheric Ozone over Pakistan in **(a)** March and **(b)** April. The contour values are in Dobson unit.

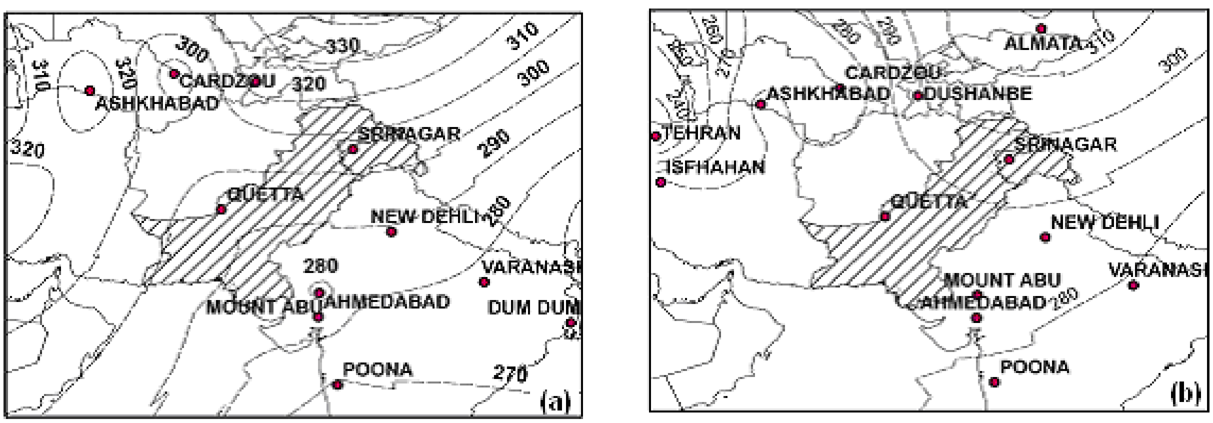

Figure 3: Zonal Flow of Stratospheric Ozone over Pakistan in **(a)** May and **(b)** June. The contour values are in Dobson unit.

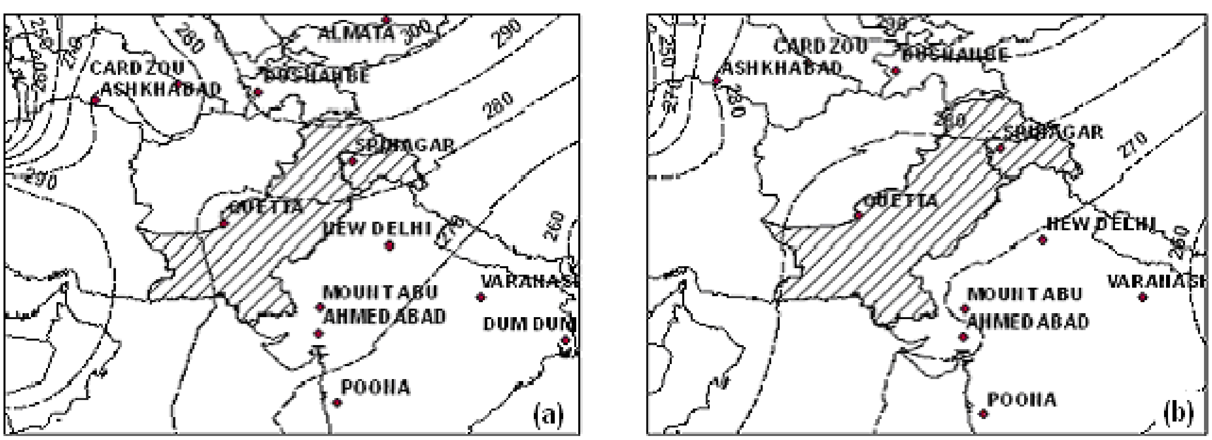

Figure 4: Zonal Flow of Stratospheric Ozone over Pakistan in **(a)** July and **(b)** August. The contour values are in Dobson unit.

During the month of May, Figure 3(a), northern areas observe 310 DU of Stratospheric Ozone while 300 DU in upper Parts of Punjab plains whereas its value reduces to 290 DU in Sindh plains and Balochistan. Over coastal areas of the country, the Stratospheric Ozone amounts to 280 DU approximately. Similarly in June, Figure 3(b), Stratospheric Ozone DU value in northern high lands and in the plains of Indus river stands reduced with the increment of 10 DU. The DU value remains unchanged in the lower half of the country.

In July, DU value in the northern areas is 290, Figure 4(a). Over the plains of Punjab, including Pothohar region and upper parts of Balochistan plateau, its value remains 280 DU. In August, Stratospheric Ozone contour of 280 shifts to the north while in central and southern region DU value reduces to 270 , Figure 4(b).

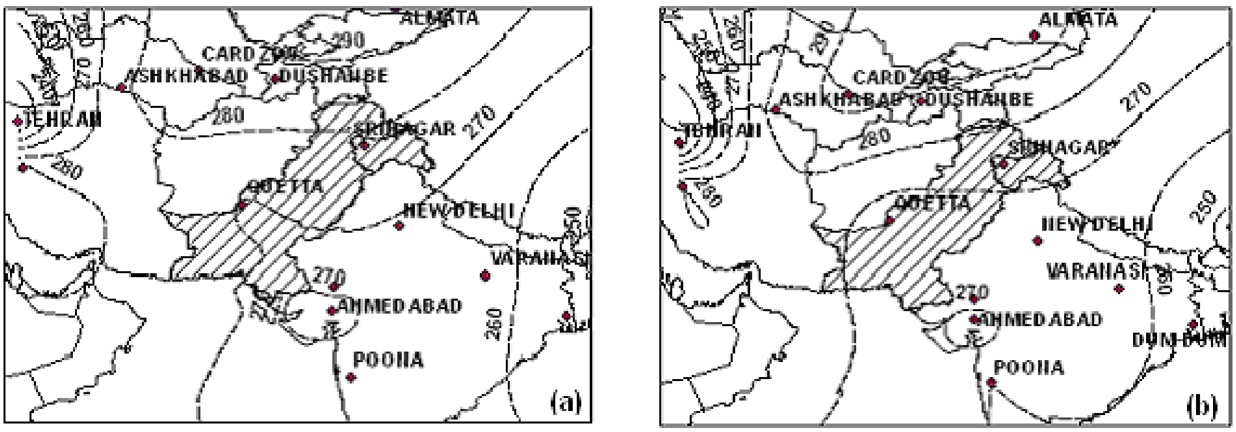

Figure 5: Zonal Flow of Stratospheric Ozone over Pakistan in **(a)** September and **(b)** October. The contour values are in Dobson unit

In case of September and October prevailing DU values remain the same as in the month of August. However Ozone shield in November is 280 DU over the northern half of Pakistan. In upper parts of Pothohar region and plains of Punjab, the DU value is 270. In Balochistan Plateau and Sindh plains DU value approaches 260, Figure 5(a) and 5(b).

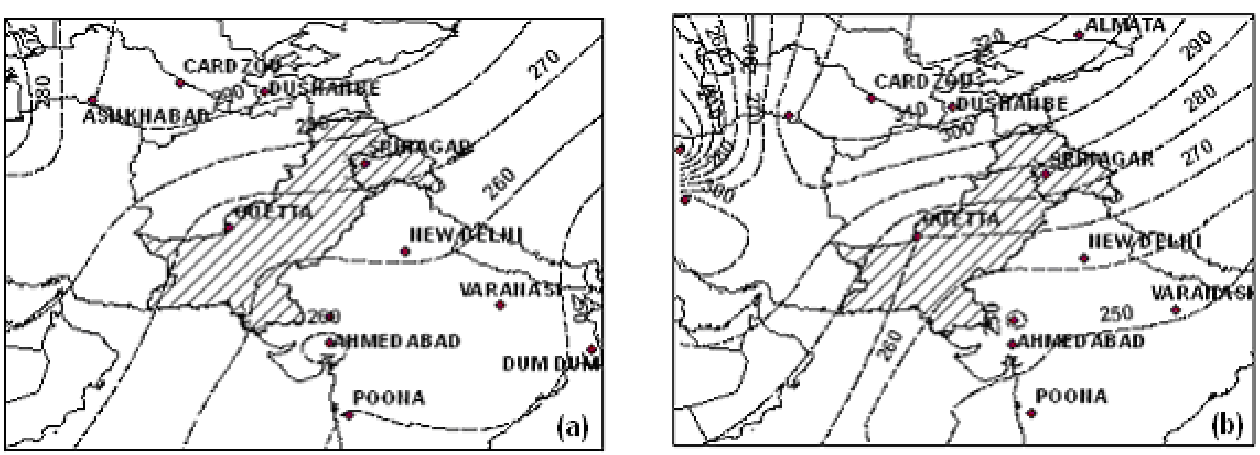

Figure 6: Zonal Flow of Stratospheric Ozone over Pakistan in **(a)** November and **(b)** December. The contour values are in Dobson unit.

In the month of November, the Stratospheric Ozone reaches to its lowest in all parts of the country. Northern region has 280 DU, Pothohar region and Punjab plains 270 DU while Sindh plains including the coastal region have the DU value of 260, Figure 6(a).

In December Stratospheric Ozone layer over Pakistan gets denser. Dobson unit values vary abruptly, both in terms of latitude and frequency. The status of Stratospheric Ozone increases somehow in this month with the increment of 10 DU in all parts of the county except coastal areas where the DU value always remain as much as in November, Figure 6(b).

Table 1: The overall variation in the complete data set

Month	mean	min	max	std
January	286	237	357	32.046
February	296	242	380	36.321
March	301	251	376	31.543
April	300	261	362	23.251
May	300	261	362	25.251
June	285	229	325	14.184
July	280	216	326	14.956
August	275	213	313	13.191
September	273	231	303	11.427
October	271	297	223	11.569
November	270	239	301	16.254
December	276	216	327	25.561

Departure from Normal

Taking into account Figure (7), (8), (9), (10) en-bloc, indicate negative trend in 80s. The overall annual mean anomaly shows decreasing trend in stations located in the Eastern regions of surrounding Pakistan i.e. Mount Abu and New Delhi. However the slop line is much more negative in case of former then later pointing out Stratospheric Ozone reduction in the South Eastern region of Pakistan.

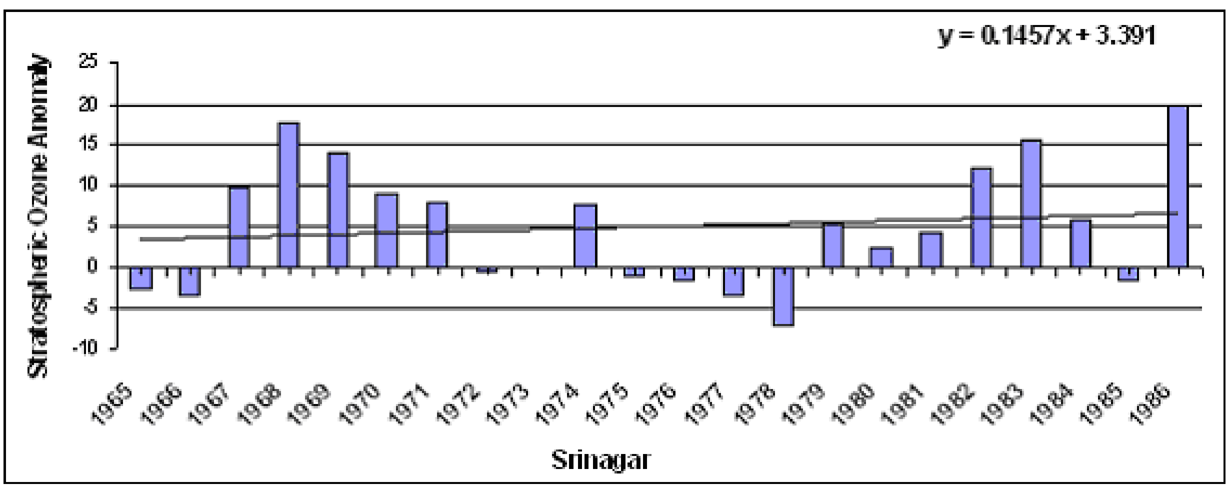

Figure 7: Deviation of annual mean concentration of Ozone at Srinagar. Time series of anomalies are presented for the data availability period.

In figure (7), Ozone concentration in Srinagar in late 60s and early 70s show positive trend with highest departure of 18 points above normal recorded in 1968. From 1972 onwards anomaly show negative trend which increases further up to the year 1979. There is again increasing trend observed from 1980 onwards. The overall variation is positive indicating no harm as such to the northern parts of the country.

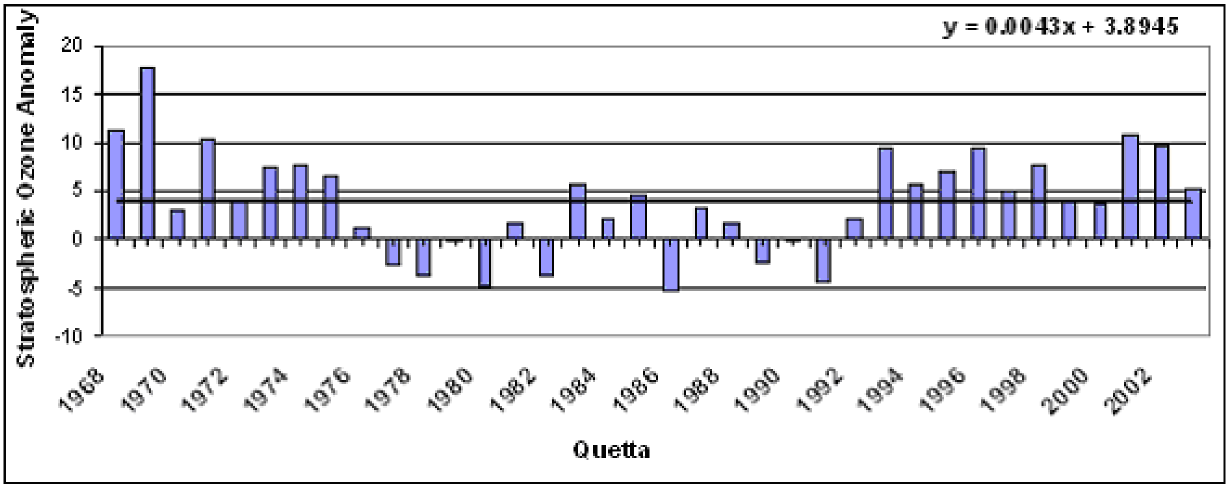

Figure 8: Deviation of annual mean concentration of Ozone at Quetta. Time series of anomalies are presented for the data availability period

Stratospheric Ozone anomaly observed in Quetta, Figure (8), from 1968 to 1976 show positive trend with maximum of 18 DU above normal recorded in 1970. From 1976 to 1993, there is vacillating behavior of the Ozone vertical column prevailing over the Quetta. However the negative trend exceeds the positive one which is partially observed in the years 1984, 1988 and 1989 respectively. In the start of 90s, Ozone concentration increases from normal within the range of 04 DU to 11 DU. The overall trend in terms of anomaly is neutral.

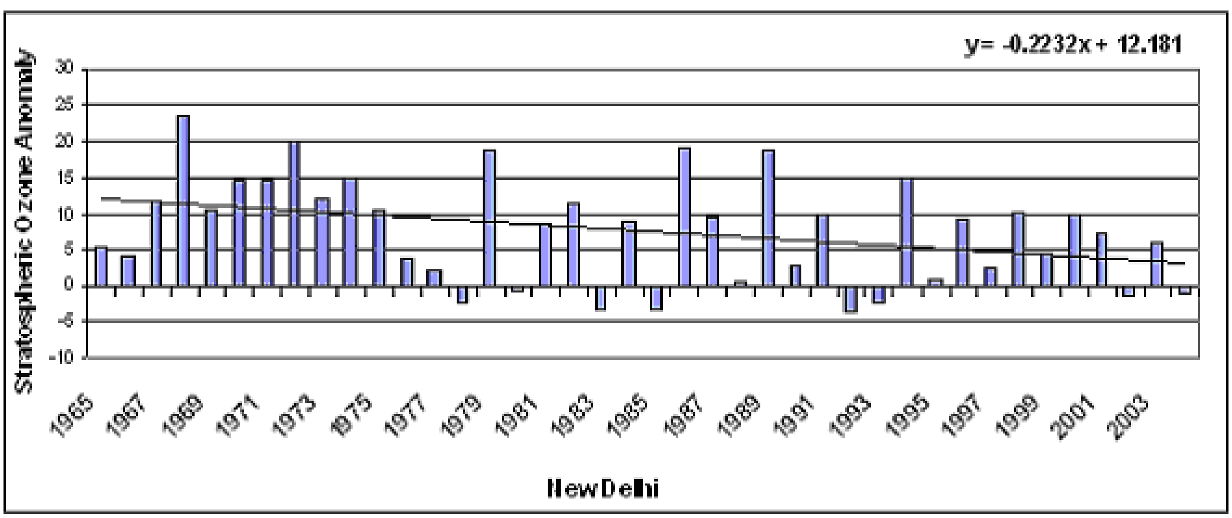

Figure 9: Deviation of annual mean concentration of Ozone at New Delhi. Time series of anomalies are presented for the data availability period.

Similarly, New Delhi, Figure (9) shows above normal Ozone level from 1965 to 1977 with maximum increase observed in 1968. There is almost increasing trend in 80s with slight decrease of 04 DU each in 1984 and 1986 respectively. Except minor decreases in the start of 90s, the trend is positive in all the other years of the same decade. However the overall trend line is negative indicating departure of 09 DU from normal in the whole time series for New Delhi.

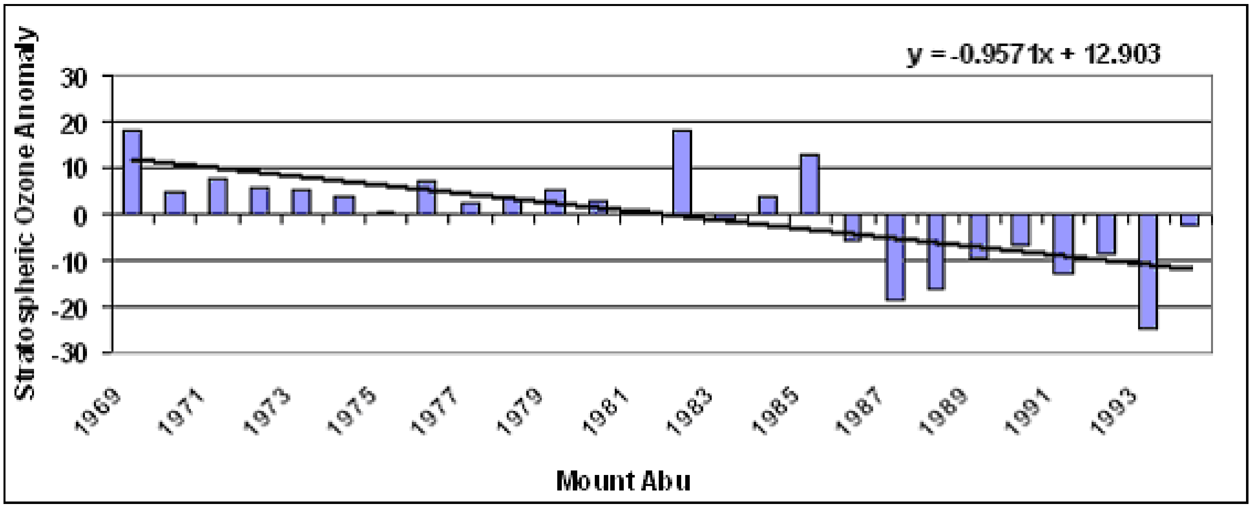

Figure 10: Deviation of annual mean concentration of Ozone at Mount Abu. Time series of anomalies are presented for the data availability period.

Mount Abu, Figure (10) rather shows asymmetrical trend if compared with all the other three stationed i.e. Srinagar, Quetta and New Delhi. From 1969 to 1983, above normal annual mean Ozone concentration is observed, but onwards up to 1994; there is incremental decreasing trend reaching its lowest point in 1993 which is 25 DU below normal. Such a sharp and regular decrease is an alarming situation for the future of Stratospheric Ozone in the region.

Comparison of Quetta with stations having same Latitude (±5º)

Three stations .i.e. Isfahan, New Delhi, Varansai having latitudes 32.51 °N, 28.65 °N, 25.31 °N respectively are compared with Quetta (30.11 °N). It can be seen in the graphs that all the three stations show close correlation through out the year. In case of the values of Isfahan, Figure (11), is quit higher then Quetta, while the later is more closely correlated with New Delhi. It confirms the fact that besides minor meridional changes Stratospheric Ozone variation along the latitude remains the same.

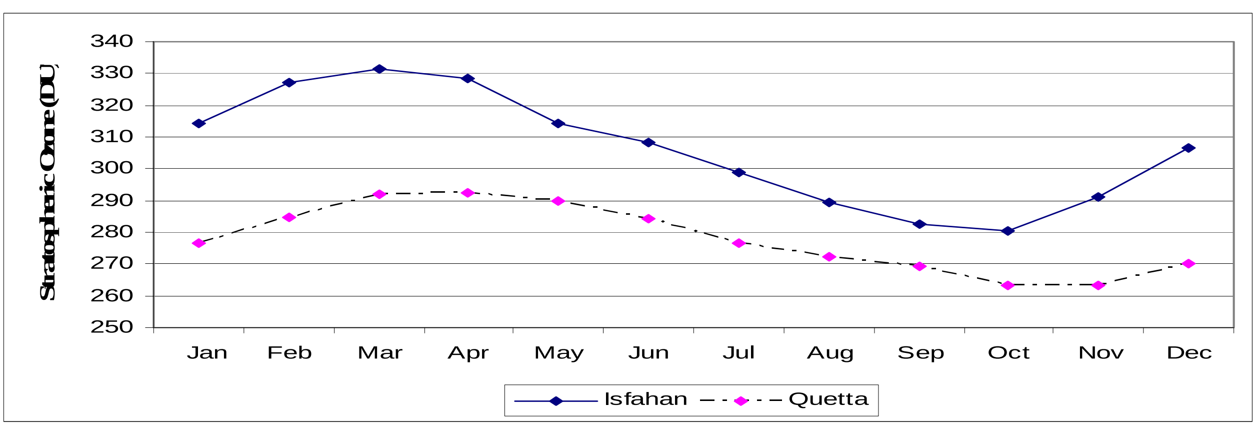

Figure 11: Comparison of monthly mean variation between Isfahan and Quetta

Monthly comparison between Quetta and Isfahan, Figure (11), shows good qualitative correlation, but in case of later DU values are higher throughout the year. From May to October the difference reduces from 24 DU to mere 10 DU. However, in the succeeding months the difference gets larger and larger. From January to April the difference is as much as 40 DU.

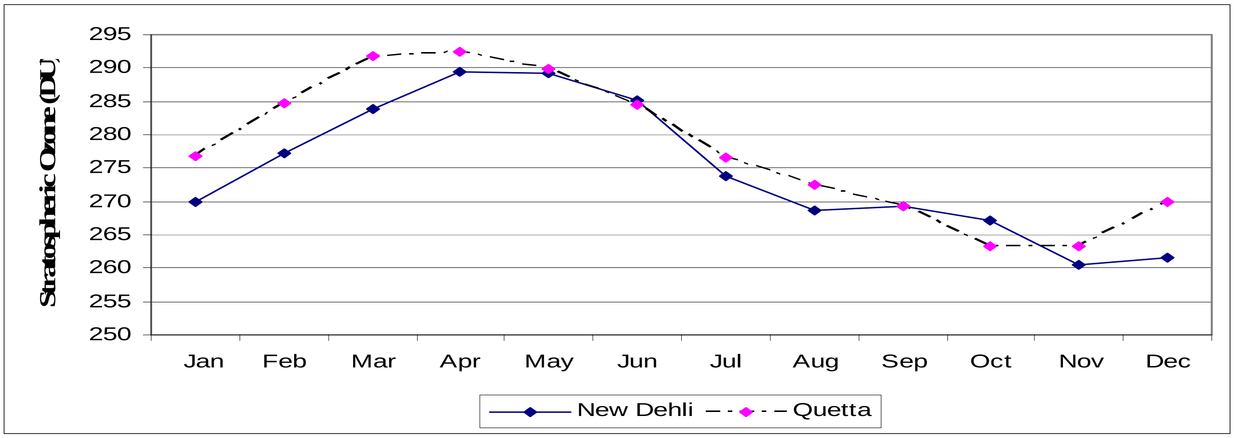

Figure 12: Comparison of monthly mean variation between New Delhi and Quetta

Quetta and New Delhi, Figure (12), shows very close qualitative and quantitative correlation from April to November. In all other months the difference is not more than 05 DU.

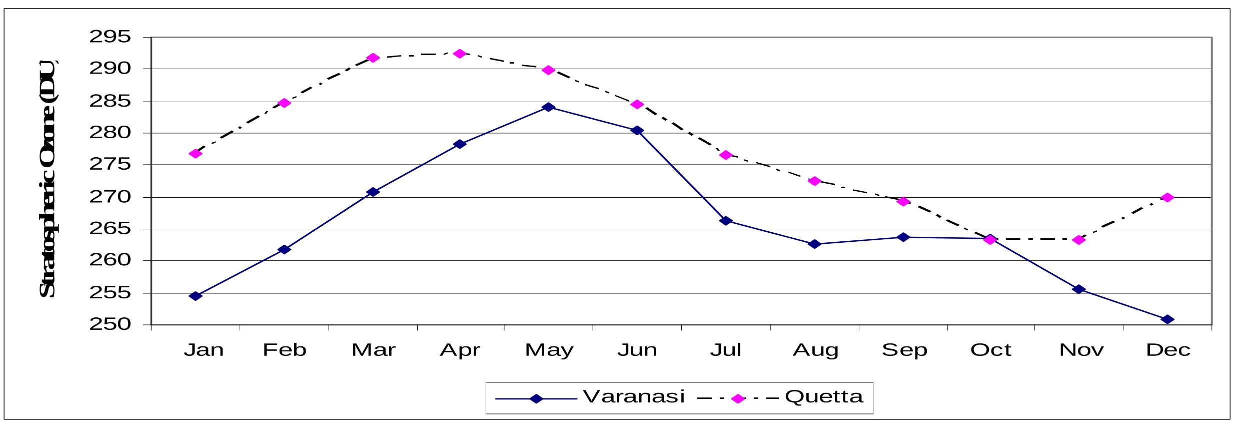

Figure 13: Comparison of monthly mean variation between Varanasi and Quetta

Similarly, monthly mean variation between Quetta and Varanasi, Figure (13), is not much in agreement with each other. From December to March the DU difference is 22. In the succeeding months i.e. April to June the difference reduces to 05 DU. However from July to September the difference in terms of DU is 10. In the month of October both stations has almost same value of DU.

Limitations

There is only one ground based station of Dobson Spectrophotometer available in Pakistan regarding measurement of stratospheric Ozone. Stations in the surroundings of Pakistan are also sparsely populated. Most of the stations have no complete data sets. Further there is no station, at all, available in the Middle East so the area covered by the contours depicts false data of the region and therefore South West region of Pakistan cannot be assessed from that data.

Conclusion

It is evident from the study that Ozone layer prevailing over Pakistan is vulnerable to serious variations. Although Ozone values vary around 320-290 DU in the north while 260 in the Southern parts of the country which is well above 220 DU yet negative trends in the south eastern region of the country clearly indicate an alarming scenario for depletion of total Ozone concentration. In northern region trend is positive in terms of annual anomalies. However all the other stations show decreasing trend.

Recommendations

Stratospheric Ozone is a shield that protects us from the harmful UV radiation. A continuous watch on its status is an important element for its investigation and generation of future scenarios. Ground stations observing Stratospheric Ozone is populated over the South Asian rgion with gaps in-between which distort the true picture when the data is extended for any particular region. Again, the instruments need to be calibrated after regular intervals otherwise the data drawn from the instrument depart from its true values with the passage of time. There is also missing pockets in the data series of many countries located in Asia. A proper maintenance of data and sending it to the end users on regular basis must be the preferred task of every observatory concerning Stratospheric Ozone.

References

Bojkov, D. R and V. E. Fioletov, 2006: Estimating the Global Ozone Characteristics during the last 30 years Atmospheric Research Volume 80, Issues 2-3, May 2006, Pages 151-164

Brasseur, G. P., M. Schultz, C. Granier, M. Saunois, T. Diehl, M. Botzet and E. Roeckner, 2005: Impact of Climate Change on the Future Chemical Composition of the Global Troposphere. Journal of climate- Special Section Vol. 19 Pages 3932-3951

Chandramadhab, P, 2010: Variability of Total Ozone over India and its Adjoining Regions during 1997–2008. Atmospheric Environment Volume 44, Issue 15, May 2010, Pages 1927-1936

Dyer, O., 2005: Surgeon is struck off for second time, BMJ 2005; 331:1292 (Published 1 December 2005)

Ennis, C. A, 2002: Scientific Assessment of Ozone Depletion: WMO Global Ozone Research and Monitoring Project- Report No. 47

Farman, J. C., B. G. Gardiner and J. D. Shanklin, 1985: Large Losses of Total Ozone in Antarctica Reveal Seasonal Cl0x/NOx Interaction published in Nature 315: 207-10

Fioletov, V. E, and G. E Bodeker, 2002: Global and Zonal Total Ozone Variations Estimated from Ground-Based and Satellite Measurements: 1964–2000 J. Geophysics. Res., 107(D22), 4647, doi: 10.1029/2001JD001350.

Gleason, J. F., P. K. Bhartia, J. R. Herman, R. M. Peters, P. Newman, R. S. Stolarski, L. Flynn, G. Labow, D. Larko, C. Seftor, C. Wellemeyer, W. D. Komhyr, A. J. Miller and W. Planet, 1993: Record Low Global Ozone in 1992. Science 23 April 1993: Vol. 260 No. 5107 page. 523-526

Maida, Z. and G. Rasul, 2010: Status of Stratospheric Ozone over Pakistan 1987-2008. Journal of Environmental Protection, 2010, 1, Pages. 374-383

McNaught, A. D and A. Wilkinson, 1997: IUPAC, Compendium of Chemical Terminology, 2nd Ed: (the "Gold Book") Blackwell Scientific Publications, Oxford

Randel, J. W, 1993: Global variation of zonal Mean Ozone during Stratospheric Warming Events. J. Atmospheric Sciences, 1993, Vol. 50 No.19 Pages. 3308-3321

Rohli, V. R. and A. J. Vega, 2011: Climatology, Secound Edition, Jones and Bartlett learning Publications, ISBN-13: 9780763791018- Page 229

Sahoo, A., S. Sarkar, R. P. Singh, M. Kafatos and M. E. Summers, 2005: Declining Trend of Total Ozone Column over the Northern Parts of India. International Journal of Remote Sensing Vol. 26, No. 16, 20 August 2005, 3433–3440

Schwartz, S. E., P. Warneck, 1995: Units for use in atmospheric chemistry. Pure Appl. Chem., 1995, Vol. 67, No. 8-9, pp. 1377-1406, doi: 10.1351/ pac199567081377

Stolarski, R., R. Bojkov, C. Zerefos, J. Staehelin, J. Zawodny, 1992: Measured Trends in Stratospheric Ozone. Science, New series, Volume 256, Issue 5055 (April 17, 1992), (342-349)