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Antarctic, Tropical And Equatorial Ozone Depletion And Their Correlation With Solar Flux

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Abstract:
The paper presents yearly and seasonal variations of total column ozone densities at Kodaikanal (10^{o}13′ N, 77^{o}28′ E), an equatorial station, Srinagar (34^{o}04′ N, 74^{o}49′ E), a tropical station and Halley Bay (76^{o}S, 27^{o}W), a British Antarctic survey station from 1988 to 2005. Yearly mean ozone values decreased gradually at all these stations with different rates from 1988 to 2005. Ozone density attained maximum during July at Kodaikanal and January to March at Srinagar and Halley Bay, whereas, minimum during January and October, respectively. Oscillatory nature of ozone variation with 10.7 cm solar flux indicates comparable contribution of solar parameter and chemical processes on ozone depletion.
Key words:*, Antarctic ozone, Equatorial ozone, Ozone depletion, Relative sunspot number, Tropical ozone.*

1.Introduction

Ozone, though a very minor atmospheric constituent, plays an important role in controlling the chemical kinetics of the atmosphere [1]. Recent ozone assessment confirms that the density of ozone had declined everywhere by a little amount [2]. But Farman et al. [3] first reported that dramatic decrease of ozone density took place at Antarctica during springtime. Several theories have been proposed by different investigators throughout the world for the dramatic decrease of ozone at Antarctica [4-5]. Chemical, dynamical and natural theories are mainly important [6].

In chemical theory, various chemical reactions play an important role in ozone depletion. The chemicals that catalyse these reactions are Ox [7], HOx [8-9], Cl and ClOx[10-11], Br and BrOx [12-14], ClOx and BrOx [15], Cl and HOx [16], CO and HOx [17-18], NOx [19-21] and PSCs (Polar Stratospheric Clouds) [22-27].

According to dynamical theory, ozone is not depleted, it is redistributed in the stratosphere. As a result, ozone hole is created at Antarctica during spring time. Conventionally ozone hole [28] is formed in a specific geographic places where its ozone abundance becomes $\leq$ 220 DU (Dobson Unit) (1DU = 0.001atm cm). Polar vortex is a small portion of its atmosphere isolated by the polar circulation during winter in that region. In southern polar region, the vortex formation is usually centered over eastern Antarctica. Antarctic polar vortex is more intense than its Arctic counterpart [6].

In natural theory, volcanic eruption, solar UV-radiation variability, relative sunspot numbers, solar flare numbers, solar flare index etc. may play an important role in ozone depletion. The effect of solar activity on ozone variation was first studied by Chakrabarty and Chakrabarty [27] in 1982. The variation of ozone with solar flare numbers [29] and solar UV-radiation [30] for the period 1967-1987 and 1978-1984, respectively, clearly showed that Antarctic ozone, solar flare number and solar UV- fluxes were mainly controlled by their October values. Intense decrease in Antarctic ozone was independent of solar flare number and solar UV-flux. Relative sunspot numbers [29] and solar flare index [31] for the period 1964-1985 had a similar effect on Antarctic ozone decline. Jana and Nandi[1] also concluded that the intense yearly decrease of Antarctic and arctic ozone concentration for the period 1986- 1997 was independent of solar parameters. The purpose of this paper is to verify the effect of solar flux on the variation equatorial, tropical and polar ozone for the later period by changing places of observation, extending the period of observation and considering the next 11-year solar cycle.

2.Characteristics Of Variation Of Ozone

2.1.Yearly Variations

Total column ozone densities of different stations have been obtained from internet website http//jwocky.gsfc.nasa.gov published from NASA, USA. Monthly mean ozone densities have been calculated from daily average value of ozone in Dobson Unit (DU) for the stations, namely, Kodaikanal, Srinagar and Halley Bay. The yearly mean ozone densities have been calculated from monthly average value of ozone in DU.

Variations of yearly mean ozone densities as well as monthly mean ozone densities for all months from 1988 to 2005 at Kodaikanal have been presented in Figure 1.The nature of variations of ozone densities for each month for different years has been compared with the variation of yearly mean ozone densities. It has been observed that the variations of ozone densities for all months and variation of yearly mean ozone values followed nearly the same trend. The nature of variation of July, August and October ozone mean values from 1988 to 2005 were the most identical with the variation of yearly mean ozone values for the same period and the variation of February ozone mean values was the least identical with the variation of yearly mean ozone values for the same period at Kodaikanal. It has also been verified by the value of co-efficient of correlation. The co-efficient of correlation between July, August and October ozone mean values with yearly mean values was the maximum (0.86) because of comparable rates of ozone decline. It was the minimum for February ozone mean values (0.11) due to the different nature of February and Yearly mean ozone variations. It may be concluded that the nature of yearly variation of ozone density may be obtained from the measurement of July, August and October ozone densities at Kodaikanal. The yearly mean ozone density as well as the densities of ozone for every month was gradually decreasing from 1988 to 2005 at different rates at Kodaikanal except February. The rate of yearly mean ozone depletion was 0.2099 DU per year. It was 0.5239 DU, 0.3896 DU and 0.143 DU per year for the months July, August and October, respectively.

Variations of yearly mean ozone densities as well as monthly mean ozone densities for all months from 1988 to 2005 at Srinagar have been presented in Figure 2.The nature of variations of ozone densities for each month for different years has been compared with the variation of yearly mean ozone densities. It has been observed that the variations of ozone densities for all months and variation of yearly mean ozone values followed nearly the same trend. In case of Srinagar, the nature of variation of January ozone mean values from 1988 to 2005 was the most identical with the variation of yearly mean ozone values for the same period whereas the variation of May ozone mean values was the least identical with the variation of yearly mean ozone values for the said period. It has also been verified by the value of co-efficient of correlation. The co-efficient of correlation between January ozone mean values with yearly mean values was the maximum (0.82) due to the nearly identical nature of January and yearly mean ozone variation. It was the minimum for February ozone mean values (0.56) because of somewhat different nature of ozone variation. It may be concluded that the nature of yearly ozone variation at Srinagar may be obtained only by measuring the ozone density in the month of January. The yearly mean ozone density as well as the densities of ozone for every month was gradually decreasing from 1988 to 2005 at different rates at Srinagar except July. The rate of yearly mean ozone depletion was 0.3898 DU per year whereas it was 0.4083 DU and 0.9749 DU per year for the months January and May, respectively. In case of the month July, ozone density had increased by 0.0453 DU per year from 1988 to 2005.

Figure 3 shows the variations of yearly mean ozone densities as well as monthly mean ozone densities for all months from 1988 to 2005 at Halley Bay. In case of Halley Bay, the nature of variation of September ozone mean values from 1988 to 2005 was the most identical with the variation of yearly mean ozone values for the same period and the variation of March ozone mean values was the least identical with the variation of yearly mean ozone values for the same period. It has been also verified by the value of co-efficient of correlation. The co-efficient of correlation between September ozone mean values with yearly mean values was the maximum (0.91) because of same nature of ozone variations. It was the minimum for March ozone mean values (0.44) due to little different type of variations of ozone. So, it may be suggested that the nature of yearly variation of ozone at Halley Bay may be achieved simply by measuring the ozone density for the month of September. The yearly mean ozone concentration as well as the concentrations of ozone for every month was gradually decreasing from 1988 to 2005 at different rates. The rate of yearly mean ozone depletion was 2.1323 DU per year. It was 3.1397 DU and 1.279 DU per year for the months September and March, respectively.

Figure 4 depicts the variations of yearly mean ozone densities at Kodaikanal, Srinagar and Halley Bay from 1998 to 2005. It clearly reveals that yearly mean ozone density was very much less at Halley Bay than that at other two stations. Srinagar had comparatively higher ozone density than Kodaikanal. Yearly mean ozone density had declined at all the stations, but at different rates. The rates of decrease of ozone densities at Halley Bay, Srinagar and Kodaikanal were 2.1189 DU, 0.3894 DU and 0.059 DU per year, respectively. The comparatively low value of ozone density and higher rate of ozone decline were due to the comparatively lower temperature, fewer amounts of oxides of nitrogen, greater concentration of Cl and ClO radicals and larger occurrences of polar stratospheric clouds. The figures 1-4 exhibit gap for the years 1995 -1996, since no measurement of total column ozone density had not been done during this period by NASA.

2.2.Seasonal Variation

Figure 5 reveals the seasonal variation of ozone densities for every year and their mean variation for the station Kodaikanal from 1988- 2005. It has been observed that seasonal variation in each year and mean seasonal variation followed nearly the same trend. The nature of seasonal variation of ozone mean values for the year 1990 among the years from 1988 to 2005 was the most identical with the mean seasonal variation and the seasonal variation for the year 2005 among the years from 1988 to 2005 was the least identical with the mean seasonal variation. It has also been verified by the value of co-efficient of correlation. The co-efficient of correlation between the seasonal variations of ozone mean values for the year 1990 with mean seasonal variation was the maximum (0.99). It was the minimum for the year 2005 (0.91). Ozone density attained the maximum value for the months of June and July. The minimum ozone density occurred at the month of January. Ozone density gradually increased from the month of January, attained its maximum for the period of June and July and then gradually decreased.

The seasonal variations at Srinagar and Halley Bay have been represented by the Figure 6 and Figure 7, respectively, for the same period. It has been observed that seasonal variation in each year and mean seasonal variation followed nearly the same trend. The nature of seasonal variation of ozone mean values for the year 1992 and 2004 among the years from 1988 to 2005 was the most identical with the mean seasonal variation and the seasonal variation for the year 1999 and 2002 among the years from 1988 to 2005 was the least identical with the mean seasonal variation , respectively. It has also been verified by the value of co-efficient of correlation. The co-efficient of correlation between the seasonal variations of ozone mean values for the year 1992 and 2004 with mean seasonal variation was the maximum (0.97 and 0.99). It was the minimum for the year 1999 and 2002 (0.44 and 0.73), respectively. In both these stations, ozone density attained the maximum value for the months of January to March. The minimum ozone density occurred at the month of October. Ozone density gradually decreased from the month of January, attained its minimum for the month of October and then gradually increased.

Figure 8 represents mean seasonal variations of ozone densities at Kodaikanal, Srinagar and Halley Bay. It shows that nature of seasonal variation of ozone density at Kodaikanal was completely different from that at other two stations. Minimum ozone density at Srinagar and Halley Bay occurred during October, whereas minimum ozone density during January at Kodaikanal because of higher latitude of Srinagar and Halley Bay and different climatic condition at these stations.

2.3.Nature Of Varition Of Solar Flux

Solar flux is obtained from the website ftp://ftp.ngdc.noaa.gov/stp/solarData/SolarfluxMonthly. Variations of monthly mean solar flux for different months and their mean variation from1988 to 2005 have been presented in Figure 9. The nature of variations of solar flux for each month for different years has been compared with the variation of yearly mean solar flux. It has been observed that the variations of solar flux for all months and variation of yearly mean solar flux followed nearly the same trend. The nature of variation of April and May solar flux from 1988 to 2005 was the most identical with the variation of yearly mean solar flux for the same period and the variation of February solar flux was the least identical with the variation of yearly mean ozone values for the same period. It has also been verified by the value of co-efficient of correlation. The co-efficient of correlation between April and May solar flux with yearly mean values was the maximum (0.97). It was the minimum for February solar flux (0.86). The yearly mean solar flux as well as the solar flux for all months was gradually decreasing from 1988 to 2005 at different rates. The rate of decrease in solar flux varied from 34.03 to 16.08 per year. The rate of decrease in solar flux was maximum for the month of February and minimum for the month of May. The rate of decrease in yearly mean solar flux was 23.7 per year.
Seasonal variations of solar flux for different years and their mean variation from 1988 to 2005 have been shown in Figure 10. The nature of seasonal variation of solar flux for each year differs from each other. It has been observed that the seasonal variations of solar flux in the year 1992 was the most identical with their mean variation and that for the year 2000 was the least identical. It has been also verified by the value of coefficient of correlation. The values of coefficient of correlation between 1992 seasonal variation

of solar flux with mean seasonal variation was 0.69 and that for 2000 was -0.39. A decreasing trend in solar flux has been observed from January to December for the years 1991 to 1995, 2000 and 2002 to 2005. The rate of decrease of solar flux varied from 74.39 for the year 1992 to 3.25 for the year 2003 per month. An increasing trend in solar flux has been observed from January to December for the rest years. The rate of decrease varied from 74.62 for the year 1988 to 0.64 for the year 1990 per month. The mean seasonal variation of solar flux showed a decreasing trend with 1.68 solar flux per month.

3.Effect Of Relative Sunspot Numbers On Ozone Variation

Figure 11 depicts the scattered diagram of variations of ozone density at Kodaikanal, Srinagar and Halley Bay with solar flux. This Figure clearly reveals that the nature of ozone variation with solar flux was oscillatory. The density of ozone had increased very slightly for above period with increase in solar flux at all stations. But generally, ozone depletion should increase with increase of solar activity. It clearly indicates that some chemical processes play an important role to control the formation and destruction processes of ozone. Hence the effect of solar parameters and chemical processes on ozone decline is comparable. So, oscillatory nature is quite expected.

4.Conclusion

Yearly mean ozone densities had decreased gradually at all the above stations with different rates from 1988 to 2005. The nature of seasonal ozone variation at Kodaikanal was quite different from that at Srinagar and Halley Bay. The maximum and minimum ozone values occurred in the months of June to July and January, respectively, at Kodaikanal, but January to March and October, respectively, in case of Srinagar and Halley Bay. Ozone values gradually increased from the month of January, attained its maximum for the period of June and July and then gradually decreased at Kodaikanal. Whereas, ozone values gradually decreased from the month of January, attained its minimum for the month of October and then gradually increased at both the stations, Srinagar and Halley Bay. The nature of variation of solar flux clearly depicts that yearly mean as well as monthly mean solar flux had declined from 1998 to 2005. Scattered diagram shows the oscillatory nature of ozone variation with solar flux which indicates that effect of solar parameters and chemical processes on ozone decline was comparable.

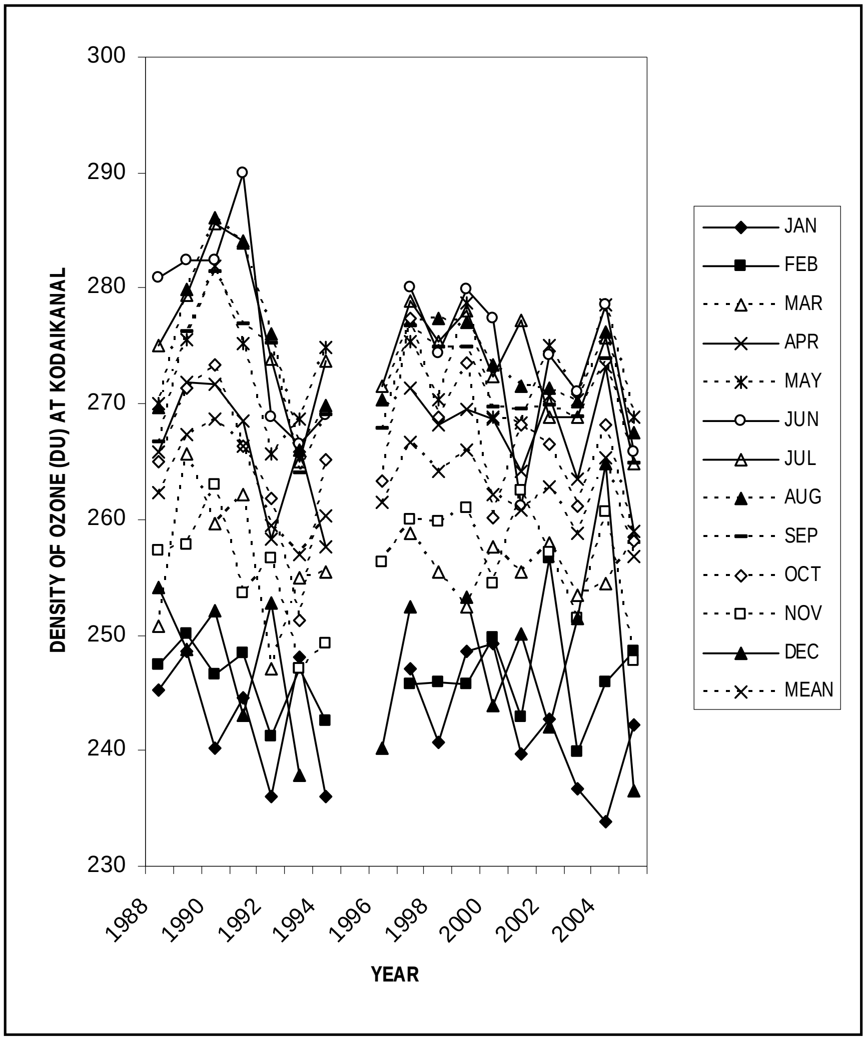

Figure 1: Variations of total column ozone densities for all months and their yearly mean variation at Kodaikanal (10°13′ N, 77°28′ E) from 1988 to 2005

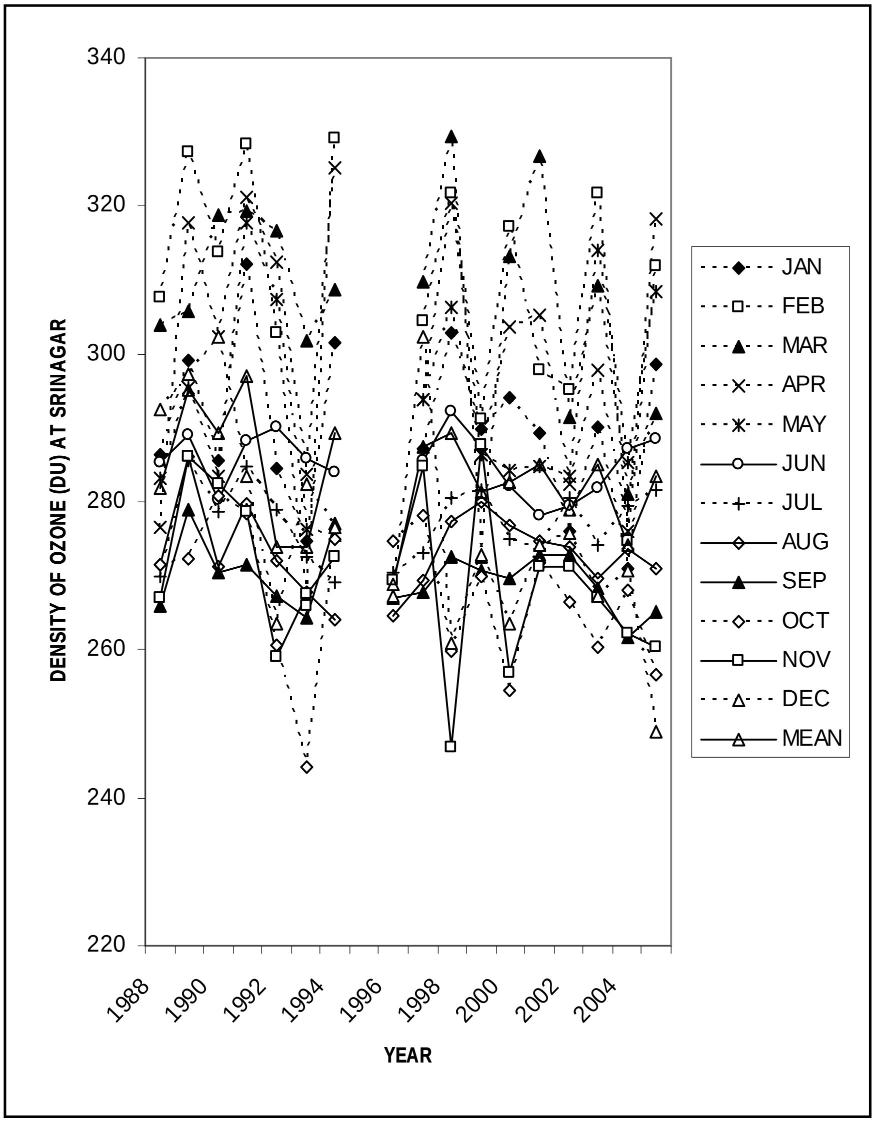

Figure 2: Variations of total column ozone densities for all months and their yearly mean variation at Srinagar (34°04′ N, 74°49′ E) from 1988 to 2005.

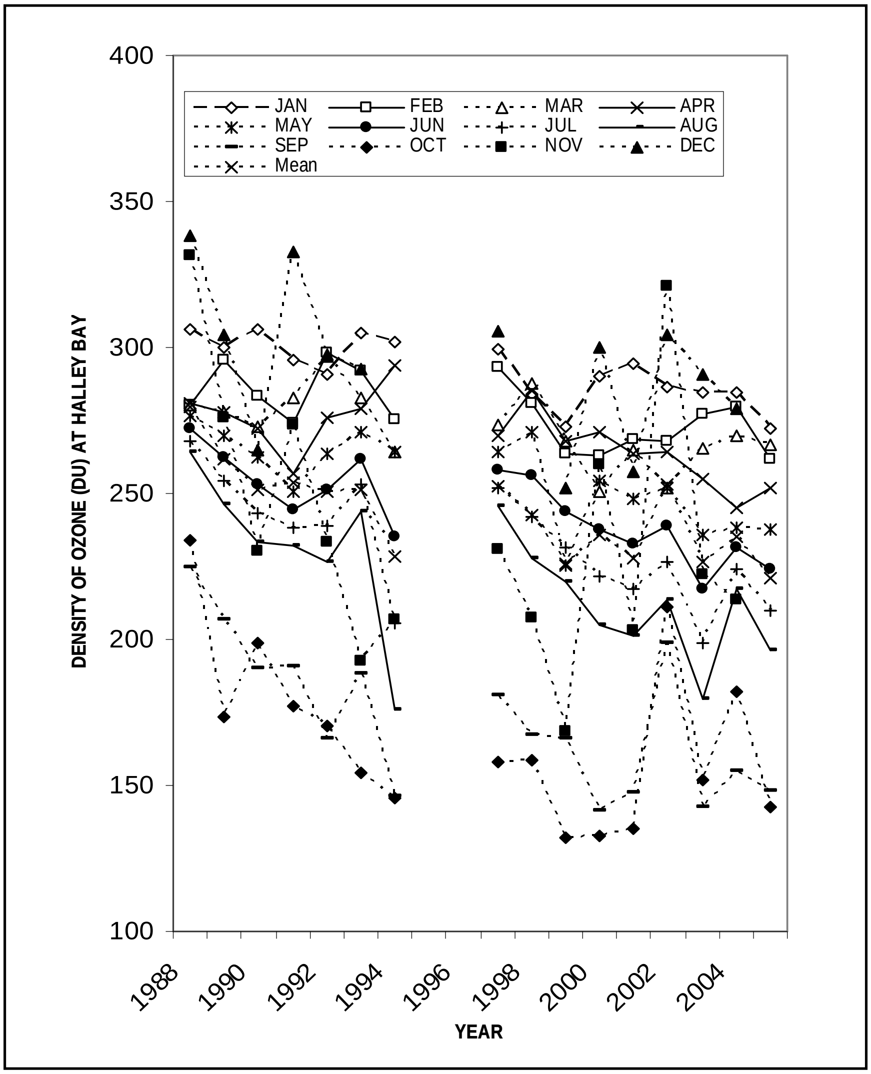

Figure 3: Variations of total column ozone densities for all months and their yearly mean variation at Halley Bay (76^{o}S, 27^{o}W) from 1988 to 2005

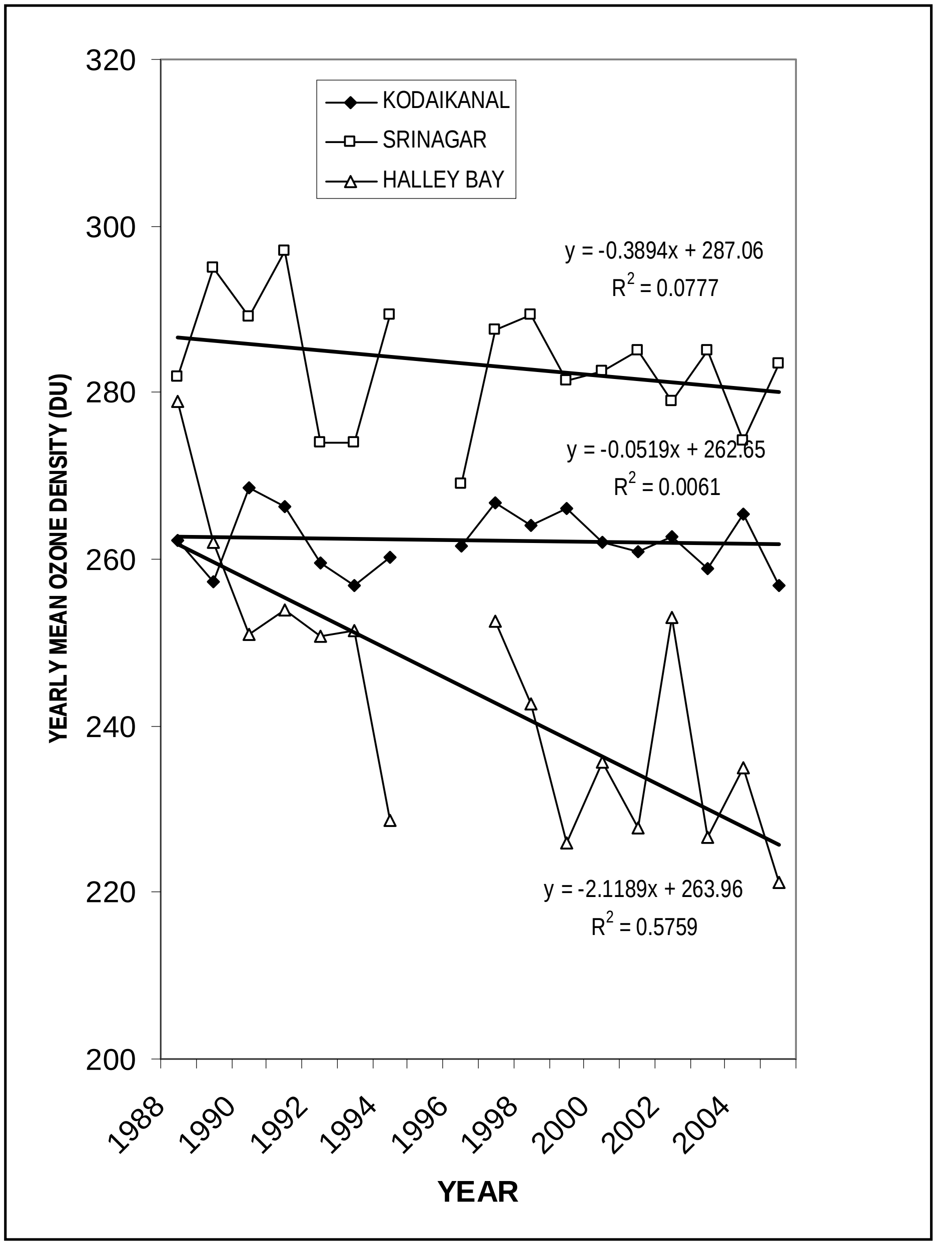

Figure 4: Variations of yearly mean column ozone densities at Kodaikanal (10°13′ N, 77°28′ E), Srinagar (34°04′ N, 74°49′ E) and Halley Bay (76°S, 27°W) from 1988 to 2005.

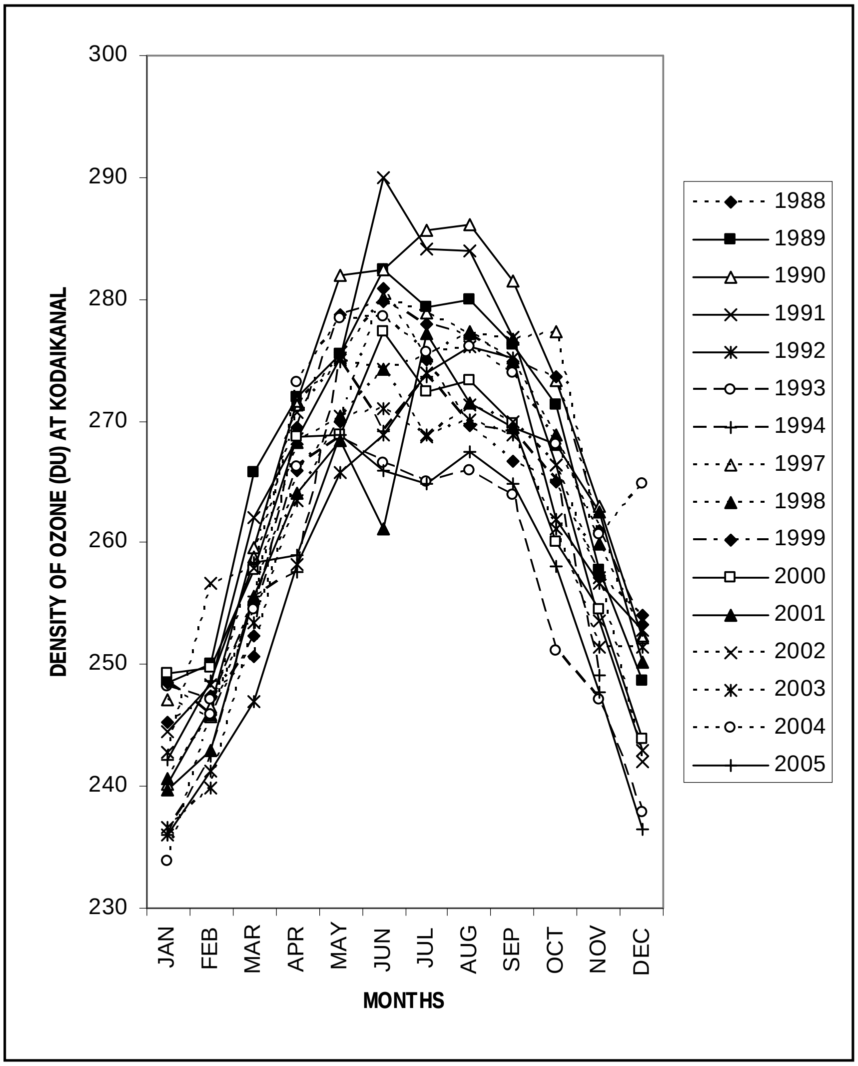

Figure 5: Seasonal variations of total column ozone densities for every year and their mean variation at Kodaikanal ($10^o13'$ N, $77^o28'$ E) for the period 1988-2005.

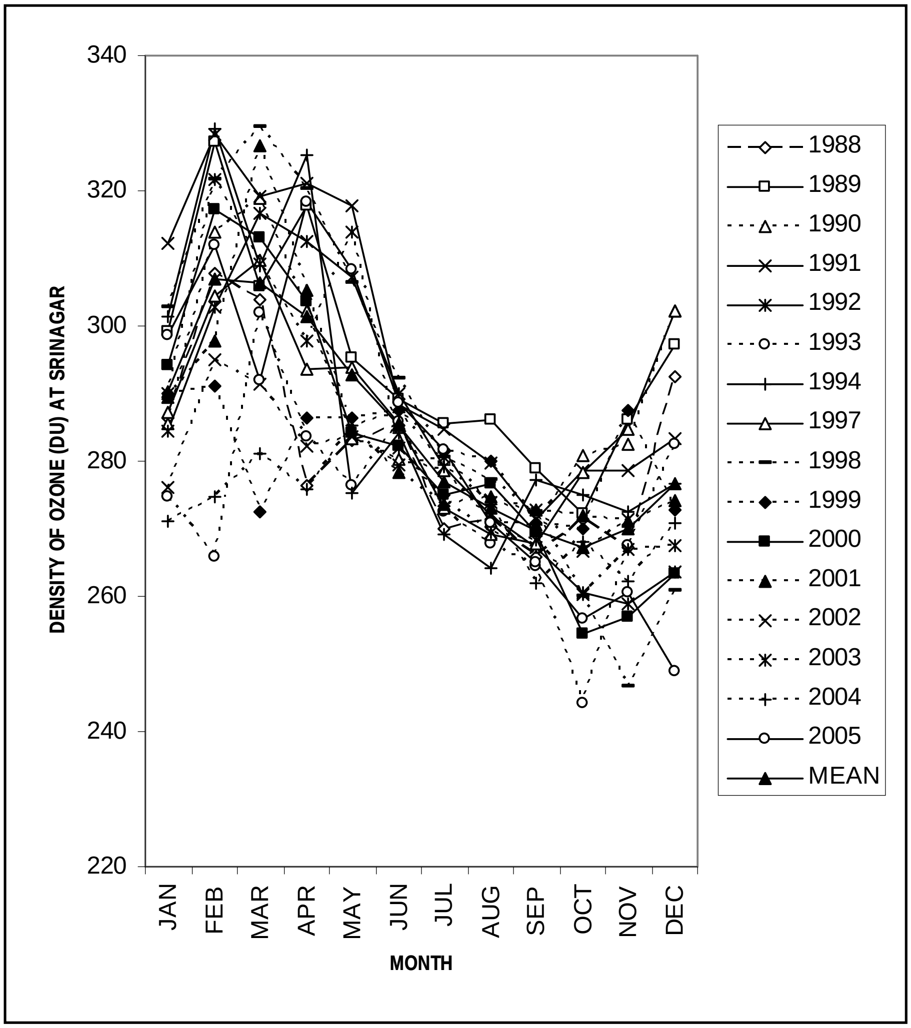

Figure 6: Seasonal variations of total column ozone densities for every year and their mean variation at Srinagar (34°04′ N, 74°49′ E) for the period 1988-2005.

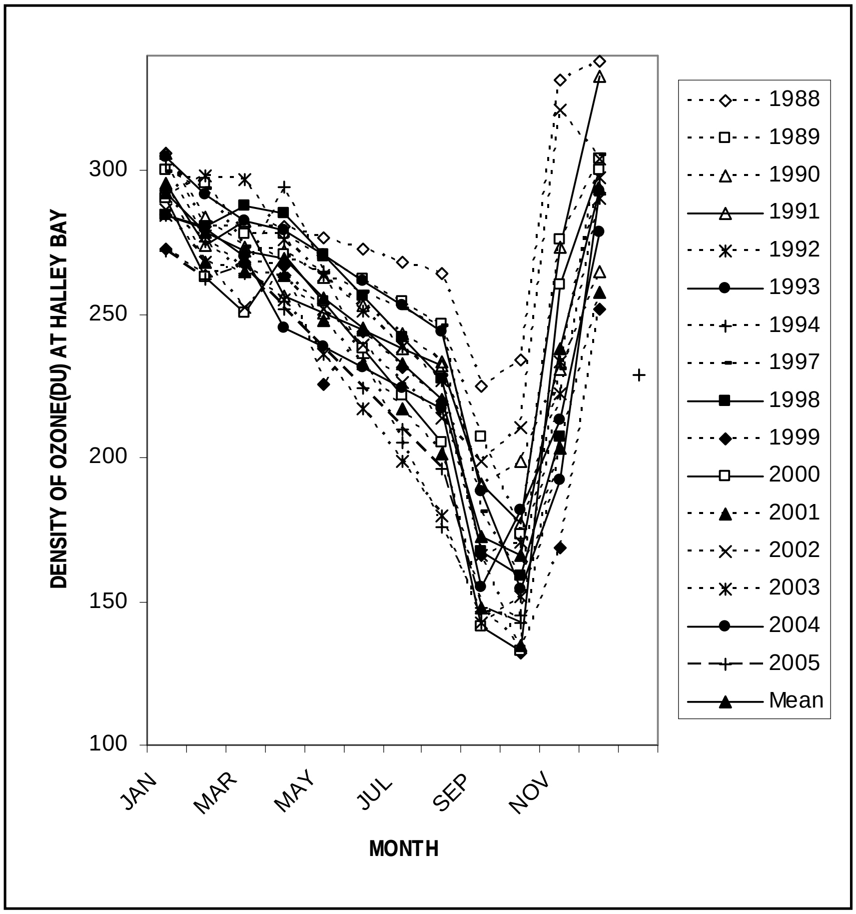

Figure 7: Seasonal variations of total column ozone densities for every year and their mean variation at Halley Bay (76°S, 27°W) for the period 1988-2005.

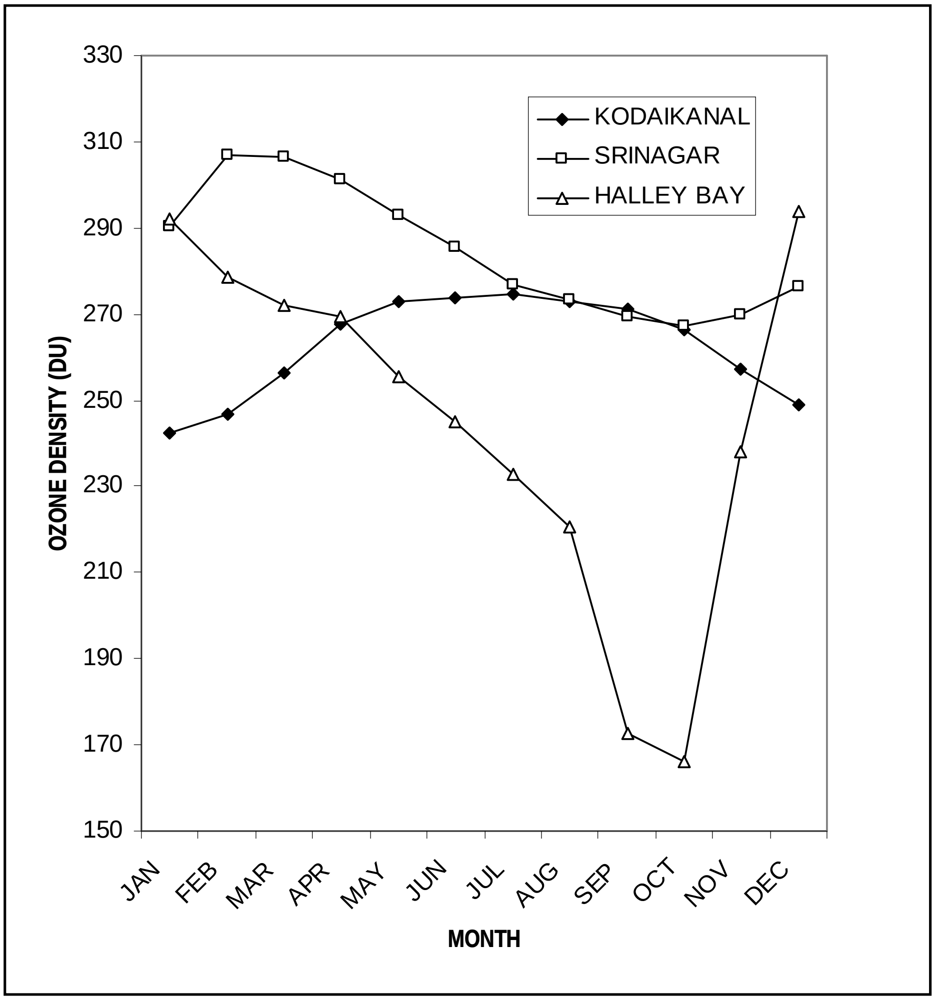

Figure 8: Mean seasonal variations of total column ozone densities at Kodaikanal (10°13′ N, 77°28′ E), Srinagar (34°04′ N, 74°49′ E) and Halley Bay (76°S, 27°W) for the period 1988-2005

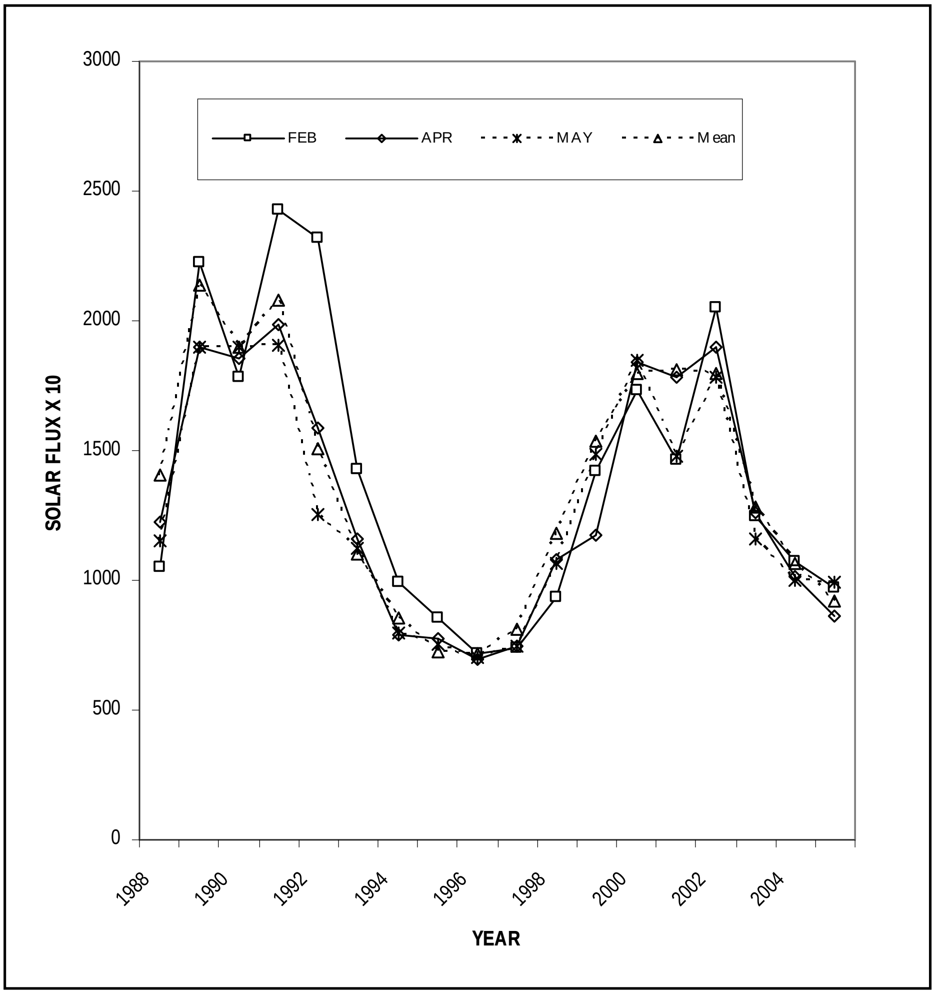

Figure 9:Variations of solar flux for all months and their yearly mean variation from 1988 to 2005.

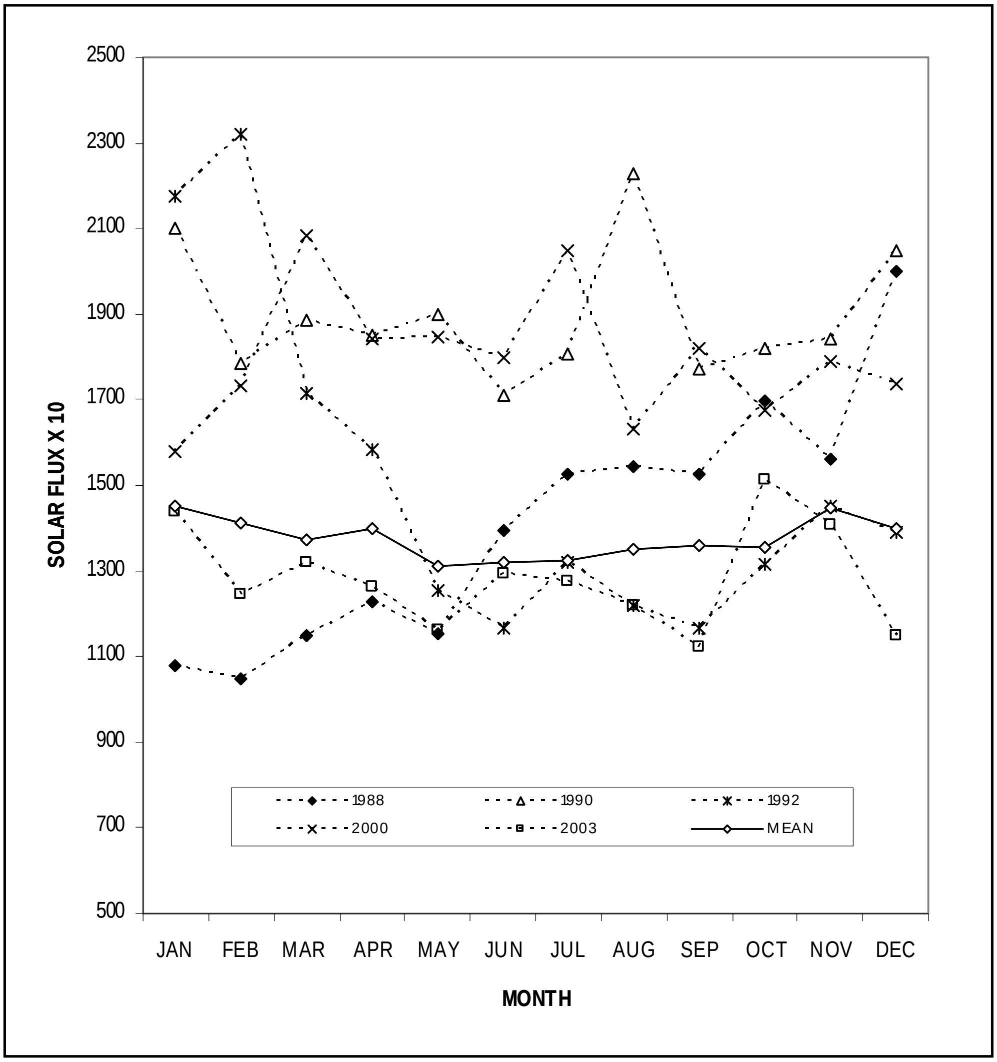

Figure 10: Seasonal variations of solar flux for every year and their mean variation for the period 1988-2005

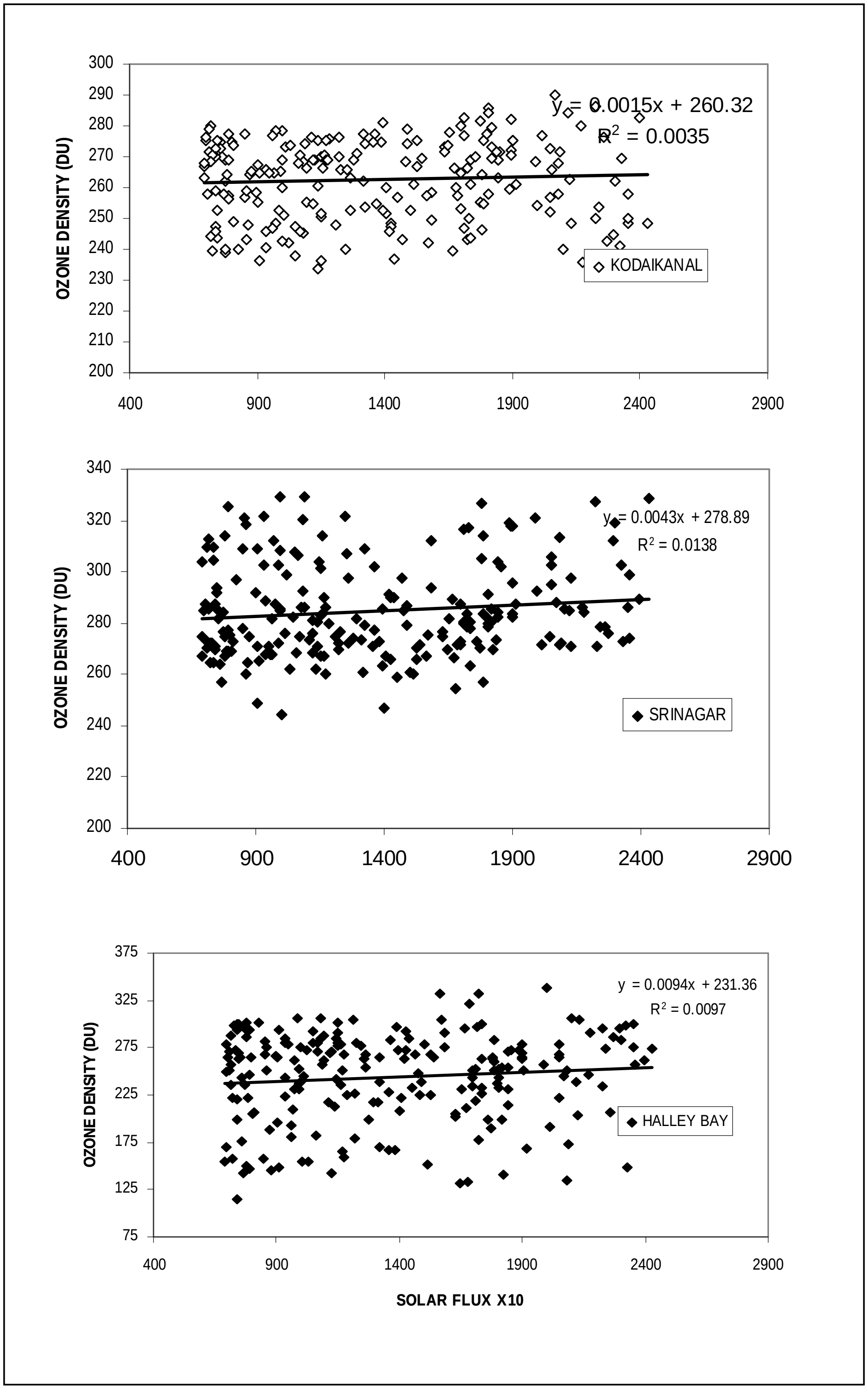

Figure 11: Scattered diagram of monthly mean ozone concentrations with solar flux for the period 1988-2005

5.Reference

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