Ozone decline and its effect on night airglow intensity of Na 5893 Å at Dumdum (22.5°N, 88.5°E) and Halley Bay (76°S, 27°W)

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The paper presents the effect of O_3 depletion on night airglow emission of Na 5893 Å line at Dumdum (22.5°N, 88.5°E), India and Halley Bay (76°S, 27°W), a British Antarctic service station. Calculations based on chemical kinetics show that the airglow intensity of Na 5893 Å line will also be affected due to the depletion of O_3 concentration. The nature of yearly variation and seasonal variation of the intensity of Na 5893 Å line for the above two stations are shown and compared. It is shown that the rate of decrease of intensity of Na 5893 Å line is comparatively more at Halley Bay due to the dramatic decrease of Antarctic O_3 concentration. A possible explanation for this dramatic decrease of Antarctic O_3 concentration is also mentioned.

1. Introduction

The self-luminescence of the upper atmosphere is called airglow (Midya and Midya 1993). Na 5893 Å line is one of the important emissions of airglow spectrum. From the excitation mechanism of sodium airglow line it is shown that the intensity of Na 5893 Å line will be affected with the depletion of O_3 concentration. The global ozone assessment confirms that ozone is declining everywhere with a smaller amount (Bojkov 1992). Farman *et al* (1985) first reported that dramatic ozone depletion occurs at Antarctica during spring time. Afterwards, it was verified by different investigators throughout the world. From the excitation mechanism of Na 5893 Å, the volume emission rate of Na 5893 Å is calculated. From the volume emission rate curve, the intensity of Na 5893 Å is calculated. Following this process, the intensity of the same line of two stations namely, Dumdum (22.5°N, 88.5°E), India and Halley Bay (76°S, 27°W), a British Antarctic survey station, are calculated for other years, considering the depletion of O_3 concentrations. The nature of variations of the intensity of Na 5893 Å line is compared for the two stations. From the variation of intensity of airglow emission line, which is related to O_3 concentration, one can estimate the variation of number density of different types of ions, atoms and molecules. In this paper, we have calculated the variation of airglow intensity of Na 5893 Å for the two stations and compared the nature of variations. This process may be continued for other stations throughout the world.

2. Symbols and notation

R – Rayleigh (unit of intensity)
DU – Dobson unit (unit of O_3 concentration).

Keywords. Ozone depletion; airglow intensity.

Table 1. *Volume emission rates of Na* 5893 Å.

	Number densities (atoms/cc)					Volume emission rates (Q) of Na 5893 Å		
Altitude in km	$n(Na) \times 10^{-3}$	$n(O) \times 10^{-11}$	$n(O_3) \times 10^{-7}$	Dumdum $n(O_3) \times 10^{-7}$ at peak emission height	Halley Bay $n(O_3) \times 10^{-7}$ at peak emission height	Normal	Dumdum	Halley Bay
85	1.0	1.00	10.0	10.25	11.50	2.60	2.66	2.99
86	1.4	1.29	10.2	10.45	11.73	4.76	4.88	5.48
87	1.8	1.58	10.4	10.66	11.96	7.69	7.88	8.85
88	2.2	1.87	10.6	10.86	12.19	11.34	11.62	13.05
89	2.6	2.16	10.8	11.07	12.42	16.18	16.58	18.61
90	3.0	2.45	11.0	11.27	12.65	21.02	21.54	24.18
91	3.5	2.99	8.5	8.71	9.78	23.12	23.69	26.60
92	4.0	3.52	6.0	6.15	6.90	21.96	22.50	25.26
93	3.6	3.98	5.0	5.12	5.75	18.63	19.09	21.43
94	3.3	4.43	4.0	4.09	4.60	15.07	15.44	17.34
95	3.1	4.54	3.0	3.07	3.45	10.98	11.25	12.63
96	2.7	4.85	2.7	2.77	3.11	9.19	9.42	10.57
97	2.3	4.86	2.4	2.46	2.76	6.90	7.07	7.94
98	1.8	4.88	2.1	2.15	2.42	4.79	4.91	5.51
99	1.4	4.76	1.8	1.84	2.07	3.21	3.29	3.69
100	0.9	4.63	1.5	1.54	1.73	1.63	1.67	1.87

3. Excitation mechanism

Chapman (1939) first discussed the photochemistry of Na. The excitation mechanism is as follows:

$$NaO^* + O \xrightarrow{K_1} Na^*(^2P) + O_2, \qquad (1)$$

$$Na^*(^2P) \longrightarrow Na(^2S) + hv(5893\,\text{Å}). \qquad (2)$$

NaO^* may be produced by other ways:

$$Na + O + M \xrightarrow{K_2} NaO^* + M, \qquad (3)$$

$$Na + O_2 + M \xrightarrow{K_3} NaO_2 + M, \qquad (4a)$$

$$NaO_2 + O \xrightarrow{K_4} NaO^* + O_2, \qquad (4b)$$

$$Na + O_3 \xrightarrow{K_5} NaO^* + O_2, \qquad (5)$$

where M represents a third body required to carry away excess energy and momentum. K_1, K_2, K_3, K_4 and K_5 are the rate co-efficients having numerical values $4 \times 10^{-11} cm^3\,s^{-1}$, $7 \times 10^{-33} cm^6\,s^{-1}$, $2 \times 10^{-33} cm^6\,s^{-1}$, $1 \times 10^{-11} cm^3\,s^{-1}$ and $6.56 \times 10^{-12} cm^3\,s^{-1}$, respectively (Kvifte 1973). The airglow emission intensity of Na 5893 Å line depends on the concentration of $Na^*(^2P)$. $Na^*(^2P)$ is formed by the reaction of NaO^* with atomic oxygen according to reaction (1). Again NaO^* is produced by the reactions (3), (4) and (5). Ghosh and Midya (1987) showed that the volume emission rate of NaO^* by the reaction (5) is greater than those by the reactions (3) and (4). The reaction (5) clearly reveals that the formation of Na^* is directly governed by the concentration of Na and O_3. The volume emission rate of NaO^* by reaction (5) is given by

$$n(Nao^*) = K_5 n(Na) n(O_3). \qquad (6)$$

Ignoring the quenching terms, the rate of production of Na^* is

$$n(Na^*) = K_1 n(NaO^*) \times n(O)$$
$$= K_1 K_5 n(Na) n(O) n(O_3). \qquad (7)$$

Using the number densities of Na, O and O_3 given in table 1, the volume emission rate of $n(Na^*)$ for different altitudes are calculated with the help of the equation (7). It attains maximum value at an altitude of 91 km. The value of intensity of Na 5893 Å becomes 161.84 R and it is considered as normal intensity. Night-time n(Na) is taken from the radar laser data of Gibson and Sandford (1971), $n(O_3)$ and n(O) are taken from Krassovosky (1971) and Jacchia (1977), respectively. Intensity is calculated from the volume

Table 2. *Yearly variation of intensity of Na 5893 Å line at Dumdum and Halley Bay.*

Year	Mean O_3 (DU) at Dumdum	O_3 fluctuation from mean % at Dumdum	Mean O_3 (DU) at Halley Bay	O_3 fluctuation from mean (%) at Halley Bay	Peak volume emission rate of Na 5893 Å at Dumdum	Peak volume emission rate of Na 5893 Å at Halley Bay	Intensity of Na 5893 Å at Dumdum	Intensity of Na 5893 Å at Halley Bay
1979	275.71	2.46	303.73	15.04	23.69	26.59	165.82	186.18
1980	269.12	0.015	301.75	14.29	23.12	26.42	161.86	184.97
1981	275.81	2.50	298.42	13.03	23.69	26.13	165.89	182.93
1982	275.24	2.29	286.09	8.36	23.65	25.05	165.55	175.37
1983	267.23	−0.69	289.70	9.72	22.96	25.37	160.72	177.57
1984	268.02	−0.39	272.28	3.12	23.03	23.84	161.21	166.89
1985	260.92	−3.03	263.72	−0.12	22.42	23.09	156.94	161.65
1986	269.43	0.13	270.77	2.55	23.15	23.71	162.05	165.97
1987	267.55	−0.57	254.54	−3.59	22.99	22.29	160.92	156.03
1988	264.59	−1.67	282.24	6.89	22.73	24.71	159.14	172.99
1989	275.69	2.45	261.90	−0.81	23.69	22.93	165.81	160.53
1990	269.39	0.12	250.39	−5.17	23.15	21.92	162.03	153.47
1991	272.02	1.09	257.21	−2.58	23.37	22.52	163.60	157.66
1992	269.52	0.16	250.62	−5.08	23.16	21.95	162.10	153.62
1993	261.73	−2.73	247.82	−6.14	22.49	21.70	157.42	151.90
1994	268.57	−0.19	233.48	−11.57	23.08	20.45	161.53	143.12
1995								
1996	261.83	−2.69	203.68	−22.86	22.49	17.83	157.49	124.84
1997	266.47	−0.97	250.84	−4.99	22.90	21.97	160.27	153.76
1998	273.59	1.68	237.32	−10.12	23.51	20.78	164.56	145.46

emission rate curve with the help of the following equation.

$$\text{Intensity} = \frac{1}{2} \times \text{layer thickness} \times \text{peak volume emission rate}. \quad (8)$$

4. Calculations and results

Equation (7) clearly reveals that the volume emission rate of Na 5893 Å is directly proportional to the concentrations of Na, atomic oxygen and ozone. The concentration of ozone in the stratosphere varies in considerable amount from year to year, as well as, from month to month. This stratospheric variation of ozone may influence the mesospheric altitudinal concentration of ozone. The percentage of ozone fluctuation for each year is calculated from the mean of the yearly mean concentration of ozone during the period 1979–1998. The effect of the variation of ozone is considered in the calculation of volume emission rate and intensities of Na, assuming that the concentrations of Na and atomic oxygen remain constant.

Monthly mean ozone concentrations for the two stations are collected from the Internet website http//www.jowcky.com for the years 1979 to 1998. The yearly mean concentrations of ozone are calculated from monthly mean values. The mean of the yearly mean values of ozone concentrations during the period 1979–1998 for the stations Dumdum and Halley Bay are 269.07 DU and 264.03 DU, respectively. Then percentages of the variation of O_3 concentration from its mean are computed for different years as shown in table 2. These are 2.46% and 15.04% for the year 1979 for Dumdum and Halley Bay, respectively. During this year altitudinal concentrations of ozone and volume emission rates of Na 5893 Å are enhanced by 2.46% and 15.04% at Dumdum and Halley Bay, respectively, as shown in table 1. The altitudinal variations of volume emission rate for normal value, Dumdum and Halley Bay are shown in figure 1. The intensities of Na 5893 Å line are then computed from volume emission rate curve with the help of the equation (8). Intensities are 165.18 R and 186.18 R at Dumdum and Halley Bay, respectively, for the year 1979. Following this procedure, the intensities for different years are calculated for the period 1979 to 1998 shown in table 2. The yearly variations of intensities are shown in figure 2(a) and 2(b). It is clear from figure 2 that the rates of decrease

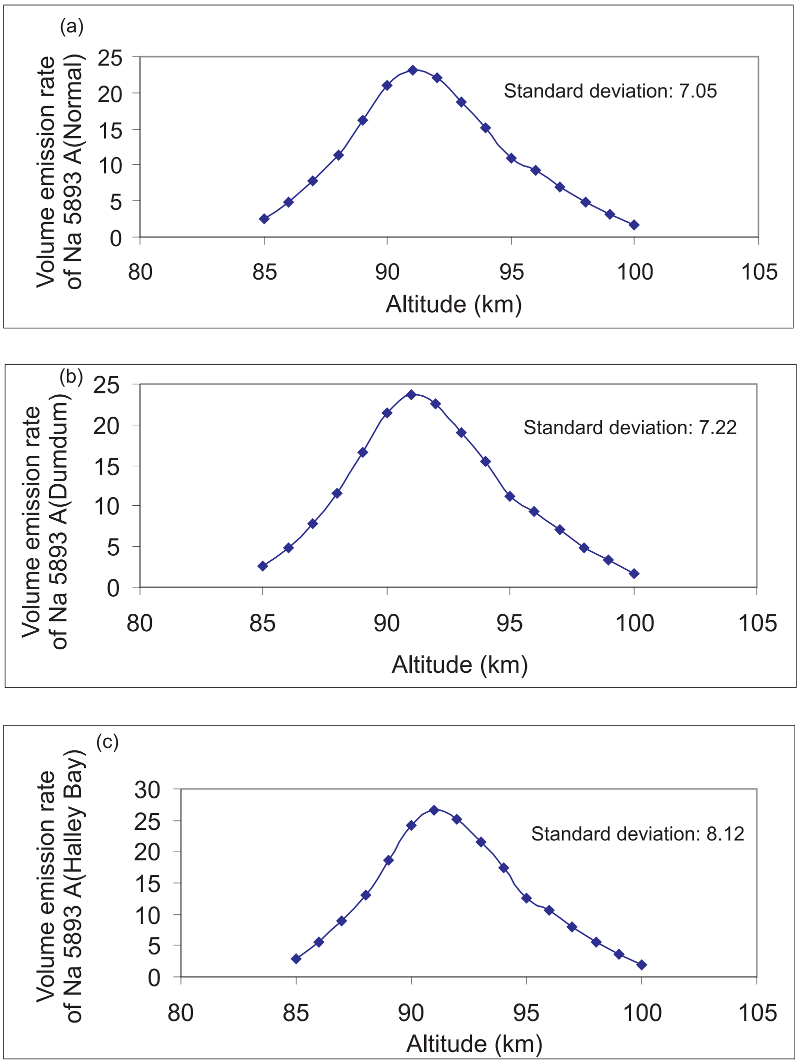


Figure 1. Volume emission rates of Na 5893 Å for normal, Dumdum (22.5°N, 88.5°E) and Halley Bay (76°S, 27°W).

of intensities at Dumdum and Halley Bay are 0.1584 R and 2.4038 R per year, respectively. Short-term analysis for the period 1979 to 1989 clearly reveals the nearly same nature of intensity trend of Na 5893 Å. The mean of the yearly mean values of ozone concentration during the period 1979–1989 for the stations Dumdum and Halley Bay are 269.94 and 280.47. Percentage of the variation of ozone concentration from these values are computed for different years and are shown in table 3(a). These are 2.14% and 8.29% for the year 1979 for Dumdum and Halley Bay, respectively. Intensities are 165.30 R and 175.26 R at Dumdum and Halley Bay respectively, for the year 1979. The yearly variations of intensities are shown in figure 3(a) and 3(b). The rates of decrease of intensities at Dumdum and Halley Bay are 0.3321 R and 2.4937 R per year, respectively.

For the next period 1990 to 1998, the percentage of variation of ozone concentration from the mean values of ozone concentration of the period 1979–1989 are computed and shown in table 3(b). These are −0.20% and −10.72% for the year 1990 at Dumdum and Halley Bay, respectively. Intensities of Na 5893 Å line are 161.52 R and 144.49 R for the two stations respectively, for the year 1990. The variation of intensities for the period 1990–1998 are shown in figure 3(c) and 3(d). The rates of decrease of intensities are 0.0929 R and 1.6901 R per year respectively.

The mean of monthly mean ozone concentration for each month during 1979–1998 is calculated and shown in table 4. Percentages of ozone fluctuation from the mean of January to December ozone values are calculated for the two stations. The intensities of Na 5893 Å are then calculated considering the corresponding ozone fluctuation percentages.

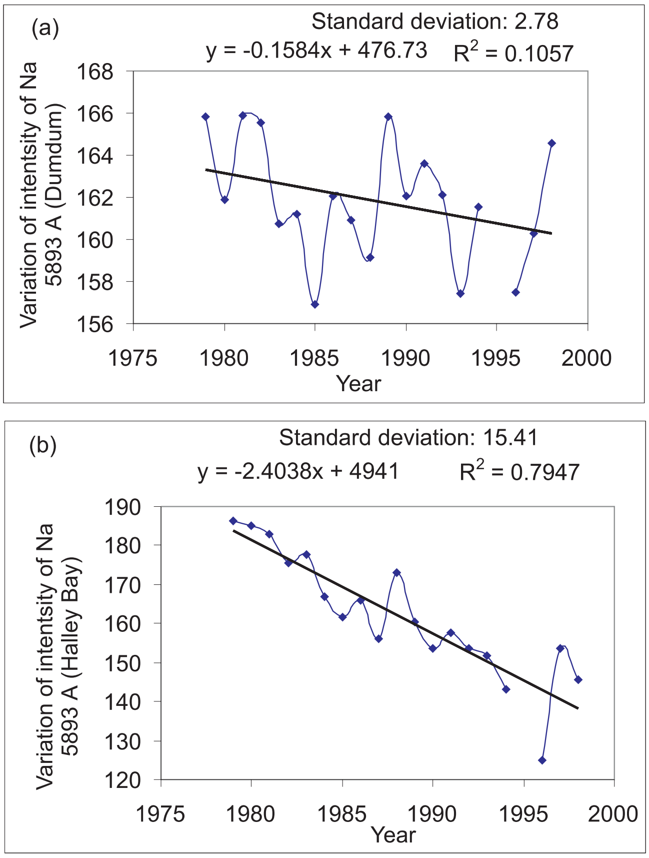


Figure 2. Yearly variations of intensity of Na 5893 Å line at Dumdum (22.5°N, 88.5°E) and Halley Bay (76°S, 27°W) for the period 1979–1998.

The variations of intensities for different months in a year for the two stations are shown in figure 4(a) and 4(b).

5. Conclusions

The volume emission rate of Na 5893 Å line attains maximum at an altitude of 91 km due to the maximum value of the product of n(O_3), n(O) and n(Na). The volume emission rate and intensity of Na 5893 Å at Halley Bay (76°S, 27°W) are comparatively higher than that at Dumdum (22.5°N, 88.5°E) in 1979 due to its higher percentage of ozone increase from its mean value. The intensity of Na 5893 Å gradually decreases from 1979 to 1998 at both the stations, Dumdum (22.5°N, 88.5°E) and Halley Bay (76°S, 27°W), but at different rates. Short-term variations of Na 5893 Å line for the period 1979–1989 and 1990–1998 clearly reveal that the rate of decrease of intensity for the period 1979–1989 is higher than that for the period 1979–1998. The rate of decrease of intensity for the period 1990–1998 is much lower than that for the whole period. Again the rate of decrease of intensity for the period 1979–1989 is much higher than that for the period 1990–1998. The rate of yearly decrease in intensity is greater at Halley Bay (76°S, 27°W) due to the larger loss rate of yearly mean ozone concentration from 1979 to 1998. Figure 4 clearly reveals that maximum intensity occurs for the month of May and minimum intensity occurs for the month of December at Dumdum (22.5°N, 88.5°E), but in the case of Halley Bay (76°S, 27°W), maximum intensity occurs during the month of December and minimum intensity occurs for the month of October. Intensity gradually increases from the month of January, attains its maximum for the period of May and June, then gradually decreases

Table 3(a). *Yearly variation of intensity of Na* 5893 Å *line at Dumdum and Halley Bay.*

Year	Mean O_3 (DU) at Dumdum	O_3 fluctuation from mean % at Dumdum	Mean O_3 (DU) at Halley Bay	O_3 fluctuation from mean (%) at Halley Bay	Peak volume emission rate of Na 5893 Å at Dumdum	Peak volume emission rate of Na 5893 Å at Halley Bay	Intensity of Na 5893 Å at Dumdum	Intensity of Na 5893 Å at Halley Bay
1979	275.71	2.14	303.73	8.29	23.61	25.04	165.30	175.26
1980	269.12	−0.300	301.75	7.59	23.05	24.87	161.35	174.12
1981	275.81	2.17	298.42	6.40	23.62	24.60	165.35	172.19
1982	275.24	1.96	286.09	2.00	23.57	23.58	165.01	165.08
1983	267.23	−1.00	289.70	3.29	22.89	23.88	160.22	167.16
1984	268.02	−0.71	272.28	−2.92	22.96	22.44	160.69	157.11
1985	260.92	−3.34	263.72	−5.97	22.35	21.74	156.43	152.18
1986	269.43	−0.19	270.77	−3.46	23.07	23.92	161.53	156.24
1987	267.55	−0.89	254.54	−9.25	22.91	20.98	160.40	146.87
1988	264.59	−1.98	282.24	0.63	22.66	23.26	158.63	162.86
1989	275.69	2.13	261.90	−6.62	23.61	21.59	165.29	151.13

Table 3(b). *Yearly variation of intensity of Na 5893 Å line at Dumdum and Halley Bay.*

Year	Mean O_3 (DU) at Dumdum	O_3 fluctuation from mean % at Dumdum	Mean O_3 (DU) at Halley Bay	O_3 fluctuation from mean (%) at Halley Bay	Peak volume emission rate of Na 5893 Å at Dumdum	Peak volume emission rate of Na 5893 Å at Halley Bay	Intensity of Na 5893 Å at Dumdum	Intensity of Na 5893 Å at Halley Bay
1990	269.39	−0.20	250.39	−10.72	23.07	20.64	161.52	144.49
1991	272.02	0.77	257.21	−8.29	23.29	21.20	163.09	148.42
1992	269.52	−0.16	250.62	−10.64	23.08	20.66	161.58	144.62
1993	261.73	−3.04	247.82	−11.64	22.42	20.43	156.92	143.00
1994	268.57	−0.51	233.48	−16.75	23.00	19.25	161.01	134.73
1995								
1996	261.83	−3.00	203.68	−27.38	22.43	16.79	156.98	117.53
1997	266.47	−1.28	250.84	−10.65	22.82	20.66	159.77	144.6
1998	273.59	1.35	237.32	−15.38	23.43	19.56	164.02	136.95

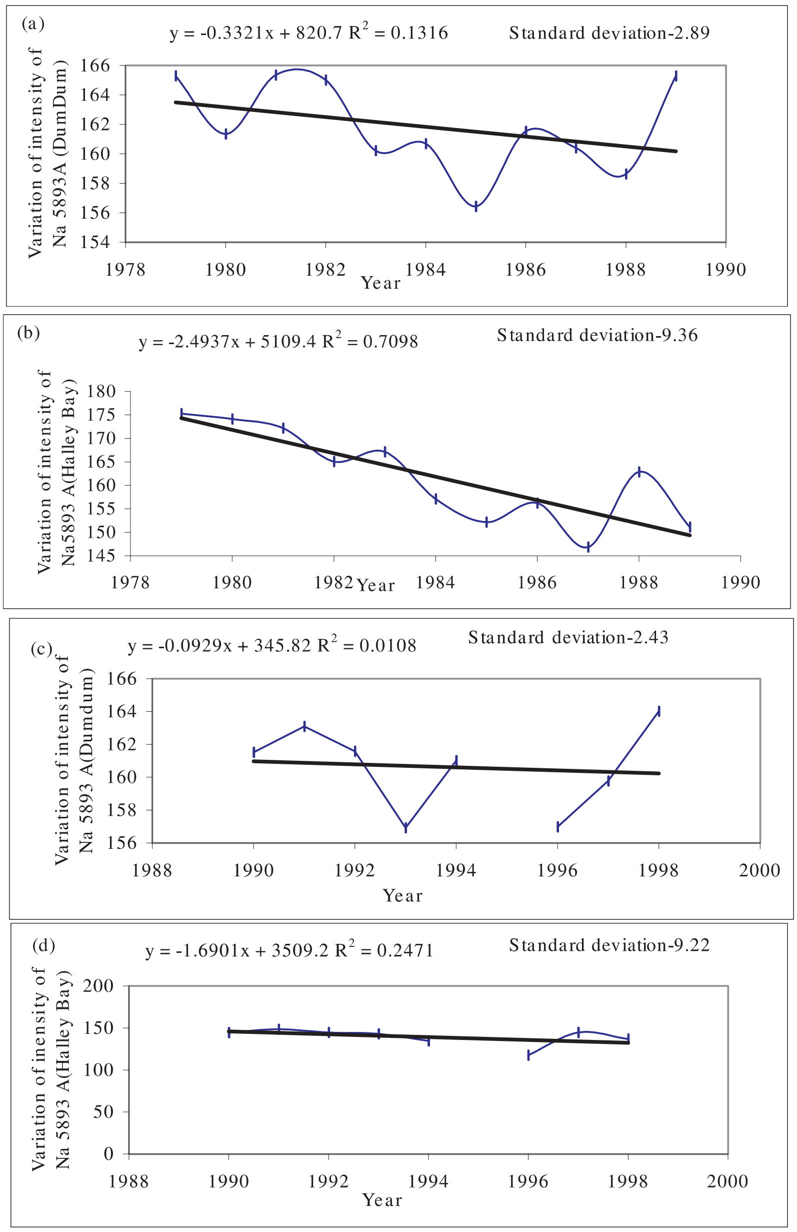
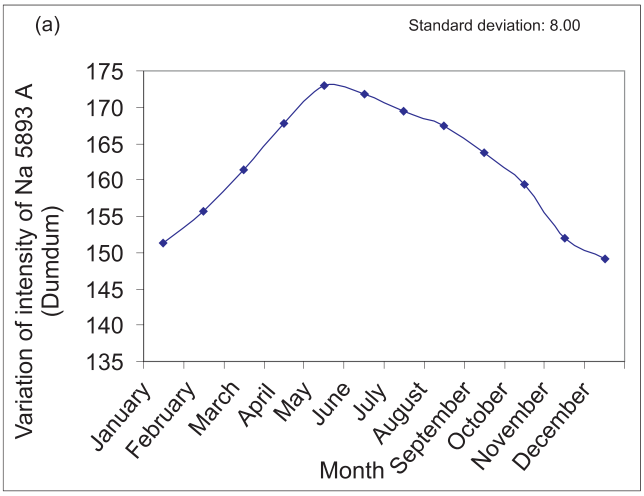


Figure 3. Yearly variations of intensity of Na 5893 Å at Dumdum (22.5°N, 88.5°E) and Halley Bay (76°S, 27°W) for the period 1979–1989 and 1990–1998.

Table 4. *Seasonal variation of intensity of Na* 5893 Å *line at Dumdum and Halley Bay.*

Month	Mean O_3 (DU) Dumdum	% fluctuation from mean at Dumdum	Intensity of Na 5893 Å at Dumdum	Mean O_3 (DU) at Halley Bay	% fluctuation from mean at Halley Bay	Intensity of Na 5893 Å at Halley Bay
January	251.60	−6.52	151.29	306.43	14.70	185.63
February	258.86	−3.82	155.66	289.39	8.32	175.30
March	268.47	−0.25	161.43	282.61	5.79	171.21
April	279.05	3.68	167.80	278.68	4.32	168.83
May	287.59	6.85	172.93	272.78	2.10	165.24
June	285.83	6.19	171.86	266.88	−0.10	161.68
July	281.87	4.73	169.50	261.98	−1.94	158.70
August	278.44	3.45	167.42	255.07	−4.52	154.52
September	272.42	1.21	163.80	210.70	−21.13	127.64
October	265.00	−1.54	159.35	202.59	−24.17	122.72
November	252.77	−6.09	151.98	258.99	−3.05	156.90
December	247.91	−7.89	149.07	319.87	19.73	193.77



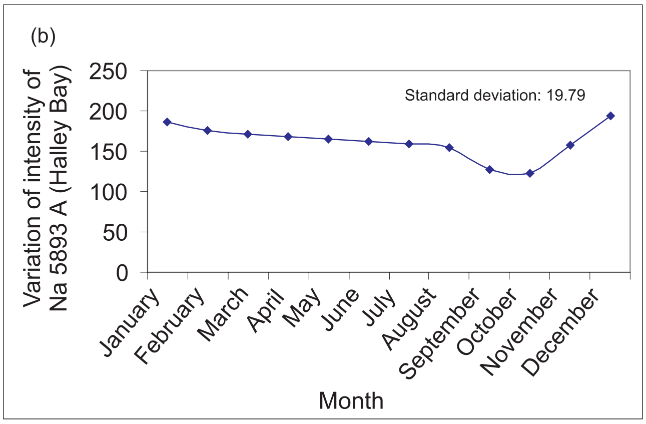


Figure 4. Seasonal variations of intensity of Na 5893 Å line at Dumdum (22.5°N, 88.5°E) and Halley Bay (76°S, 27°W).

and attains its minimum value for the month of December at Dumdum (22.5°N, 88.5°E). But for Halley Bay (76°S, 27°W) the maximum ozone concentration occurs for the month of December and January, then gradually decreases, attains minimum for the month of October, then gradually increases. The minimum intensity during the month of October at Halley Bay is due to the dramatic decrease in ozone concentration at Halley Bay during springtime because of the special atmospheric climatic condition at Antarctica during springtime. The special atmospheric conditions of Antarctica are as follows (Jana *et al* 2001):

- During Antarctic spring, temperature becomes very low (−80°C) (1991).
- Concentrations of Cl and oxides of chlorine are elevated.
- Concentrations of oxides of nitrogen become low.
- Large amount of polar stratospheric clouds appear. These are supported by several expeditions.

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