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Effect of solar parameters on Antarctic, Arctic and tropical ozone during the last solar cycle

P K Jana & S C Nandi

Department of Chemistry, Institute of Education (PG) for Women, Chandernagore, Hooghly 712 138, West Bengal, India

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A critical analysis has been made on the variations of Antarctic, Arctic and tropical ozone and different solar parameters during the last solar cycle. It has been observed that yearly variations of ozone concentrations at Halley Bay (76°S, 27°W), a British Antarctic survey station, at Sodankyla (67.4°N, 26.6°E), an Arctic survey station and at Ahmedabad (23°N, 72.6°E), an Indian survey station are identical to that of August, April and March concentrations, respectively. The yearly variations of solar flare numbers and solar uv-fluxes are identical to that of October values, but relative sunspot numbers and solar flare index are identical to that of April values. The correlation coefficients between ozone concentrations and different solar parameters are not so significant. It is also concluded that the intense yearly decrease of Antarctic and Arctic ozone concentrations from year to year during springtime is independent of solar parameters.

Key words: Ozone depletion, Solar activity, Antarctic ozone, Arctic ozone, Tropical ozone
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1 Introduction

Ozone, though a very minor atmospheric constituent, plays an important role to control the chemical kinetics of the atmosphere. Recent ozone assessment confirmed that ozone is declining everywhere[1]. Farman *et al.*[2] first reported that dramatic decrease of ozone concentration takes place at Antarctica during springtime. We have mentioned earlier[3-4] that different theories have been proposed by different investigators throughout the world for the dramatic decrease of ozone concentration at Antarctica. Chemical, dynamical and natural theories[5] are mainly important.

In chemical theory, different chemical reactions are responsible for ozone depletion. The chemicals which catalyse these reactions are O_x (Ref. 6), HO_x (Refs 7-8), Cl & ClO_x (Refs.9-10), Br & BrO_x (Refs 11-13), ClO_x & BrO_x (Refs 11-14), Cl & HO_x (Ref. 15), CO & HO_x (Refs.16-17), NO_x (Refs 18-20) and PSCs (Refs 21-26).

According to dynamical theory, O_3 is not depleted, it is redistributed in the stratosphere. As a result, O_3 hole is created at Antarctica during springtime. Polar vortex is a small portion of its atmosphere isolated by the polar circulation during winter in that region. In south polar regions, the vortex formation is usually centered over eastern Antarctica. Antarctic polar vortex is more intense than its Arctic counterpart.

In natural theory, volcanic eruption, solar UV-radiation variability etc. may play an important role in ozone depletion. The variation of ozone with solar activity was first studied by Chakrabarty and Chakrabarty[27]. The effects of solar flare number[3] and solar uv-radiation[28] on Antarctica O_3 depletion for the period 1967-1987 and 1978-1984, respectively, clearly revealed that Antarctic ozone, solar flare number and solar uv fluxes were mainly controlled by their October values. Dramatic decrease of Antarctic ozone was independent of solar flare number and solar UV-flux. Relative sunspot numbers[29] and solar flare index[30] for the period 1964-1985 had a similar effect on Antarctic ozone depletion. The purpose of this paper is to verify the above facts of above solar parameters on high latitude Arctic, Antarctic and low latitude tropical ozone depletion afterwards, from 1987 to 1997 during the last solar cycle.

2 Characteristics of variation of ozone and solar parameters

The nature of variation of yearly mean concentration of ozone in Dobson Unit (DU) during the last 11 year solar cycle, 1987-1997, at Halley Bay (76°S, 27°W), a British Antarctic Survey station follows nearly the same trend as that of August concentration shown in Fig. 1[(a)-(b)].

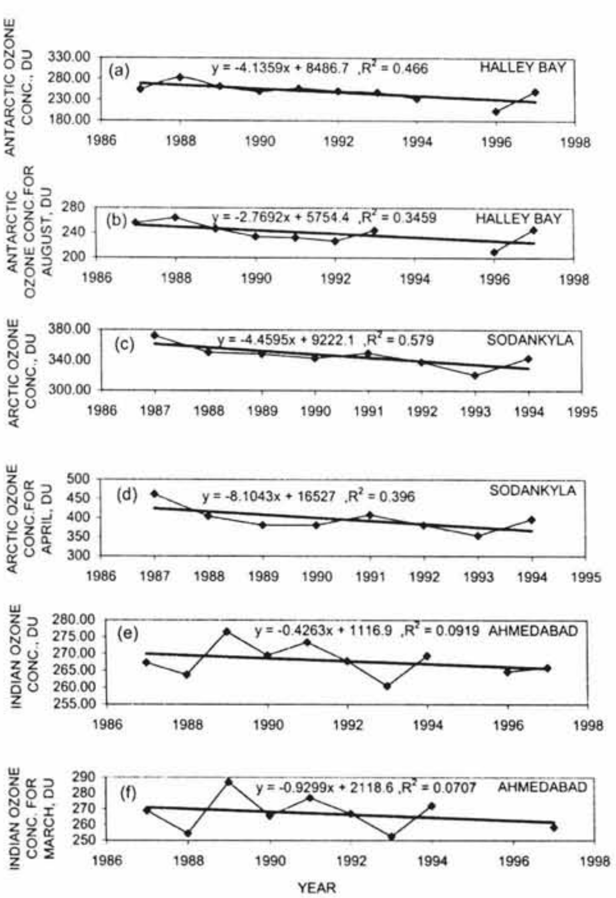

Fig. 1—Variation of O_3 concentration: (a) yearly mean and (b) August values at Halley Bay (76°S, 27°W); (c) yearly mean and (d) April values at Sodankyla (67.4°N, 26.6°E); (e) yearly mean and (f) March values at Ahmedabad (23°N, 72.6°E) for 1987-97

But at Sodankyla (67.4°N, 26.6°E), Finland, an Arctic Survey station and at Ahmedabad (23°W, 72.6°E), tropical Indian Survey station, the yearly variations follow nearly the same trend as that of April and March concentration of ozone, respectively, shown in [Fig. 1(c)-(d)] and [Fig. 1(e)-(f)], respectively. In Table 1 (top three rows) the authors have given the correlation coefficient between yearly mean ozone and monthly mean ozone for Antarctic, Arctic and tropical region. It is also evident from Table 1 that the correlation coefficient between yearly mean concentration and monthly mean concentration of ozone attains maximum for the months of August, April and March at Halley Bay, Sodankyla and Ahmedabad, respectively. The rate of depletion of ozone reaches a maximum value at Antarctica, Arctic Station and Indian Station during the months of November, February and February, respectively and are shown in [Fig. 2(a)-(c)]. The rates are 6.8138 DU, 12.913 DU and 1.6332 DU per year, respectively. Ozone concentration at Halley Bay and Ahmedabad are obtained from internet website http//jwocky.gsfc.nasa.gov.

Solar flare numbers and relative sunspot numbers are collected from solar geophysical data book, NOAA, published by Department of Commerce, U.S.A. Solar uv-flux [28] and solar flare index[30] are calculated from the following equations.

$$\text{UV-flux} = 0.2672 + 2.7578 \times 10^{-5} \times \text{S.F.No.}$$

Table 1—Values of correlation coefficient

Correlation Coefficient between	Jan	Feb	Mar	Apr	May	June	Jul	Aug	Sept	Oct	Nov	Dec
Antarctic yearly mean O_3 & monthly mean O_3	0.1613	0.005	0.3119	–0.2593	–	–	–	0.84	0.7947	0.5522	0.7529	0.4790
Arctic yearly mean O_3 & monthly mean O_3	0.7194	0.6597	0.9429	0.9461	0.8996	0.8174	0.8563	0.9180	0.8261	0.0124	0.1667	0.1735
Indian yearly mean O_3 & monthly mean O_3	0.5504	0.5589	0.9626	0.7538	0.5738	0.8862	0.8843	0.8918	0.8551	0.5561	0.3990	0.2506
Antarctic O_3 & Relative Sunspot no.	–0.4192	0.2520	0.2528	–0.5648	–	–	–	0.0941	0.6683	0.5522	0.7529	0.4790
Arctic O_3 & Relative Sunspot no.	0.3519	0.4385	0.3554	–0.2986	–0.2416	–0.3228	–0.2389	–0.0714	–0.0610	0.3984	–0.0562	–0.5711
Indian O_3 & Relative Sunspot no.	0.1340	0.2045	0.4280	0.2665	0.3568	0.6437	0.4514	0.5707	0.5931	0.2536	0.6594	0.7797

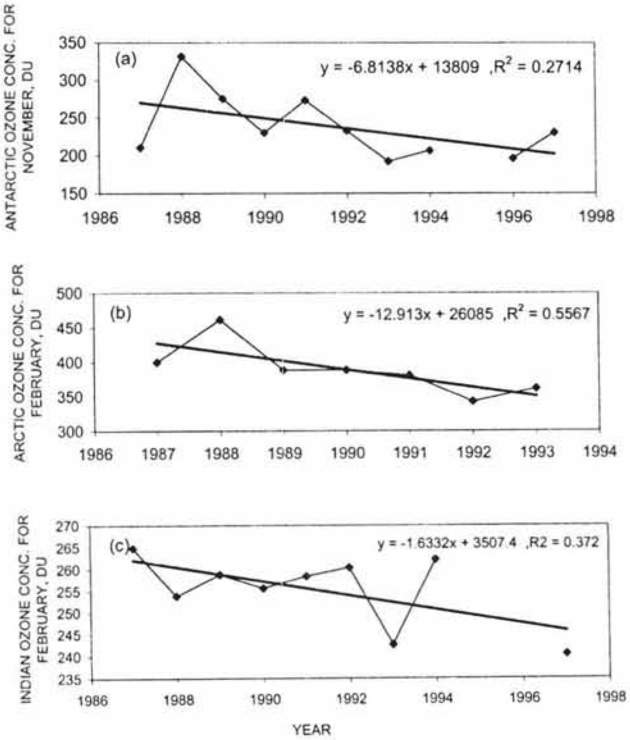

Fig. 2—Variation of O_3 concentration, (a) in November at Antarctica, (b) in February at Arctic and (c) in February in Indian Stations from 1987 to 1997

Solar flare index (SFI) = 1.0932 × relative sunspot number − 9.4391

Since SUV is proportional to SSN, sunspot number becomes the overall representative of solar parameters. In [Fig. 3(a)-(c)] the authors have plotted the monthly mean ozone concentration for Antarctic, Arctic and Ahmedabad against monthly mean sun spot numbers. The variation is found to be scattered. In Table 1 (bottom three rows) we have shown the correlation coefficient between monthly mean ozone and monthly mean sunspot numbers for Antarctic, Arctic and Ahmedabad. From Table 1, it will be seen that correlation coefficients between monthly mean Antarctic ozone concentration and monthly mean values of SSN are positive for all the months except January and April. In case of September-November, very high positive correlation has been obtained. In Sodankyla, Arctic station, correlation coefficient between monthly mean ozone and SSN is positive for January-March and October and negative for all other months. But in Ahmedabad, coefficients of correlation are positive for all the months.

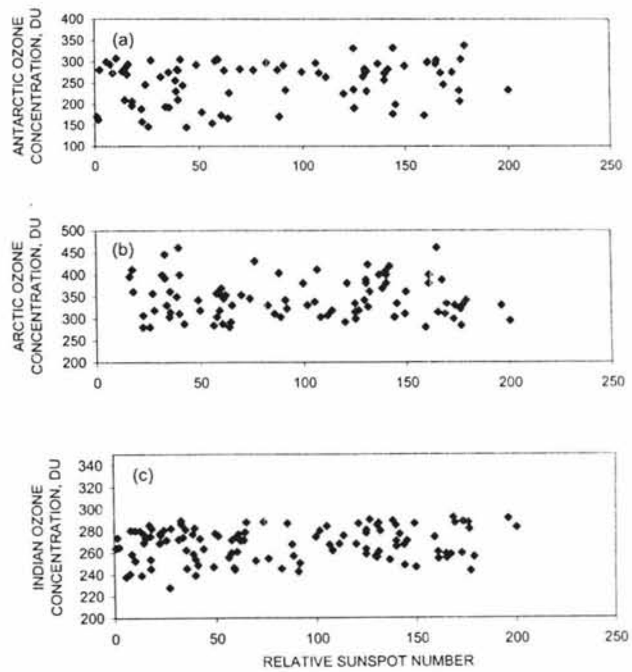

Fig. 3—Variation of O_3 concentration at (a) Antarctic, (b) Arctic and (c) Indian stations with relative sunspot numbers

3 Analysis of ozone trend and conclusions

The analysis of ozone trend has been performed by different investigators at different stations over the world. Decreasing and increasing trends in ozone at mid-latitude sub-tropical regions, e.g. Reykjavik (64.1°N), Hohenpeissenberg (48°N), Sappore (43.1°N), Kagoshima (31.6°N) and Quetta (30.2°N), at high latitude Antarctic regions, e.g. Halley Bay (76°S) and low latitude tropical regions, e.g. Trivandrum (8.25°N), Bangalore (13°N), Hyderabad (17.25°N), Bombay (19°N), Dumdum (22.5°N), Ahmedabad (23°N), Varanasi (25.5°N) and Srinagar (34°N) were already reported in the authors previous paper[31]. Chakrabarty *et al.*[32] also showed an increasing trend in ozone at Kodaikanal (10°N), Pune (18°N), Mount Abu/Ahmedabad (24°N), New Delhi (28°N) and Srinagar (34°N) and a decreasing trend in Varanasi (25°N) over a long period. The cause of this trend is partly due to the trends of ozone in the troposphere.

Figure 4 shows the plot of monthly mean ozone values against the year for Antarctic, Arctic and Ahmedabad. From both Figs 4 and 1, it is well clear that ozone is gradually decreasing, but at different rates, at Halley Bay, Sodankyla and Ahmedabad, from 1987 to 1997. The rate of depletion of yearly mean O_3 concentration at Halley Bay is 4.1359 DU per year, for August it is 2.7692 DU per year; whereas

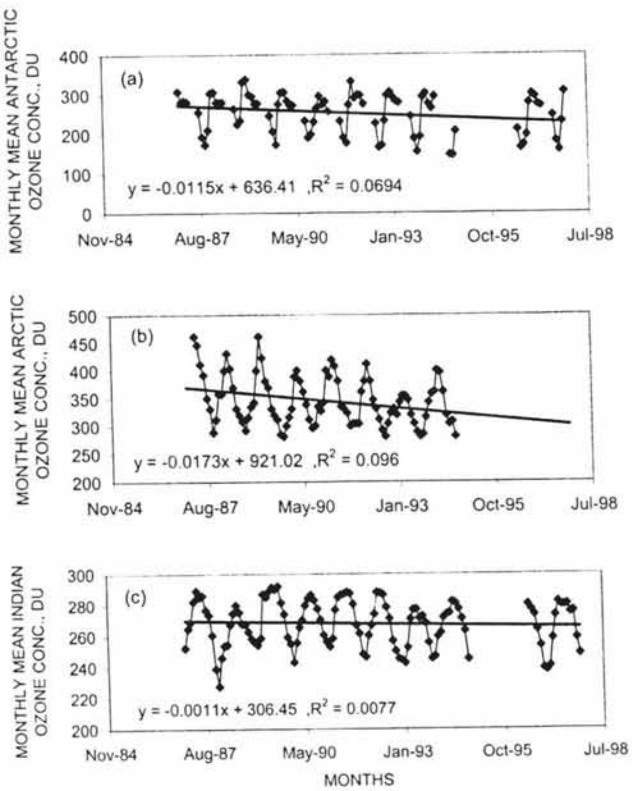

Fig. 4—Variation of monthly mean O_3 concentration at (a) Antarctic, (b) Arctic and (c) Indian stations from 1987 to 1997

monthly depletion trend is 0.0115 DU per month. In case of Sodankyla, the rate of depletion of O_3 concentration is 4.459 DU per year, 0.0173 DU per month and for April it is 8.104 DU per year, respectively.

For the station Ahmedabad, decreasing trends by 0.4263 DU per year, 0.0011 DU per month and 0.9299 DU per year for yearly mean O_3, monthly mean O_3 and March mean O_3, respectively, have been observed.

Our present analysis clearly reveals that O_3 depletions are greatly marked at Antarctic and Arctic region than that at Equatorial region during last solar cycle. Also correlation between Antarctic, Arctic and tropical ozone and solar parameters is not significant.

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