

Ground-based measurements of column abundance of ozone and UV-B radiation over Zhongshan Station, Antarctica in the 1993 "Ozone Hole"

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Abstract Measurements of column amounts of ozone, and UV-B radiation by using Brewer Ozone Spectrophotometer over Zhongshan Station (69.38°S, 76.37°E), Antarctica in the 1993 "Ozone Hole" are introduced. Low total ozone amount near or below 200 DU had been detected from August to November with focus moon light or direct solar light. High coherent variation between the ozone column amounts and the temperatures within altitude from 70 hpa to 50 hpa is very obvious. UV-B radiation is greatly controlled by the Solar Zenith Angle (SZA), total ozone amount as well as the sky conditions. Preliminary statistics analysis shows that noontime biologically weighted damaging UV-B (DUV-B) dose rate is a negative exponential function of the ozone slant column abundance (OSCA). The ratios of noontime irradiance for wavelength at 300.5 nm to that at 323.5 nm reveal that ozone is one of the most important factors for the surface UV-B enhancing during the ozone depletion period.

Key words ozone, UV-B, irradiance.

1 Introduction

Ever since Farman *et al.* (1985) reported a substantial (almost 50%) reduction in column ozone abundance during the previous decade over Halley Bay Station, Antarctica, the possibility of significant ozone loss over the polar regions resulting from anthropogenic emissions of chlorofluorocarbons and its impact on enhancing UV radiation have been a matter of considerable concern. The temporal and spatial evolution of this so-called "ozone hole" occurring over Antarctica during austral spring time has been closely monitored by ground-based as well as space-borne instruments (Anderson *et al.*, 1991; Deshler and Hofman, 1991). Now the most widely accepted theory is that ozone destruction from the chlorine-catalyzed reactions take place on the particles of the polar stratospheric clouds (PSCs) (Solomon, 1988).

After the autumnal equinox, the polar regions fall into darkness and the solar ultraviolet heating ceases. Emission of thermal radiation quickly cools the polar stratosphere to make temperatures much lower than those of the mid-latitude stratosphere. A latitudinal pressure gradient then develops between the polar and mid-stratosphere, which combined with earth rotation, produces a circumpolar belt of westerly winds referred to as the polar

night jet or polar vortex. Polar vortex over south pole is a high degree of dynamical isolation and extremely cold system. Not similar to the north pole, planetary-scale waves which propagate upward from the troposphere for mixing the stratosphere is weak because that all around the continent is almost homogeneous ocean. Polar vortex exists for a longer time than it does above the north pole (Schoeberl and Hartmann, 1991). This is necessary for the temperatures within the polar vortex to fall low enough to form the clouds of nitric acid trihydrate (NAT) and ice which is generally called PSCs. The most important heterogeneous reaction is that converts the relatively unreactive chlorine species to reactive molecular chlorine (Cl_2) on the surface of the NAT or ice crystal (when temperature is lower than -88°C). Cl_2 is photolyzed in the spring sunlight, and atomic chlorine quickly reacts with O_3 and an ozone destruction takes place. With the increasing of the solar radiation and the intensive motion of planetary waves, the polar vortex breaks down at the end of October or beginning of November, then the ozone destruction stops and the "Hole" eventually closes (Solomon, 1991; Webster *et al.*, 1993).

A decrease in ozone is generally expected to lead to an increase in the penetration of UV radiation. There has been concern that enhanced UV levels might adversely impact the base of the Antarctica food web and might result in changes in the taxonomic structure of communities (Karentz, 1988; Karentz and Lutze, 1990). To investigate this important issue the U. S. National Science Foundation (NSF) has sponsored a program to monitor the UV radiation levels at four stations at or near Antarctica: South Pole Station (90°S), McMurdo Station ($77.73^\circ\text{S}, 166.67^\circ\text{E}$), Palmer Station ($64.67^\circ\text{S}, 64.07^\circ\text{W}$) and Ushuaia ($55.00^\circ\text{S}, 68.00^\circ\text{W}$), Argentina (Stamnes *et al.*, 1992; Lubin *et al.*, 1992). Measurements of UV-B irradiance have also been done at Japanese Syowa Station ($69.00^\circ\text{S}, 39.59^\circ\text{E}$) for several years. In this paper, we report for the first time the ground-based observational results of total ozone column abundance and UV-B radiation at Zhongshan Station, the Prydz Bay, east part of Antarctica, during the period 1993 "Ozone Hole". The observation is very helpful for the research work on the ozone depletion and its adverse impact on the ecosystem in this region.

2 Instrumentation

Brewer ozone spectrophotometer was designed by AES (Atmospheric Environment Service), Canada. The automated Brewer spectrophotometer has been recommended by WMO (World Meteorological Organization) and widely been used in many countries. The instrument is capable of taking measurements of direct sunlight, zenith sky, UV-B and Umkehr in unattended operation for several days (Kerr and McElroy, 1980). The equipment mainly consists of spectrophotometer, azimuth tracker, and the control computer. The spectrophotometer is the most important part of the system, it mounts on the azimuth tracker and consists of fore-optical system, spectrometer, UV sensitive photomultiplier tube (PMT) used in the pulse counting mode and control electronics package for controlling all the stepper motors. Tracking the disk position of the sun or the moon is determined by the orientation of the zenith prism (for zenith tracking) of the fore-optical system and the azimuth tracker (for azimuth tracking).

The type of Brewer instrument installed at Zhongshan Station is MKIV. It uses 5 wavelengths within ultraviolet Huggins absorption bands to measure ozone column abundance. The wavelengths are normally set at 306.3 nm, 310.3 nm, 310.1 nm, 313.5 nm, 316.8 nm and 320.0 nm. SO₂ having an intensive absorption coefficients within the Huggins bands is considered when taking a ozone measurement. The influence on the optical system from ambient temperature is also considered for any operation (Lamb, 1991).

For the measurements of UV-B irradiance, a thin disk of teflon is used as a transmitting diffuser. The disk is mounted on the top of the instrument under a 5 cm diameter quartz dome, and is thus exposed to the horizontal UV irradiance. Measured radiation through the fore-optical to the spectrometer, wavelength round-trip scanning with the interval from 290 nm to 325 nm at increments of 0.5 nm is executed by the stepper motor which controls the 1800 lines/mm holographic grating rotation. The irradiance measured within wavelengths between 290 nm and 292.5 nm is as an estimation of the stray light for the whole UV-B irradiance correction. A correction of the photomultiplier dead-time (4.5×10^{-8} s) is also taken for any UV-B measurements.

The Brewer system had been calibrated by the SCI-TEC company in April, 1992 before it was deployed at Zhongshan Station. A precisely wavelength-calibration is achieved by the internal mercury vapor lamp before the determination of ozone or the UV-B irradiance. Daily tests for the instrument, including the electronic package, the optical-mechanism system and dead-time of PMT assure that there is a good operational state of the instrument during the "ozone hole" time. Periodically 200 W lamp which had been tested by the U. S. National Institute of Standard Technology (NIST) was positioned above the UV-B dome as a standard of spectral irradiance for the calibration of the UV-B absolute irradiance. Having consistent wavelength-calibrations and the periodically UV-B absolute irradiance calibration throughout the season, there is estimated about 1% uncertainty in determination of ozone column abundance and 5% uncertainty in the UV-B absolute irradiance measurements.

The Brewer ozone spectrophotometer was installed in the end of March. Some discreet data of ozone were obtained by using focus moonlight under clear condition during the polar night. Consistent measurements by using direct sunlight or zenith scattering light (only cloudy weather) were undertaken since the end days of August. The erythemal weighted damaging UV-B (DUV-B) dose rate is obtained by convoluting the measured irradiances with the action spectrum (weighted curve), this process may be defined in this formula (Hanawalt and Setlow, 1975; McKinley and Diffey, 1978):

$$DUV-B = \int_{uv-b} F(\lambda) \times A(\lambda) d\lambda$$

where $F(\lambda)$ is the measured irradiance [$W/(m^2 \cdot nm)$], $A(\lambda)$ is the action spectrum currently, there are 2 action spectrum adopted for Brewer UV-B measurements (see Fig. 1). One is the curve recommended by the American Conference of Governmental Industrial Hygienists, National Institute for Occupational Safety and Health (ACGIH-NIOSH), because it is conveniently available as an analytic function of wavelength. The

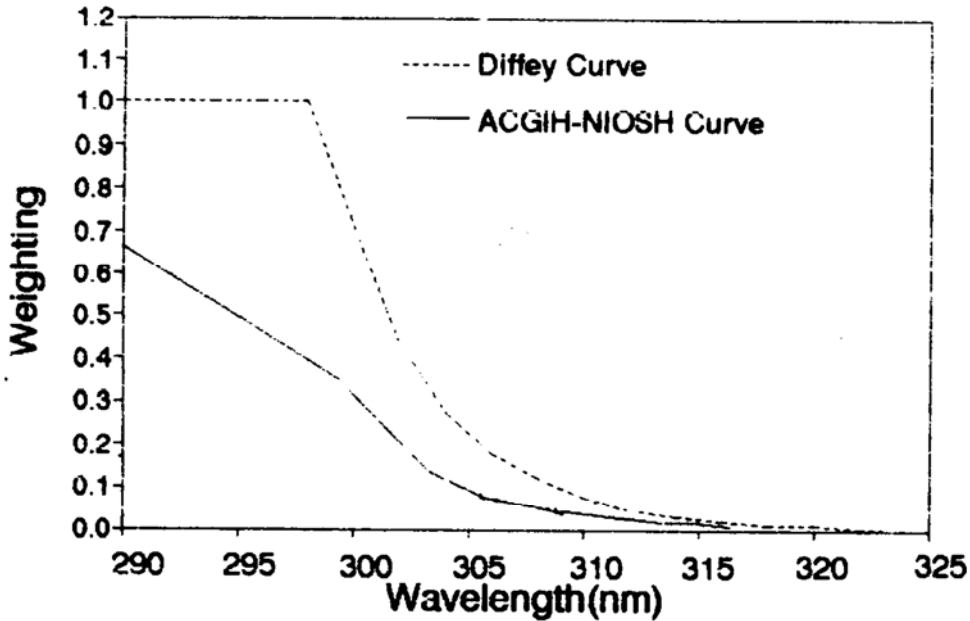


Fig. 1. AGGIH-NIOSH and Diffey curves as spectra used in Brewer UV-B measurements.

other curve is Diffey curve for its being widely accepted as the reference action spectrum (McKinlay and Diffey, 1987).

3 Results and discussions

Measurements of ozone column abundance by Brewer ozone spectrophotometer and the continuous data from TOVS/NOAA-12 (only from July 12 to October 3) are shown in Fig. 2. The observations from the ground surface and the space are in agreement. The first low ozone column abundance near 200 DU is detected by Brewer instruments on August 2 by using focus moon light. Brewer consistent measurements started at the end of August when the "Ozone Hole" had begun to develop. More than 10 times intensive variations of ozone column amounts with the range of 20~30 DU per day occurred over Zhongshan Station in this season. The lowest value is 147 DU on October 9 (day 282), and the highest 371 DU is on November 5 (day 309). But there is still a decreasing process during the middle time of November and a low value of 182 DU on November 14 (day 318). The "Hole" started to recover at the end of November. From the WMO Bulletin (Bojkov, 1994), the 1993 "Ozone Hole" over the Antarctica came out one week earlier than that in 1992. At the end of August, total ozone abundance above the sun-sunshine area had reduced to less than 200 DU, whereas the abundance had been in a normal state of 310 DU in July. A depleted area, being ozone amount less than 150 DU had enlarged since the mild days of September, and the center position of the "Hole" stayed over the east part of the continent for several weeks. The description is very close to the surface Brewer observation at Zhongshan Station. The intensive diurnal variations of o-

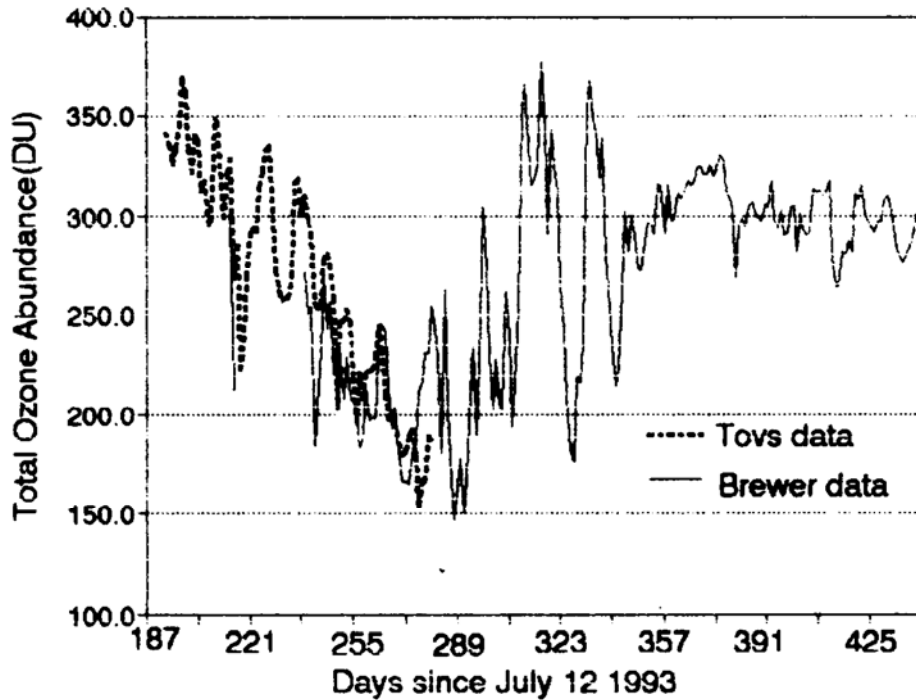


Fig. 2. Measurements of ozone column abundance at Zhongshan Station, Antarctica from Jul. 1993 to Feb. 1994; a comparison between TOVS data and Brewer data.

zone amounts may be mainly caused by the dynamical process of the stratospheric air transportation. In Fig. 3, the temperature at 70 hpa and 50 hpa altitude from July to November is given. These data were obtained by radiosonde at Australian Davis Station (68.6°S, 78.0°E) which is sited very near Zhongshan Station. The changes of the temperature have the same trends as that of ozone.

Measurements of noontime biologically weighted damaging UV-B (DUV-B) dose rate are shown in Fig. 4. Diffey weighted value is about 4~5 times as large as the ACGIH-NIOSH weighted value because of adopting different weighted curve. Considered SZA limiting the radiation penetration, a preliminary statistical analysis is made here (see Fig. 5). The noontime DUV-B dose rate is a negative exponential function of the ozone slant column abundance (OSCA), and the fitting formula is:

$$Y_{duv-b} = \exp(-0.00421776X_{osca}) \times 96.2203$$

Generally, the daily DUV-B dose rate has a symmetrical variation with the axis of the local noontime because of the symmetrical changes of SZA. This case is very obvious under a cloudless weather condition (see Fig. 6). But this regulation may be disobeyed on a cloudy weather condition. Fig. 6 also gives 2 examples of surface DUV-B dose rate measured on November 27 and November 29 respectively. On November 27 the surface largest DUV-B value appeared before the local time, while on November 29, it appeared after the local time. This is caused by the varieties of the cloud. From the cloud record, on November 27 Sc tra at 8:00 (A. M.) with cloudiness increasing and at 2:00 (P.

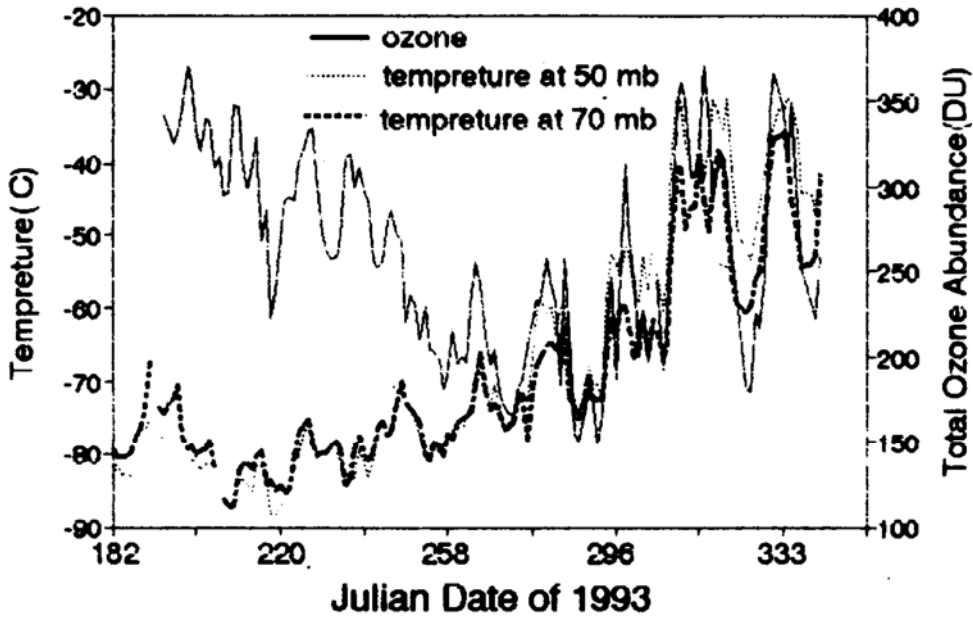


Fig. 3. Total ozone abundance and stratospheric temperature over Zhongshan Station, Antarctica from July 1993 to November 1993.

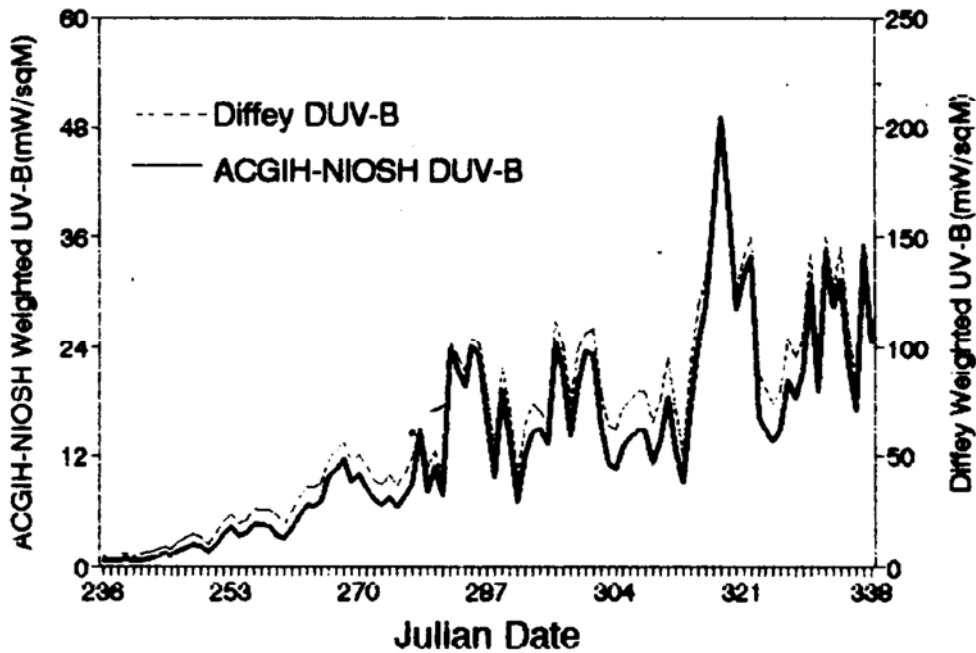


Fig. 4. Noontime DUV-B dose rate at Zhongshan Station, Antarctica in the 1993 "Ozone Hole".

M.) Sc tra became Sc op; contrarily, on November 29, Sc op at 8 : 00 (A. M.) with cloudiness decreasing and Sc tra at 2 : 00 (P. M.).

Global UV-B spectral irradiances are obtained when taking a UV-B wavelength

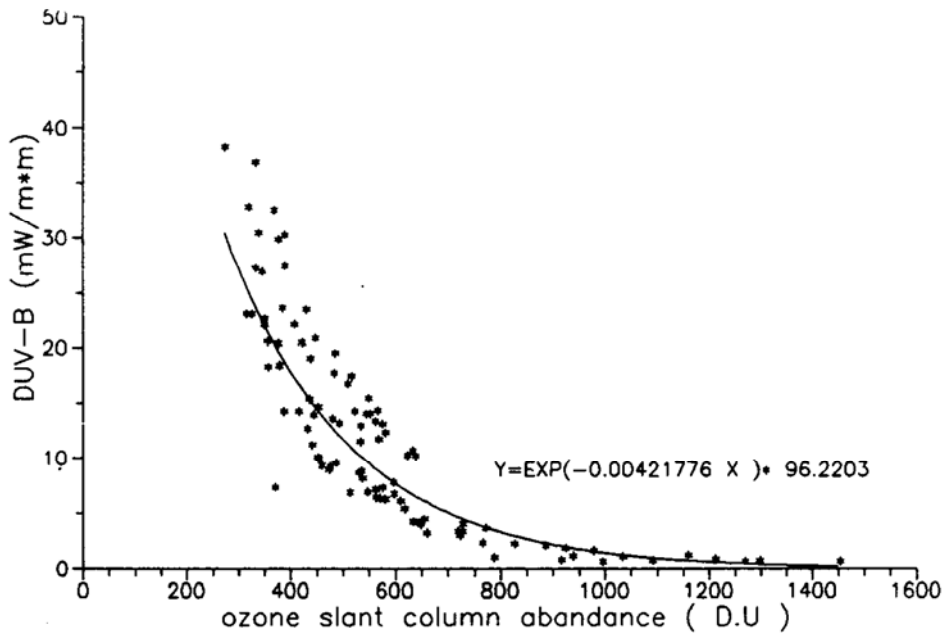


Fig. 5. Preliminary statistical result; noontime DUV-B does rate is a negative exponential function of slant ozone column abundance.

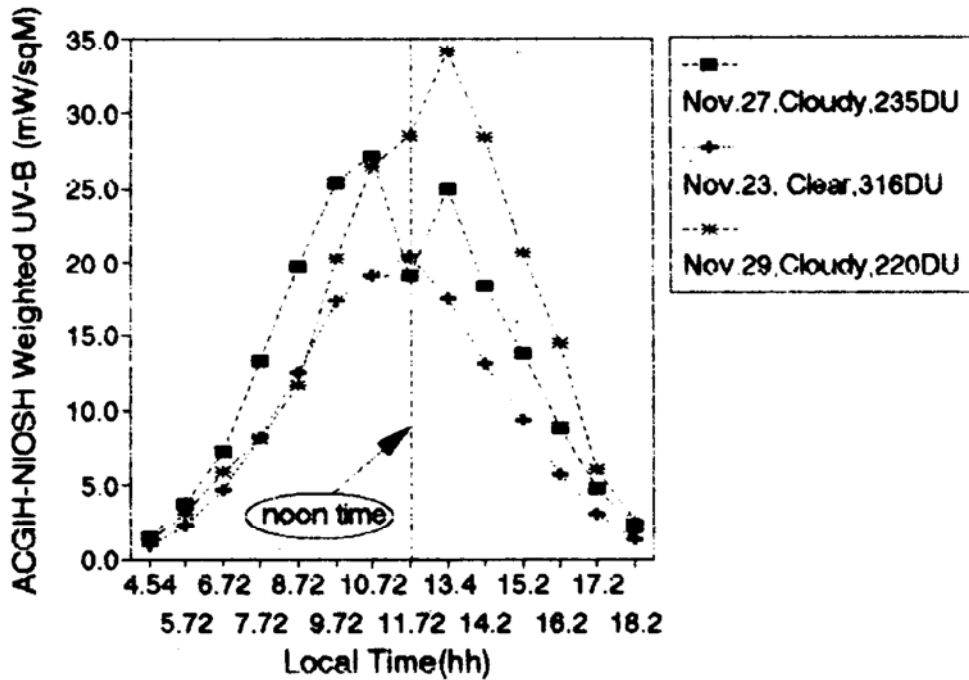


Fig. 6. Examples of measurements of DUV-B does rate under different weather condition.

scanning measurement. 4 groups of UV-B spectra measured under different ozone condition present in Fig. 7. Measurements on day 282 and day 309, have almost the same

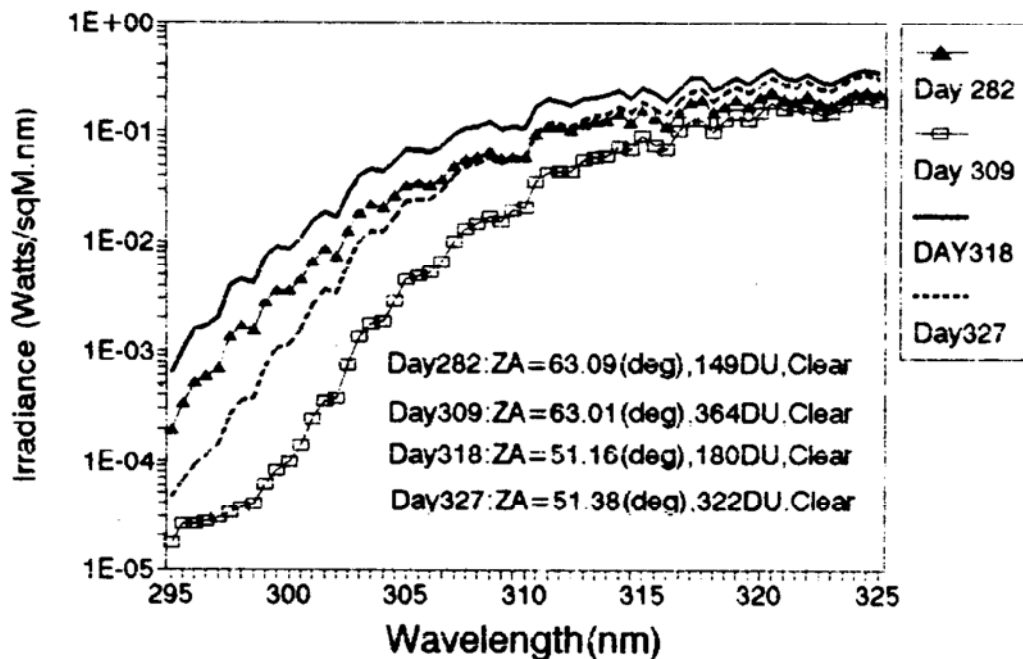


Fig. 7. UV-B solar spectra at Zhongshan Station under different ozone condition in the 1993 "Ozone Hole".

SZA, so do on day 318 and day 327. When the wavelength shrinks, the UV-B spectral irradiances on day 282 are more stronger than that on day 309 because of the different ozone abundance. Similar scenarcase also occurs on the comparison between on day 318 and day 327.

Time series of the measured irradiance for 300 nm, 305 nm, 310 nm, 315 nm, 320 nm, and 325 nm at local noontime respectively is shown in Fig. 8. More rapid variations in the irradiance at the short wavelength such as at 300 nm, 305 nm, and 310 nm compared with that at relatively long wavelength are very obvious. The reason that is the shorter wavelengths are more sensitive to the changes of ozone column abundance.

The ratio of the noon time irradiance at 300.5 nm to that at 323.5 nm is shown in Fig. 9. Ozone absorption coefficients at 300.5 nm is about 38 times of that at 323.5 nm when temperature is 226K (Molina and Molina, 1986). Because scattering by clouds is essentially independent of wavelength in the ultraviolet, much of the variability associated with cloud cover, albedo, scattering by aerosol may be canceled in this ratio. If the column ozone abundance remained constant over the entire period, This irradiance ratio would show a slow increase until the summer equinox because of the reduction of the SZA. But the ozone depletion from August to November leads the ratio quickly increase during those days of low ozone value. This case is very similar to the measurements made by Lubin at Palmer Station in 1988 and Stamnes at McMurdo Station in 1990, although the weak absorption wavelength adopted here is at 323.5 nm instead of 340 nm they used at Palmer Station (Lubin *et al.*, 1989; Lubin and Frederick, 1991; Stamnes *et al.*, 1992).

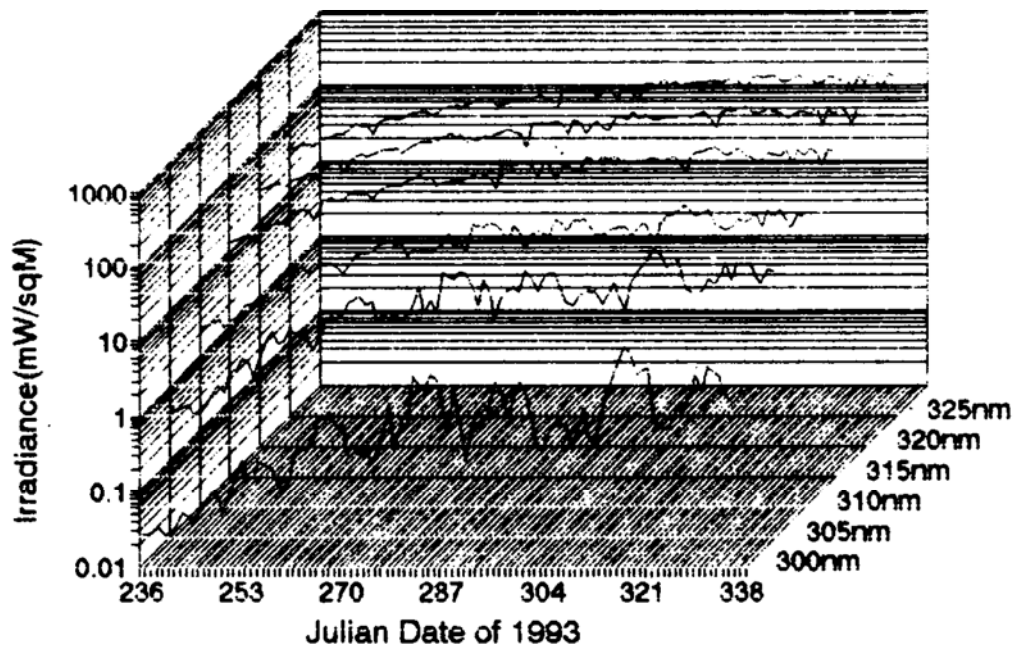


Fig. 8. Noontime series irradiance at Zhongshan Station ,Antarctica in the 1993 "Ozone Hole".

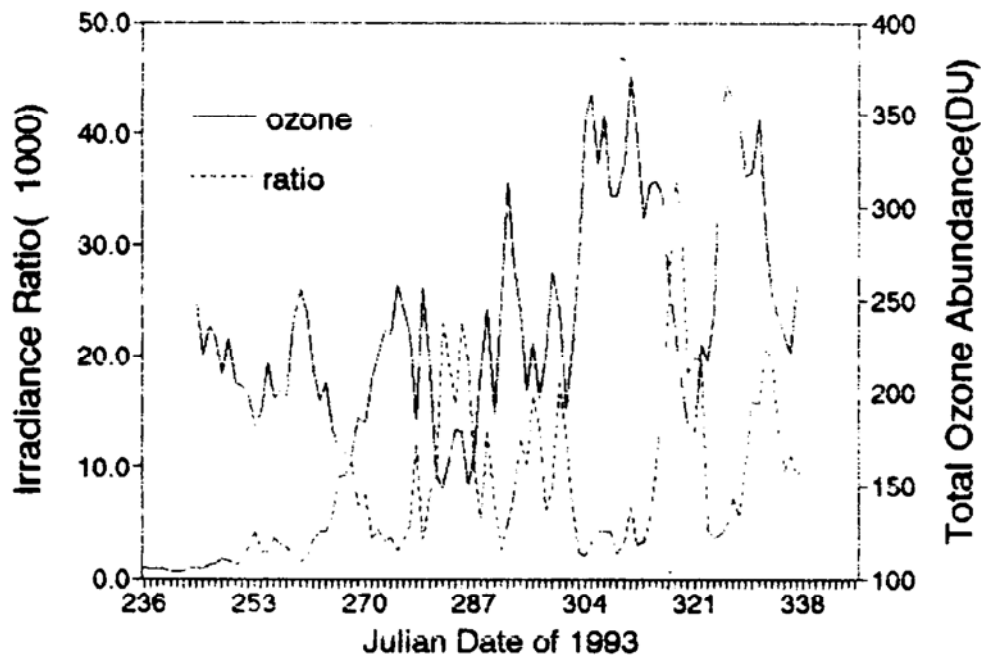


Fig. 9. Noontime series ratio ;300.5/323.5 nm at Zhongshan Station in the 1993 "Ozone Hole".

4 Conclusion

(1) "Ozone Hole" did take place over Zhongshan Station, Antarctica in 1993 and lasted almost 4 months. There are high coherent variations between the ozone column

amounts and the low stratospheric temperature. Rapid changes of diurnal ozone column abundance may be mainly due to the dynamic processes of the polar vortex.

(2) DUV-B dose rate is a negative exponential function of ozone slant column abundance by preliminary statistical analysis. Daily DUV-B dose rate has symmetrical variation with the axis of the local noontime under cloudless condition. Cloud plays major role on the daily UV-B penetration.

(3) Within the UV-B band, irradiance is more sensitive to the changes of ozone when the wavelength shrinks. Ozone is one of important roles for the UV-B radiation enhancing.

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