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Measurement of Total Ozone, D-UV Radiation, Sulphur Dioxide and Nitrogen Dioxide through Brewer Spectrophotometer At Maitri, Antarctica during Year 2000

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Abstract

Brewer Spectrophotometer has been installed at Maitri, the permanent Indian Scientific Research Station, Antarctica in July 1999 to measure total ozone, damaging ultra-violet radiation (D-UV), Sulphur dioxide ($S0_2$) and nitrogen dioxide ($N0_2$). The depletion of ozone and its fluctuation could be monitored day to day during Antarctic spring season (August-October). The data collected during the year 2000 are analyzed in this paper. The instrument Brewer spectrophotometer, (here after called Brewer) and its functions are described briefly. The values of total ozone and D-UV are compared in each month. The sudden increase or decrease of D-UV confirms further depletion or recovery of ozone in the successive days during the spring season. The measurements confirm the existence of 'Ozone Hole' over Antarctica during 2000. The measurements of $S0_2$ and $N0_2$ at Maitri show very low values.

Introduction

It is now recognized that the significant fluctuations in atmospheric ozone and sulphur-dioxide concentrations are related to a variety of adverse environmental conditions. The ozone layer, which shields the earth from the harmful effects of solar ultra-violet (UV) radiation, is believed to be vulnerable to attack by chlorofluorocarbons (CFC) and other effluents. There is a general fear that the depletion of ozone concentration may alter climatic pattern of the earth. Atmospheric sulphur dioxide is closely associated with 'acid rain' phenomenon, which like ozone depletion has implications for the global environment.

From 1987 onwards, it has been confirmed that the depletion of ozone concentration during spring months (August-October) at Antarctica has increased year-by-year and its monitoring becomes an essential scientific program in every Indian scientific expedition. IMD had used Dobsonspectrophotometer to measure total ozone at Dakshin Gangotri (70°05' 37" S, 12°00' 00"E) the first Indian Antarctic station during 1989. IMD installed Brewer at Marti (Lat 70°45'39" S and Long 11°44'48" E) in July 1999 to measure total ozone, UV Radiation, $S0_2$ and $N0_2$. This instrument could be operated using moon light in the absence of sunlight during polar night period to measure total ozone, $N0_2$ and $S0_2$.

Brewer Spectrophotometer

Brewer is the latest and highly sophisticated scientific instrument, which measures atmospheric ozone, D-UV radiation, $S0_2$ and $N0_2$. The Brewer spectrophotometer is the core component of a complete Brewer system, which comprises:

1. Brewer spectrophotometer, 2. Microcomputer, 3. Control software and 4. Printer. The spectrophotometer is associated with automated iris and filter-wheel controls, azimuth & zenith trackers and UV-B monitor. External view of the complete Brewer system is shown in Fig.1. and the configuration of its optical elements is shown in Fig.2. The PC is programmed to interact with an operator to control the Brewer in fully automated mode of operation. This optical instrument is designed to measure ground level intensities of the attenuated incident solar ultra violet CUV) radiation at five specific wavelengths (306.3, 310.1, 313.5, 316.8, 320.1 nm) in the absorption spectra of ozone (0_3) and sulphur dioxide $(S0_2)$. This system allows switching to $N0_2$ operation at 430-450 nm.

The Brewer Spectrophotometer Fig.1 consists of three major optical assemblies. The fore optics, the spectrometer and the photo multiplier. Sunlight enters the fore optic system through the quartz inclined window.

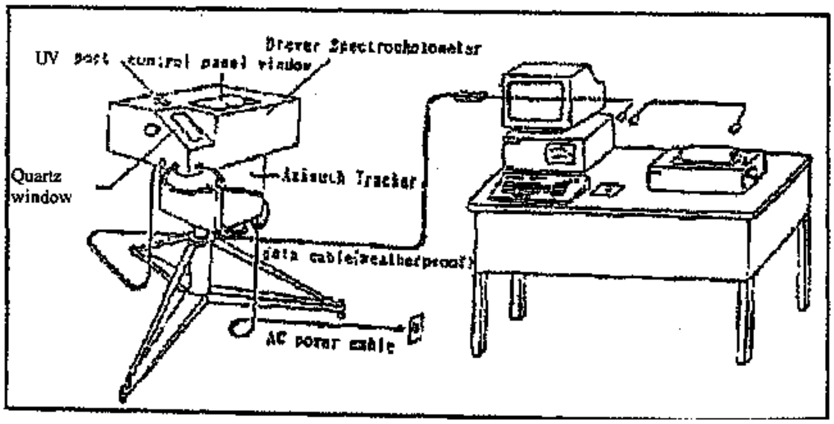


Fig. 1: External view of the Brewer Spectrophotometer

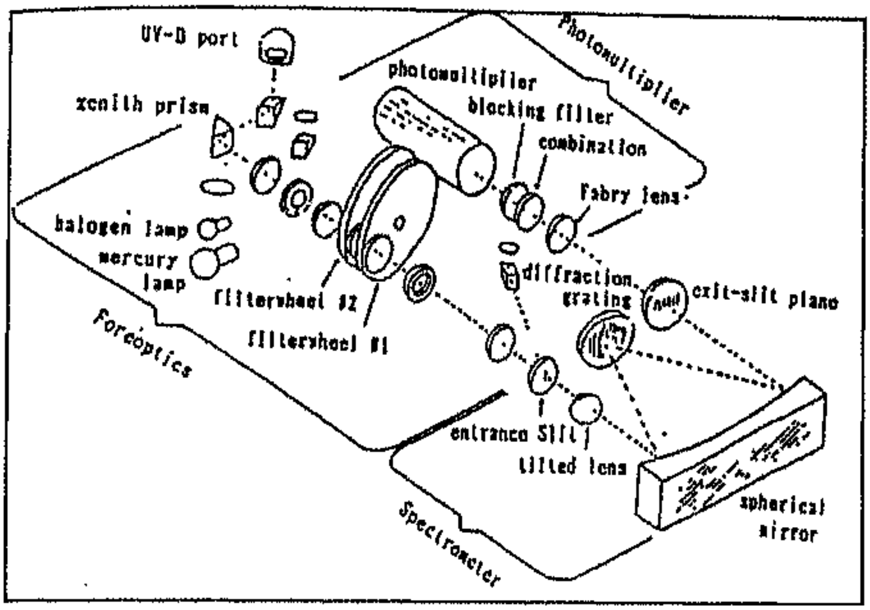


Fig .2:configuration of the optical elements

Incoming light is directed through the fore optics by a director prism, which may be rotated to select light from either the zenith sky, the direct sun or one of the two calibration lamps. A mercury lamp provides a line of source for wavelength calibration of the spectrometer; a halogen lamp provides a well-regulated light source so that the relative spectral response of the spectrometer may be monitored.

A modified Ebert grating spectrometer disperses ultra violet light on to a focal plane. Six exit slits are positioned along the focal plane at the operating wavelengths: 303.2 nm (for mercury wavelength calibration), 306.3 nm, 310.1 nm, 313.5 nm, 316.8 nm and 320.1 nm in 0_3 mode with 0.6 nm resolution and 426.4 nm 431.4 nm, 437.3 nm, 442.4 nm, 448.1 nm, 453.2 nm in NO_2 mode with 0.85 nm resolution. Wavelength is adjusted by rotating the grating with a stepper motor, which drives a micrometer acting on a lever arm. The exit-slit plane is shielded by a cylindrical mask which exposes only one wavelength slit at a time. The mask is positioned by a stepper motor which cycles through all five operating wavelengths approximately once per second. Light passing through the exit slits is collected on the cathode of a low-noise (EMI 9789QB05) photomultiplier. The photon pulses are amplified, discriminated, and divided before being transmitted to a counter. The resulting photon count is registered in one of six wavelength channels.

The Brewer Spectrophotometer contains its own microprocessor board, which controls all internal instrument operations. The spectrophotometer provides automated stepper-motor control of the micrometer (which rotates the diffraction grating) and the slit mask. Azimuth and zenith pointing system provide the necessary hardware and electronics to enable the spectrophotometer to track the sun or moon across the sky automatically. Both azimuth and zenith stepper motors are controlled by the COSMAC microprocessor with the spectrophotometer from an I / 0 board. The central path of radiation passing through the entrance slit is horizontal and defines the axis of the fore-optics. The first element in the fore-optics is a reflecting prism, which can be rotated about this horizontal axis by a stepper motor. The orientation of the prism determines the zenith angle of observation. The azimuth of the measured radiation is determined by the orientation of the whole instrument about the vertical axis. Azimuth control has been achieved by mounting the spectrometer and fore-optics on a "single axis sun tracker" whose stepper motor is driven by the same electronics package as the other motors in the system.

A mercury vapour lamp and a quartz halogen lamp are located immediately below the reflecting prism. They are in the spectrometer field of view when the reflecting prism is rotated as if for a zenith angle of 180°. Measurements on these lamps permit wavelength calibration and monitoring of the sensitivity of the spectrometer at different wavelengths.

Ultra-violet-B Monitor

The UV-B monitor is an optical assembly, which enables the Brewer to measure UV-B irradiance using a thin disc of Teflon as a transmitting diffuser. The disc is mounted on the top of the instrument under a 5 cm diameter quartz dome, and is thus exposed to the horizontal UV irradiance. Under the disc, there is a fixed reflecting prism which is located so that the disc is in the spectrometer field-of-view when the rotating zenith prism is set for a zenith angle of 270°. The UV measurement software routine supplied scans from 290 to 325nm on slit 1, in 0.5nm increments and then scans back to 290nm. The irradiance at each wavelength is integrated to produce a damaging UV value (D-UV) weighted to the DIFFEY action spectrum.

The Control System

An RCA CDP18501 microcomputer is located within the instrument. It coordinates the movement of the wavelength mask motor with the accumulation of photon counts in different registers and drives the five other stepper motors in the instrument. It also controls the reference lamps and through an A/D interlace, monitors various supply voltages and the temperature of the instrument .The microcomputer has an internal battery powered precision quartz clock, Communication to an external computer or to a manually operated terminal is by an RS-232 link. The microcomputer accepts (ASCII) commands, executes each commanded task and signals the task completion back to the external computer. Some of the commands cause measured data to be transferred back to the external computer. Multiple commands are stored by the microcomputer and executed in sequence. The external computer issuing a series of commands and then receiving and analyzing the measured data performs any particular observation type or instrument test. Analyzed data are recorded on floppy discs and data summaries are printed,

Method of Observation and Data

Brewer spectrophotometer has been operated in all months during 2000, subject to the sky condition. During polar nights (in absence of the sun), the system was operated and it measured total ozone, $S0_2$ and $N0_2$ using focused moon light. Observations of total ozone, $S0_2$, $N0_2$ and D-UV radiation were taken on all the operated days. On an average, each month about 20 days were operated through focused / direct sun light during summer and transition periods, and about 6 days during polar winter months using focused moon light. Table-1 shows the number of Brewer operational clays during the year 2000.

Table 1: No. Brewer operational days during the year 2000

Month	No. of clays
January	23
February	21
March	19
April	20
May	7
June	6
July	7
August	13
September	17
October	24
November	22
December	27

Results and Discussion

Mean daily values of total ozone, SO_2, NO_2 and Maximum D-UV have been taken for analyzing the data.

(a) **Total Ozone:** Total ozone has been measured through direct sun (DS), zenith sky (ZS), focused sun (FZ) and focused moon (FM). The monthly values of total ozone have been plotted linearly and are shown in Figs 3-14. Total ozone has varied between 300 DU and 250 DU in the first seven months since January and reduced below 200 DU in August steadily. During September and up to first week of October the total ozone depleted steadily and declined to the lowest value of 113 DU on 27th September 2000 and 116 DU on 3rd and 6th October. The last week of September and first week of October could be considered as severe ozone depletion period when the total ozone was below 125 DU. The ozone concentration recovered steadily from the value of 116 DU from the first week of October to 160 DU at the end of October. By the end of second week of November, total ozone value exceeded 200 DU. On 30th November, total ozone increased above 300 DU leading to sudden warming in the stratosphere noticed through temperature profile of ozone sonde ascent as shown in Fig. 15. This confirms the total recovery from the depletion of ozone over Antarctica.

(b) Damaging Ultra-Violet radiation (D-UV): UV-B (290-320nm) radiation is considered as dangerous to human skin and hence damaging UV radiation reaching ground has been measured in ozone mode in all the operational days except polar night period. In general, when the elevation of sun increases the value of UV-B radiation also increases and vice-versa. The maximum value reaches around the local noon of any day. At Maitri, it has been observed that the maximum values of D-UV were reported between 1030 and 1130 UTC. For discussion about D-UV values in different periods/seasons, maximum D-UV of each day was considered. Maximum D-UV values have been plotted for all months. The highest value of maximum D-UV radiation of 178mW/m^2 has been reported at 1105 UTC on 05 November during the year 2000.

(c) Salient features of total ozone and maximum D-UV values during 2000:

(i) **In** January (Fig.3), total ozone was around 280 DU most of the days except on 15th when a peak value of 301 DU was reported. The daily maximum D-UV value steadily decreased from the first week onwards suddenly decreasing to 108.1 mW/m^2 on 15th and again reached a peak of 134.3 mW/m^2 on 18th.

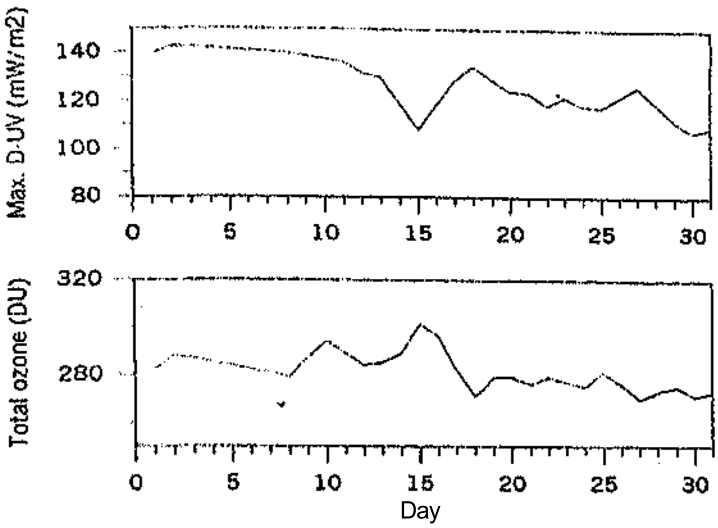
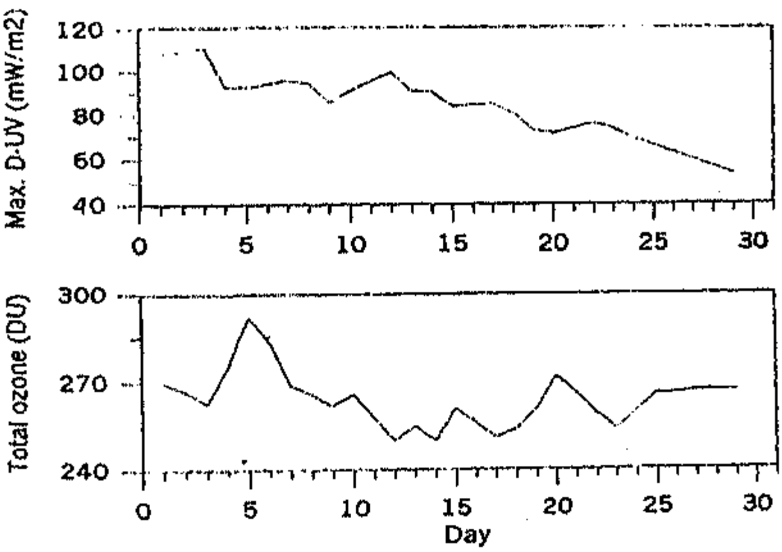


Fig.3: Max. D-UV (top panel) and Total ozone (bottom panel) during January 2000

(ii) In February (Fig. 4), the highest value of total ozone of 292 DU was reported on 5th and there was a significant fall of D-UV values (92.7 mW/nr) on the same day. The maximum D-UV fell steadily as elevation of sun came down gradually.



0 5 10 15 20 25 30

Day

Fig. 4: Max. D-UV (top panel) and Total Ozone (bottom panel) during February 2000

(iii) During March (Fig.5), the maximum D-UV further fell steadily from 56 mW/m^2 to 20mW/m^2, but the total ozone was varied between 285 DU and 239 DU.

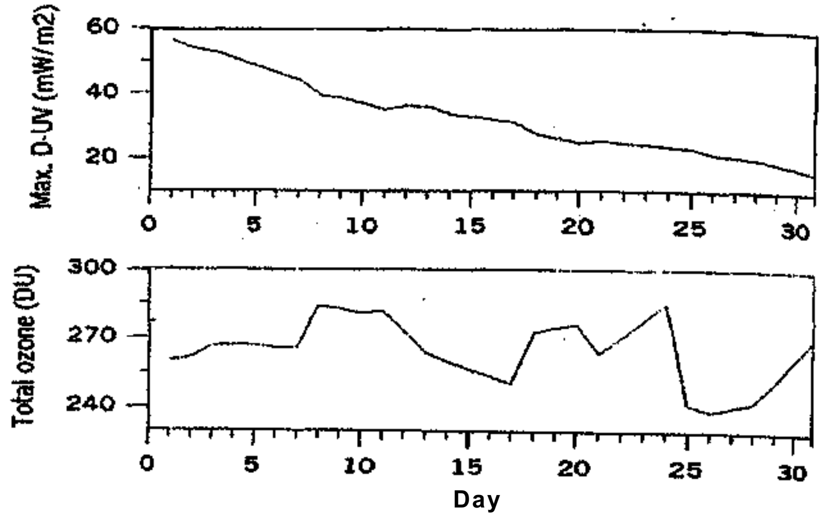


Fig. 5: Max. D-UV (top panel) and Total Ozone (bottom panel) during March 2000

(iv) In April (Fig. 6), maximum D-UV fell to low value when the elevation of the sun lowered further to <5 deg. A lot of daily variations in total ozone have been observed.

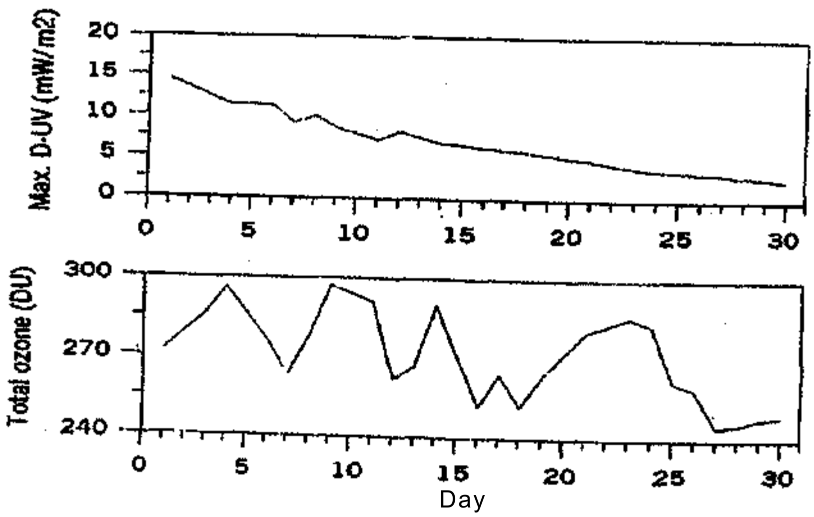


Fig. 6: Max. D-UV (top panel) and Total Ozone (bottom panel) during April 2000

(v) By the end of May (Fig.7), maximum D-UV dropped to less than 0.5 mW/m^{2}' as sun was its lowest elevation. The total ozone was almost steady in the first week and there was an increase significantly in the second week. A peak value of 317 DU was reported on 15th. There was no observation after 17th.

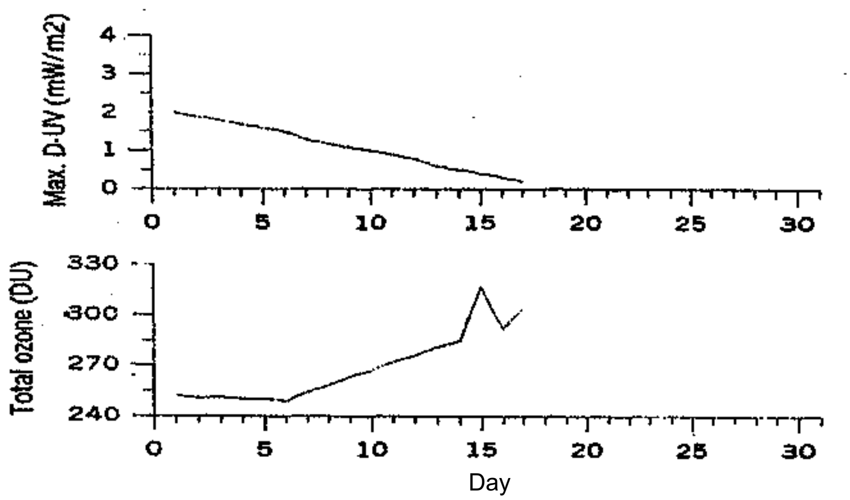


Fig. 7: Max. D-UV (top panel) and Total Ozone (bottom panel) during May 2000

(vi) During total polar night in June (Fig. 8), in the absence of sunlight total ozone was measured through focused moon light. The total ozone steadily fell from 277 DU on 11th to 256 DU on 17th. D-UV during this month was nil due to the absence of sunlight.

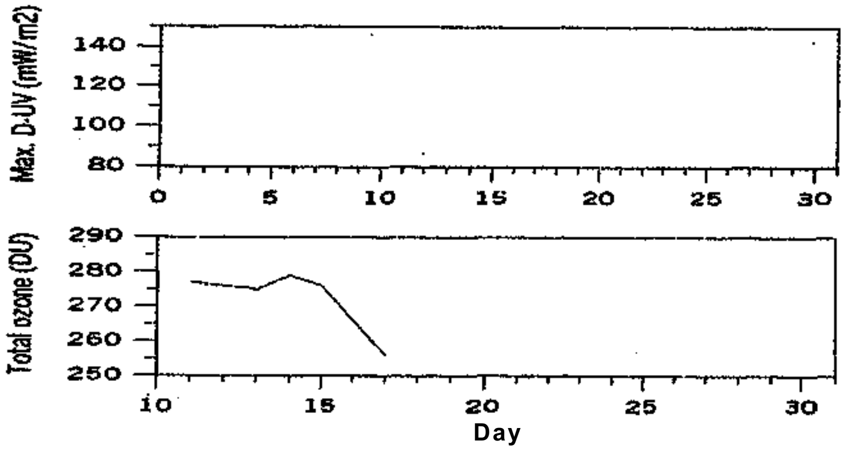


Fig. 8: Max. D-UV (top panel) and Total Ozone (bottom panel) during June 2000

(vii) During July (Fig. 9), after polar night, the sun reappeared in the last week. Hence, the D-UV was too less and within 1.0mW/m^2 while total ozone varied between 286 DU and 245 DU.

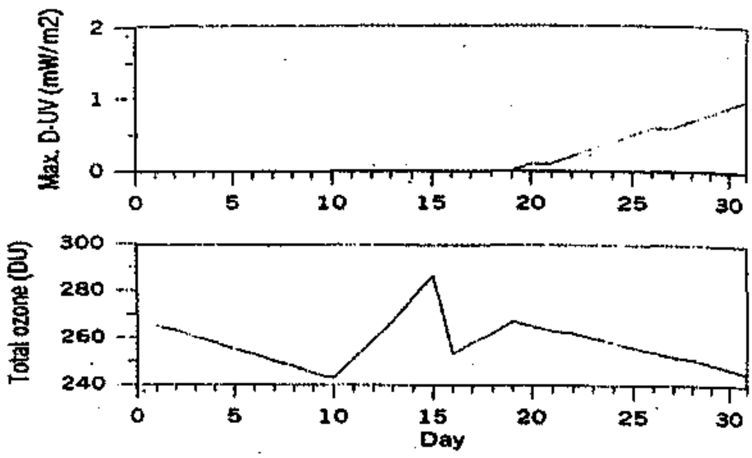


Fig. 9: Max. D-UV (top panel) and Total Ozone (bottom panel) during July 2000

(viii) In August (Fig. 10), when the elevation of the sun has rose day-by-day, maximum D-UV also increased steadily. The total ozone fell steadily from 240 DU and further dropped below 200 DU from 3rd week onwards which confirmed the beginning of the ozone depletion period.

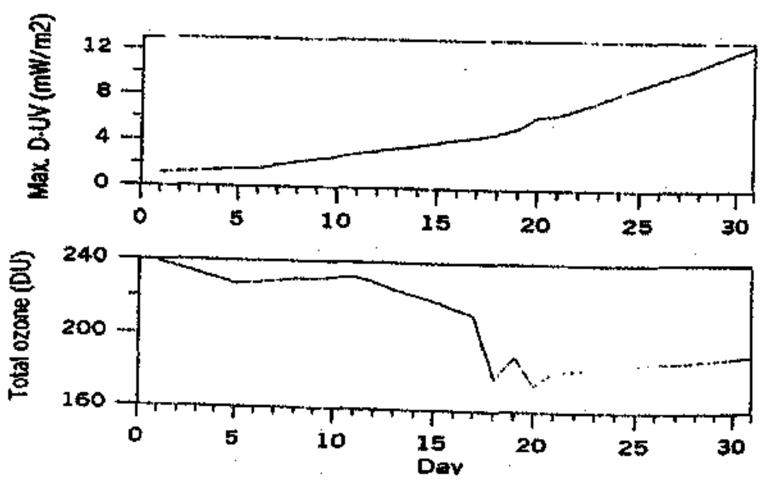


Fig. 10: Max. D-UV (top panel) and Total Ozone (bottom panel) during August 2000

(ix) In September (Fig. 11), the maximum D-UV increased gradually till third week. In the fourth week there was a sudden rise of 88.3 mW/ m^2 has been observed. The severe depletion of ozone was noticed in the fourth week and the total ozone was well below 125 DU. The lowest value of 113 DU was reported on 27^{th}.

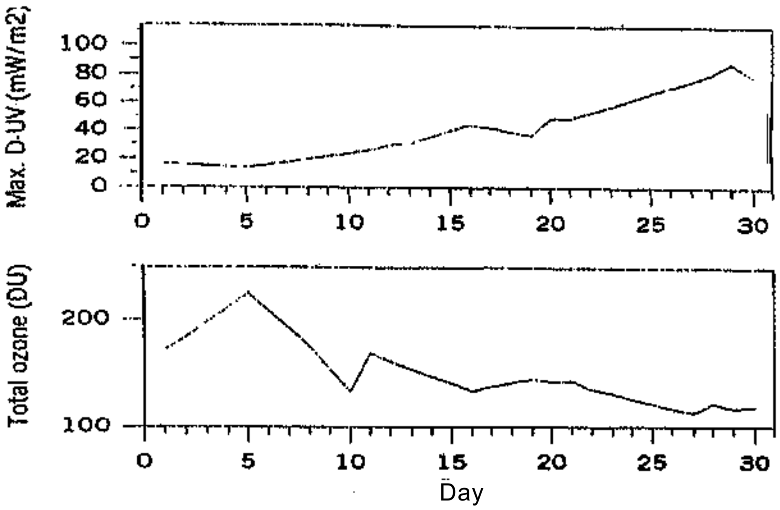


Fig. 11: Max. D-UV (top panel) and Total Ozone (bottom panel) during September 2000

(x) During the first week of October (Fig. 12), the total ozone was within 125 DU and the lower value of 116 DU was reported on 3^{rd} and 6^{th}. From second week onwards, the ozone recovered significantly and

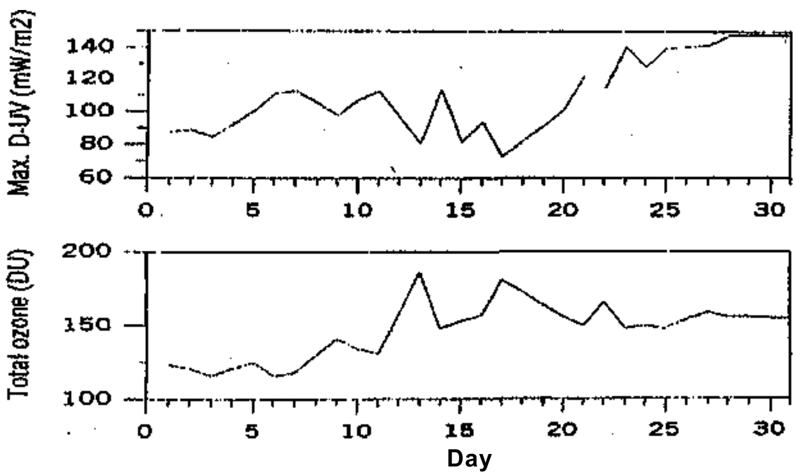


Fig. 12: Max. D-UV (top panel) and Total Ozone (bottompanel) during October 2000

the maximum value of 186 DU was reported on 13th and 181 DU on 17th. Significant variations were observed in maximum D-UV values.' The lowest value of 72.3 mW/m^2 was reported on 17th, while the highest value of 147.8 mW/m^2 was reported on 28th.

(xi) During November (Fig. 13), the ozone recovered further steadily up to 26th and crossed the mark of 200 DU by the end of second week. From 27th onwards there was a sudden rise in total ozone and by the end of the month total ozone crossed 300 DU. Highest peak value of D-UV of 178.4 mW/m^2 was reported on 5th. In the second half of the month, D-UV fell steadily and a steep fall was noticed from 27th onwards.

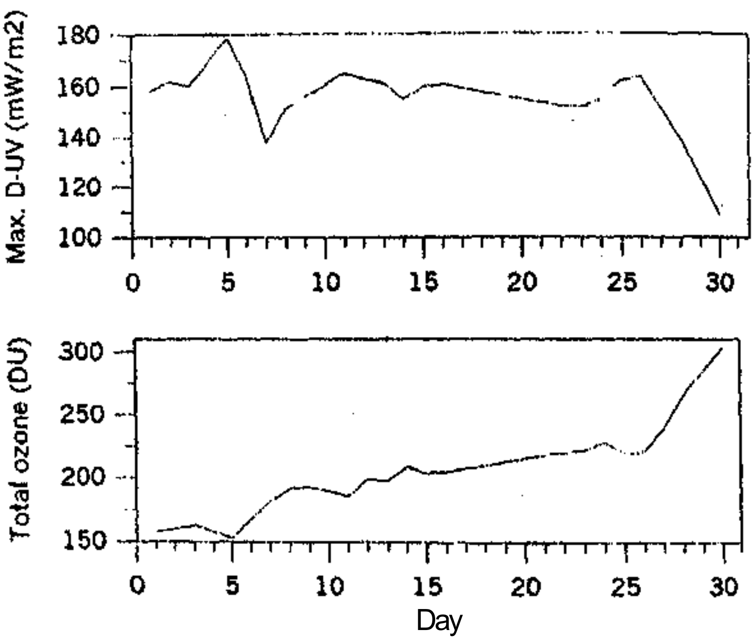


Fig. 13: Max. D-UV (top panel) and Total Ozone (bottom panel) during November 2000

(xii) During December (Fig. 14), even though the elevation of the sun was at its maximum position at Maitri latitude, the max. D-UV value was lower than that of November month. Most of the days, the value was around 125mW/m^2. The total ozone in the first 9 days was much higher than that of normal values. The highest value of 335DU was reported on 01 December 2000 and most of the days, the values were between 280DU and 320DU.

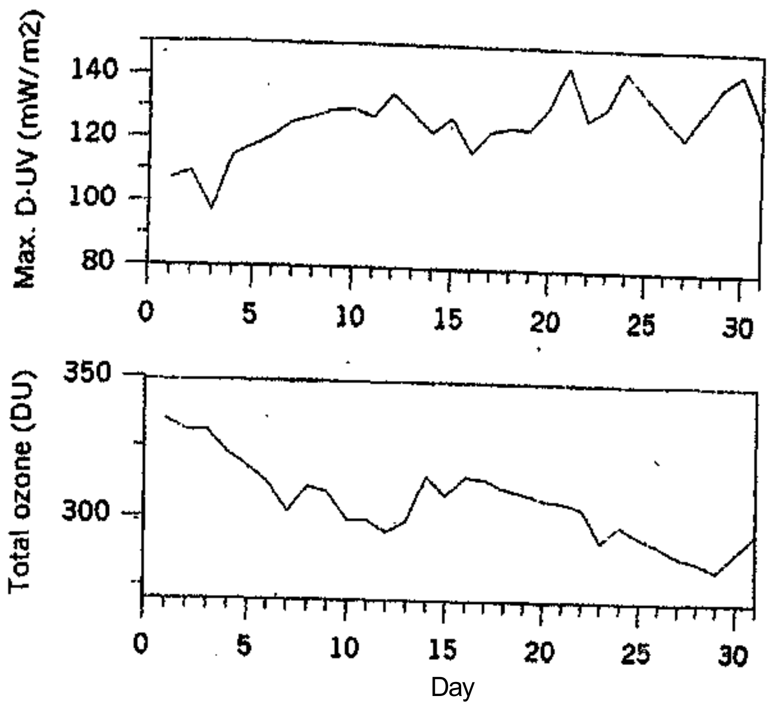


Fig. 14: Max. D-UV (top panel) and Total Ozone (bottom panel) during December 2000

(d) Comparative study of D-UV Radiation and Total Ozone during 2000: The maximum values of D-UV radiations of each day have been plotted for all month along with total ozone and shown in Figs 3-14. For study of co-relation between maximum D-UV and total ozone, ozone depletion period (Antarctic spring months August-November) have been considered. When the elevation of the sun increases day-by-day, it is obvious that maximum D-UV values also increases. From the Table-2, and the diurnal variation of total ozone and maximum D-UV for the ozone depletion months, it is clear that whenever the total ozone increases suddenly, the maximum D-UV value decreases abruptly and whenever total ozone decreases from the previous day or successive days, the maximum D-UV increases simultaneously. When the values of total ozone are compared with maximum D-UV values between 11 October and 14 October (all clear sky day observations), it is evident that whenever there was a sudden depletion (recovery) of ozone, there was also a sudden rise (fall) of max. D-UV values. Hence, we can say that, when there is a sudden increase of value in total ozone, there must also be a sudden decrease in maximum D-UV values and

Table 2: Comparision of total ozone with maximum D-UV values

Date	Total 0_3 D.U	Max. D-UV mW/m^2
31-Aug	191	12.7
1-Sep	164	16.0
2-Sep	172	15.3
5-Sep	225	13.2
11-Oct	131	112.8
12-Oct	157	96.6
13-Oct	186	81.1
14-Oct	148	113.8
3-Nov	163	160.0
5-Nov	153	178.4
6-Nov	168	163.8

vice-versa during depletion period. The curves of total ozone and maximum D-UV curves for Antarctic autumn and spring months were compared. It is observed that the values of maximum D-UV in spring month (August-October) is more than one and a half times that of the values of autumn months (March - May) during 2000. The difference is mainly due to ozone depletion in the stratosphere, which causes more of ultra-violet rays to reach the ground over Antarctica.

Measurement of Sulphur Dioxide and Nitrogen Dioxide

The presence of sulphur dioxide ($S0_2$) and nitrogen dioxide ($N0_2$) in the atmosphere was measured by Brewer through 0_3 mode and $N0_2$ mode respectively. The mean value of $S0_2$ and $N0_2$ in each month during 2000 is presented in the Table-3. The result shows that the pollutants $S0_2$ and $N0_2$ are available in the Antarctic atmosphere in very little quantity. The quantity of both gases was more in summer than in the winter and transition periods. The table also shows the absence of $S0_2$ in August and very little or meager in April. In the same way, $N0_2$ gas was also more in summer than in the winter. However, comparatively higher values of $S0_2$ as well as $N0_2$ in June were reported during polar night days (no sun light was available). This may be due to the observations in June were taken through focused moon light instead of direct sun light which was absent. The values show the presence of very low quantity of $S0_2$ and $S0_2$ at Maitri, Antarctica.

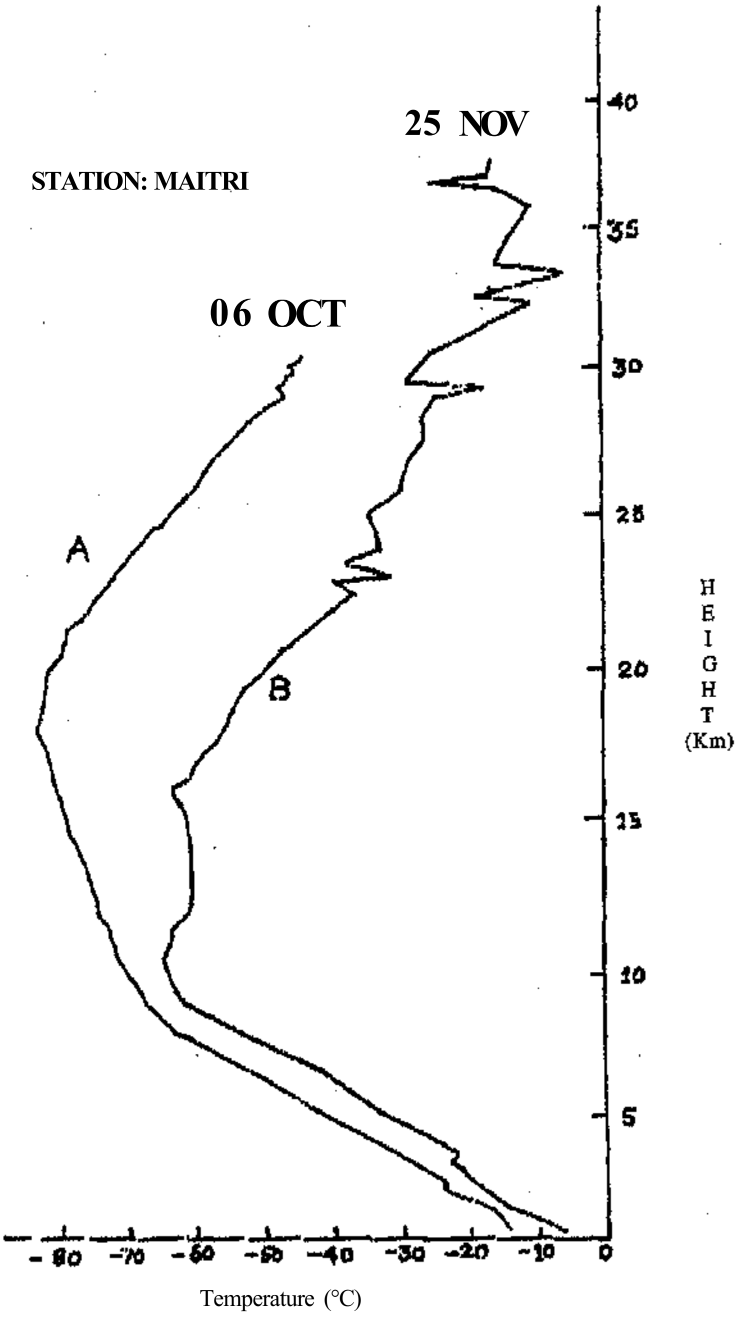


Fig. 15: Temperature profile of Maitri on (A) 06 Oct. 2000 and (B) on 25 Nov. 2000

Table 3: Presence of $S0_2$ and $N0_2$ during the year 2000

Month	$S0_2$ in DS D.U	$N0_2$ in DS D.U
Jauuary	2.1	0.83
February	1.7	0.68
March	0.8	0.55
April	0.4	0.35
May	2.2	0.33
June	3.4	1.00
July	1.4	0.94
August	0.0	0.32
September	1.1	0.43
October	2.0	0.66
November	2.1	0.82
December	2.1	0.98

Table 4: Katabatic windy days at Maitri during 2000

Month	Number of days
January	10
February	17
March	13
April	19
May	14
June	12
July	11
August	5
September	5
October	13
November	9
December	11

Conclusions

The measurement of total ozone, D-UV radiations, sulphur dioxide and nitrogen dioxide made by Brewer using direct sun light and focused moon light during 2000 were very much useful to monitor 'ozone hole ' phenomena over Antarctica. Daily variations of total ozone were observed in each month, and especially during ozone depletion period. The sudden increase or decrease of total ozone and D-UV radiations confirmed further ozone depletion or recovery of ozone during the Antarctic spring months. The variation of total ozone in each month measured by Brewer also confirms the results obtained by ozone sonde ascents. The deep depletion period also coincides with ozone vertical profile by ozone sonde ascents taken in spring season. Brewer measurements confirm the existing of ozone hole over Antarctica during spring months during 2000. The presence of very little amount of $S0_2$ and $N0_2$ in pollution free atmosphere over Antarctica is confirmed. Variations of these values are to be monitored for some more years to get a concrete conclusion.

Acknowledgements

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