Korean Journal of Polar Research 10(1): 9-16

Effects of Total Ozone Decrease on the Solar Radiation and Their Variations at King Sejong Station in King George Island, West Antarctica

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ABSTRACT. This study showed variations of total ozone, horizontal global solar radiation, surface UV radiation, and erythemal UV-B radiation over King Sejong station in West Antarctica during the period starting from January 1995 to December 1997. Total ozone data were obtained from NOAA-SBUV/2 and Earth Probe/TOMS provided by NOAA and NASA, respectively. Horizontal global solar radiation, surface UV radiation and erythemal UV-B radiation are directly measured by using Eppley pyranometer, Eppley UV radiometer and Robertson-Berger UV-Biometer at King Sejong station, respectively. Erythemal UV-B radiation for December is slightly larger than that for November of 1997. Annual average total ozone increased by about 6 % in this period. Erythemal UV-B radiation increased by about 1.7% and 2.3% for solar zenith angles of 60° and 70° with 1% decrease of total ozone. This means that erythemal UV-B radiation to total ozone at King Sejong station is more sensitive than in Seoul of the northern mid-latitude. This study, however, showed that King Sejong station located on the spatial boundary of the typical ozone hole area was not yet affected directly and continuously by the ozone hole until now, but could be affected indirectly or can be influenced largely as the occasion demands by the ozone depletion.

Key Words: total ozone, horizontal global solar radiation, surface UV radiation, erythemal UV-B radiation, King Sejong station

Introduction

Since the Antarctic ozone hole was first reported by Farman *et al.* (1985), there were many studies on the relationships between depletion of stratospheric ozone and the impact of increased solar Ultraviolet (UV) radiation reaching the Earth's surface (Lubin *et al.*, 1989; Stamnes *et al.*, 1990; WMO, 1995; Wardle *et al.*, 1997), and climatological and biological effects due to the increase of solar UV radiation (Madronich, 1993; Weiler and Penhale, 1994). Among them, the study on harmful UV-B (wavelengths 280~315 nm) radiation to the human body and ecosystem, and their data collection are importantly based on biological and meteorological investigations related to the decrease of ozone amount. Stratospheric ozone is well known to be the most important atmospheric factor determining clear sky UV-B radiation reaching the Earth's surface. The potential increase of UV-B exposure is the cause of mounting concern about the ozone layer. The solar radiation in the region from about 290 to 320 nm has enough energy to induce significant effects and the biological effectiveness for some important processes increase rapidly towards shorter wavelengths. Wavelengths shorter than 200 nm are absorbed at very high altitudes by oxygen and other gases.

According to a recent report (WMO 1998), the Antarctic ozone hole is extending gradually. Its area spreads out up to 9 million km^2 in the year 1997, and the decreasing rate of ozone is relatively large during the period from 1980 to 1992. At Halley Bay

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station (75.7°S, 26.7°W) which is one of the English Antarctic stations, annual mean total ozone for October from 1975 is rapidly decreased, after then mean total ozone for the Antarctic springtime was recorded not by half amount than it during 20 years before 1970s (Center for Atmospheric Science, 1998). Halley Bay station is located on the coast of East Antarctica where fronts toward the Weddell Sea, and is almost center position of ozone hole area during the Antarctic springtime. King Sejong station (62.2°S, 58.8°W) located on King George Island where is about 1,800 km distant from Halley Bay station is situated at the boundary of the Antarctic ozone hole in most cases or within the ozone hole depending on the spatial extent of it. The location is also within the coverage area of the annual Antarctic vortices that are commonly developed over the Weddell Sea, Antarctica (Turner *et al.*, 1993). So it is proper area for research on variations of the Antarctic stratospheric ozone and UV radiation. The relationships between various phenomena taking place in the atmosphere are complex and not known well. Therefore, the ground based UV measurement is necessary to explore atmospheric changes and resultant effects on the biosphere.

Objectives of this paper are to analyze data obtained from the atmospheric measurement carried out during the period from January 1995 to December 1997 at King Sejong station, to understand the interrelation between the Antarctic ozone depletion and solar UV radiation, and to provide useful results for monitoring of atmospheric environmental variations continuously. Fields of solar radiations were observed using some radiometers at the station. Because UV radiation at the Earth's surface is largely controlled by the solar zenith angle except the extent of cloud cover, this article showed characteristics of solar radiations, and the correlation of total ozone and UV radiation with the changing solar zenith angle over King Sejong station.

Data and Methods

Total ozone

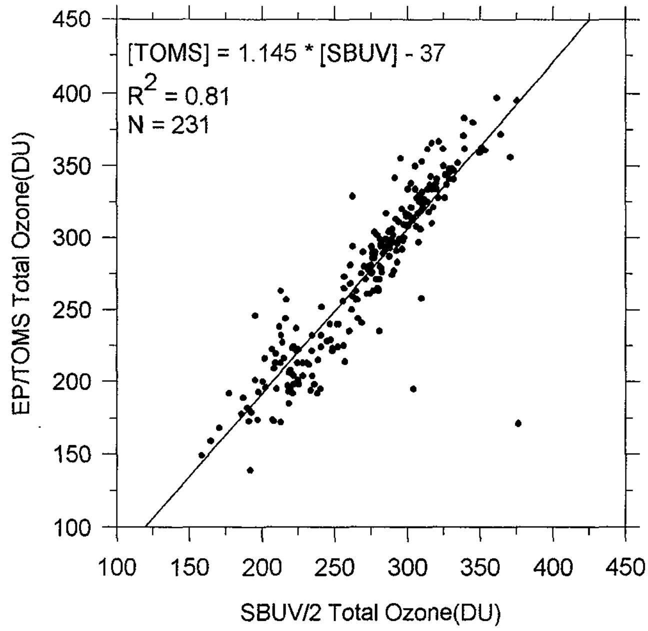

Fig. 1. Comparison of total ozone between NOAA-SBUV/2 and Earth Probe/TOMS over King Sejong station, Antarctica (1996. 8~1997. 3).

We used total ozone data obtained from NOAA-SBUV/2 (Solar Backscattered Ultraviolet Radiometer/Version 2) (1995. 1~1997. 3) and Earth Probe/TOMS (1996. 8~1997. 12). NOAA-SBUV/2 data selected in this study were used to make up for the missed TOMS data during the period from January 1995 to July 1996, and were provided by National Center for Environmental Prediction of NOAA. Earth Probe/TOMS data were downloaded from FTP site of NASA Goddard Flight Center. In order to know relations between two kinds of data, daily total ozone data of NOAA-SBUV/2 during the period from August 1996 to March 1997 were compared with those of Earth Probe/TOMS for the same season with more substantial data than other seasons (Fig. 1). NOAA-SBUV/2 total ozone amounts were converted into values of Earth Probe/TOMS type by using the correlations between them in this figure. Through the application of these results, we could derive time series of daily total ozone in Dobson Units (DU) from January 1995 to December 1997.

Horizontal global solar radiation and UV radiation

Horizontal surface global solar radiation at King Sejong station has been measured by an Eppley precision spectral pyranometer (model PSP). The pyranometer, using wire-wound plated thermopiles, has a black sensor protected by double dome Schott optical glass (clear WG7) with the wavelength range 285~3000 nm. The instrument is temperature compensated so that response is independent of ambient temperature. Sensitivity of the thermopile is approximately 9 $\mu V/W\ m^{-2}$ with linearity ± 0.5% from 0 to 2800 W m^{-2}. From laboratory measurements, its cosine response deviations do not exceed 3% for zenith angles from 0 to 70° and 7% for zenith angles from 70 to 80°.

UV radiation at the station has been measured by an Eppley total UV radiometer (model TUVR) which provides a continuous measurement of solar and sky UV radiation. This radiometer consists of a selenium barrier-layer photoelectric cell with a sealed-in quartz window, a bandpass filter to restrict the wavelength response of the photocell to the wavelength range 290~385 nm. It has been compared with Standard Total Ultraviolet Radiometer of Eppley's Research Observatory with an average ambient temperature of 24°C, and found to have a sensitivity of 173 $\mu V/W\ m^{-2}$ within linearity ± 2.0% up to 70 W m^{-2}. From observatory measurements, its temperature compensation coefficients are between –0.1% per °C from -40 to +25°C and –0.2% per °C from +25 to +50°C. Calibration comprises exposure, in the Eppley's laboratory, of a standard TUVR radiometer to an National Institute of Standards and Technology (NIST) of spectral irradiance. Horizontal surface global solar radiation and total UV radiation data have been obtained as a type of average every 10 minutes through Automatic Meteorological Observation System, which was programmed with scanning interval for every 10 seconds. These data are selected from January 1995 to December 1997.

Erythemal UV-B radiation

This radiation is measured with an UV-Biometer of Robertson-Berger type, which was measured every 5 minutes as an accumulated value. Erythemal UV-B radiation refers here to the range 280~315 nm. The UV-Biometer was developed as a broad band instrument with a spectral response following the Erythema Action Spectrum. The UV-Biometer can indicate the effectiveness of solar radiation for the induction of sunburn, phytoplankton mortality, skin elastosis and thymine dimers among other effects (Solar Light Co., 1992). Also, the instrument can be used for global UV monitoring, especially in conjunction with information about ozone thickness, cloud cover and air pollution (Madronich, 1993). The erythema action spectrum is only one of many action spectra observed in nature, with similar slope and wavelength range. The action spectrum mounted on this UV-Biometer is based on that of CIE (International Commission on Illumination) for ultraviolet-induced erythema in human skin, which is steep changing response through the UV-B region (Solar Light Co., 1992). This instrument has a resolution better than 0.01 MED/HR and an accuracy within ± 5% for daily total. UV-B data were selected from January 1995 to December 1997.

To maintain stability of instruments and obtain good-quality data, pyranometer, UV radiometer and UV-Biometer, which have been operated at King Sejong station, were checked every year through comparing with standard, which was itself calibrated by their manufacturer, based on to the recommendation of manual for each instrument. Ideally, any comparison or calibration should cover through all period, with continuous observations even under any conditions. This has not yet been possible, and here we have replaced other or new instruments calibrated by their manufacturer in order to keep up the observational continuity during the period of calibration for used instruments. The units of radiations are given in MJ m^{-2} day^{-1} and kJ m^{-2} day^{-1} for daily accumulated value or W m^{-2} for daily averaged value, respectively.

Results and Discussion

Fig. 2 shows time series of daily total ozone (DU), daily horizontal global solar radiation (MJ m^{-2} day^{-1}), UV radiation (MJ m^{-2} day^{-1}), and erythemal UV-B radiation (kJ m^{-2} day^{-1}). From this figure, we can see the seasonal variations obviously. Total ozone was

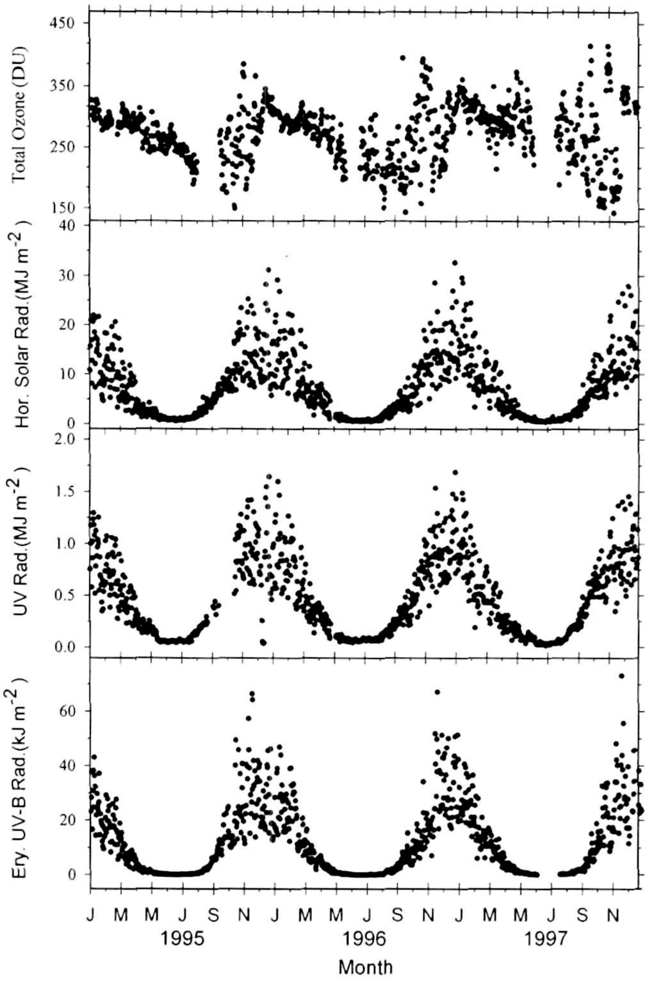

Fig. 2. Time series of total ozone, horizontal global solar radiation, surface UV radiation, and erythemal UV-B radiation (1995. 1~1997. 12).

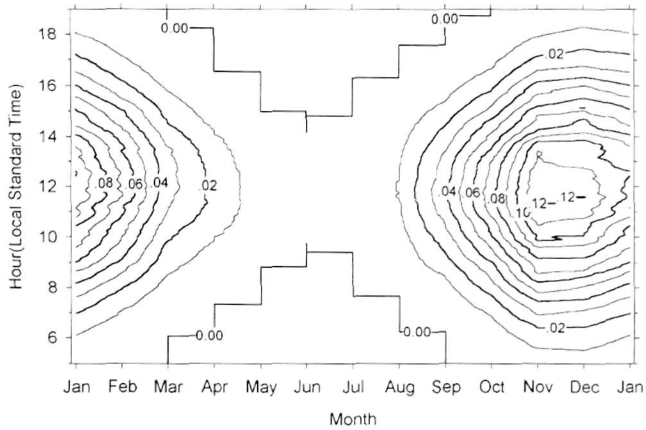

Fig. 3. Diurnal variation of monthly average erythemal UV-B radiation (x 10 W m^{-2}) for the same period as in Fig. 2.

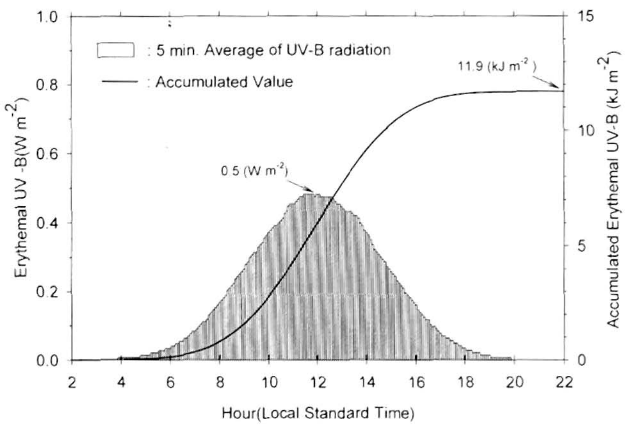

Fig. 4. Diurnal variation of annual average values and accumulated value for erythemal UV-B radiation for the same period as in Fig. 2.

gradually decreased in July and August. In September, it was recorded minimum value to be occurred in the Antarctic ozone hole. After October, total ozone was increased rapidly, and was recorded maximum value in November. Daily horizontal global solar radiation, UV radiation and erythemal UV-B radiation were recorded maxima during the Antarctic summertime and minima during wintertime.

Fig. 3 and 4 show the diurnal variations of monthly and annual average of erythemal UV-B radiation by integrating over 5 minutes, respectively. As can be seen in Fig. 3, maximum value was recorded as 1.2 W m^{-2} at 12:00 LST for December and minimum value as 0.02 W m^{-2} for June. Also, in the case of Fig. 4, there was daily maximum value as 0.5 W m^{-2} at 12:00. Annual average of daily accumulated value was 11.9 kJ m^{-2} day^{-1} as an almost constant without distinct variation during the 3 years from 1995 to 1997.

Monthly average for daily accumulated erythemal UV-B radiation are represented in Fig. 5 with the maximum values of the month. Maximum and minimum value of monthly average showed 35.0 kJ m^{-2} day^{-1} and 0.14 kJ m^{-2} day^{-1} for November and June in the year 1995, respectively. During the 3 years, maximum value of the month was recorded the greatest value in November of 1997 with 73.3 kJ $m^{-2}day^{-1}$. From the view point of monthly standard deviation there were large variations in the Antarctic spring- and summertime during the 3 years. These patterns may be caused by frequent clouds coverage and many foggy days at King Sejong station, however, many-sided analyses are necessary to find other fac-

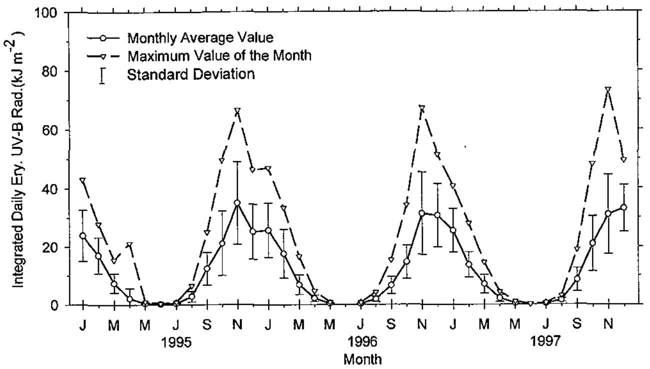

Fig. 5. Time series of monthly average and maximum values of the month for total daily erythemal UV-B radiation for the same period as in Fig. 2.

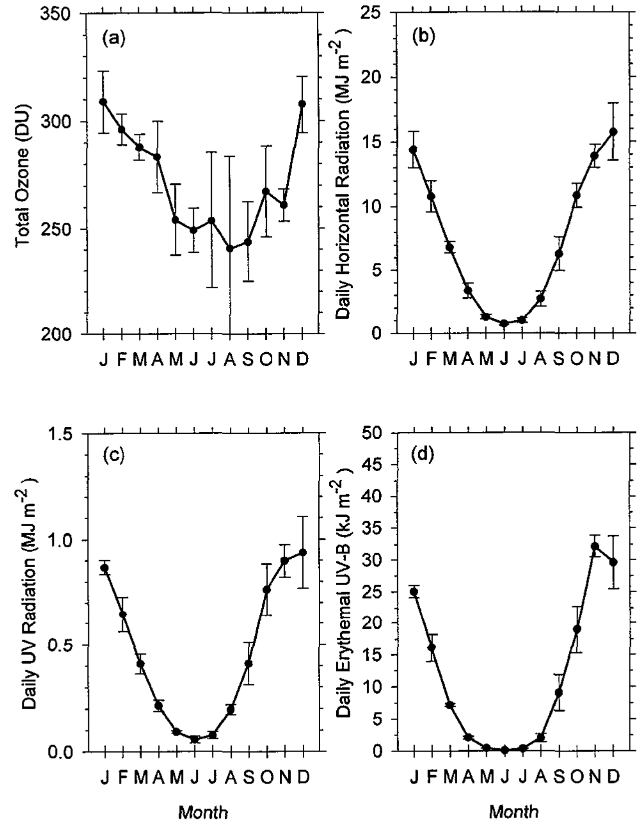

Fig. 6. Variations of monthly average value for (a) total ozone, (b) horizontal global solar radiation, (c) UV radiation, and (d) erythemal UV-B radiation for the same period as in Fig. 2.

tors to be applicable through the continuous monitoring.

Fig. 6 illustrates variations of monthly average value for total ozone, horizontal global solar radiation, UV radiation, and erythemal UV-B radiation. Maximum value of total ozone was calculated to be 309 DU in January, after then it was gradually decreasing. Minimum value was represented for August with 241 DU. These values are quite different compared with a previous study (Lee *et al.*, 1997). The range of total ozone for a year was 68 DU. All of horizontal global solar radiation, UV radiation, and erythemal UV-B radiation were recorded minimum values for June. Maximum values of horizontal global solar radiation and UV radiation were recorded in December, and that of erythemal UV-B radiation in November.

Fig. 7 shows the correlations among horizontal global solar radiation, UV radiation, and erythemal UV-B radiation at every 12:00 LST. Correlation coefficient (r^2) was the largest as 0.93 between horizontal global solar radiation and UV radiation. In this figure, we can see that the correlation between erythemal UV-B radiation and other two quantities is more diffusive and has smaller correlation coefficient than that of others. This means UV-B radiation may be more sensitive because it has short range of wavelength.

Maximum and minimum value of seasonal average for daily total ozone were 304 DU during summer and 248 DU during winter, respectively. These are rather increased than the previous analysed values during 1995~1996. Standard deviations were 18 DU during autumn as the largest value, and 7 DU during summer and winter as the smallest value. Annual average of total ozone was 271 DU, which was increased at a rate of 6.4% compared with that of Lee *et al.* (1997). In this study, there were no distinct difference from horizontal global solar radiation and UV radiation of the previous results during 2 years. Horizontal global solar radiation and UV radiation showed 13.64 MJ m^{-2} day^{-1} and 0.82 MJ m^{-2} day^{-1} during summer as maximum values, and 1.47 MJ m^{-2} day^{-1} and 0.11 MJ m^{-2} day^{-1} during winter as minimum values, respectively (Table 1). Annual average values were 7.32 MJ m^{-2} day^{-1} for horizontal global solar radiation and 0.46 MJ m^{-2} day^{-1} for UV radiation. The rate of UV radiation to horizontal global solar radiation was 6.3%. Daily accumulated erythemal UV-B radiation was maximum during summer with a value of 23.6 kJ m^{-2} day^{-1}, and minimum during winter as 0.8 kJ m^{-2} day^{-1}. Its annual

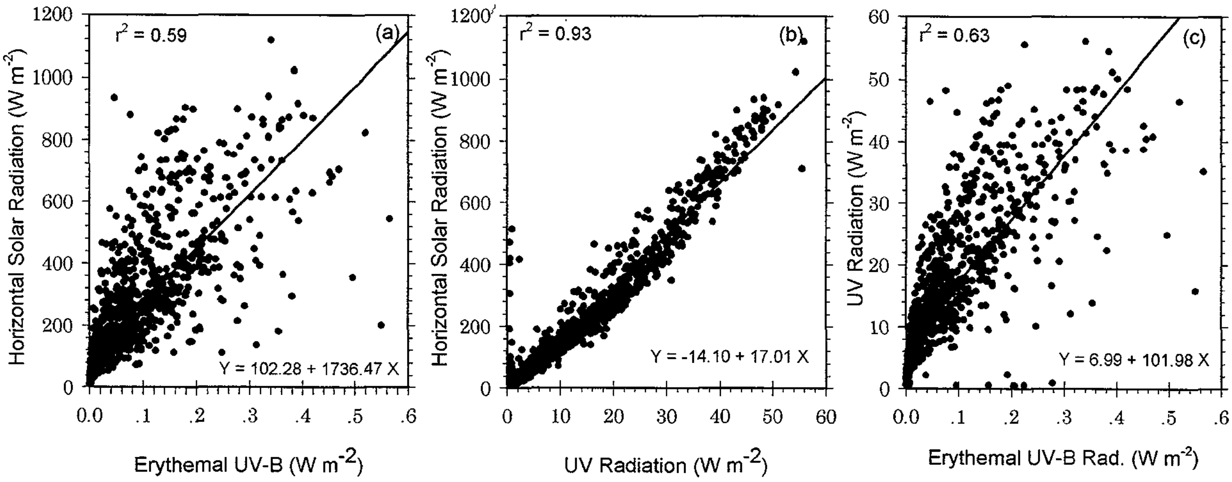

Fig. 7. Scatter diagram of horizontal global solar radiation, UV radiation and erythemal UV-B radiation as a daily average type, and correlation of those radiations (1995. 1~1997. 12).

Table 1. Seasonal average and standard deviation for total ozone, horizontal global solar radiation, UV and erythemal UV-B radiations at King Sejong station (1995. 1~1997. 12)

Season (Month) / Elements	Spring (SON)	Summer (DJF)	Autumn (MAM)	Winter (JJA)	Annual
	Ave.(S. D.*)	Ave.(S. D.)	Ave.(S. D.)	Ave.(S. D.)	Ave.(S. D.)
Total Ozone (DU)	257(11)	304(7)	275(18)	248(7)	271(25)
Hor. Solar Rad. (MJ m^{-2} day^{-1})	10.34(3.82)	13.64(2.57)	3.82(2.80)	1.47(1.07)	7.32(5.62)
UV Rad. (MJ m^{-2} day^{-1})	0.69(0.25)	0.82(0.16)	0.24(0.16)	0.11(0.08)	0.46(0.34)
UV-B Rad. (kJ m^{-2} day^{-1})	20.2(11.6)	23.6(6.9)	3.2(3.5)	0.8(1.0)	11.9(12.1)

*S.D. = Standard Deviation

average value was 11.9 kJ m^{-2} day^{-1}, which was 0.16% as a portion to horizontal global solar radiation. Seasonal standard deviations for horizontal global solar radiation, UV radiation and erythemal UV-B radiation were maximum in the Antarctic springtime.

Variation of erythemal UV-B radiation depending on total ozone

To investigate the correlation of total ozone and erythemal UV-B radiation, this study showed a time series analysis for them. Fig. 8 represents a time series of total ozone and erythemal UV-B radiation when solar zenith angle is 60°. In this figure, we could confirm there was an inverse relationship between them, however, it was not clear because of insufficient data for erythemal UV-B radiation during winter when solar zenith angle could not reach within 60°Δ. So, in order to do more quantitative analysis of increase of erythemal UV-B radiation due to ozone depletion, we introduced a method of Radiation Amplification Factors (RAF) defined as follow by Madronich (1993).

$$RAF = -\frac{\frac{\Delta F}{F}}{\frac{\Delta X}{X}}$$

where F and X are irradiance and ozone column concentration, and ΔF and ΔX are their respective variations. RAF is unitless sensitivity coefficient that relate the decreases in total ozone in the atmosphere to increase in some defined measures of irradiance,

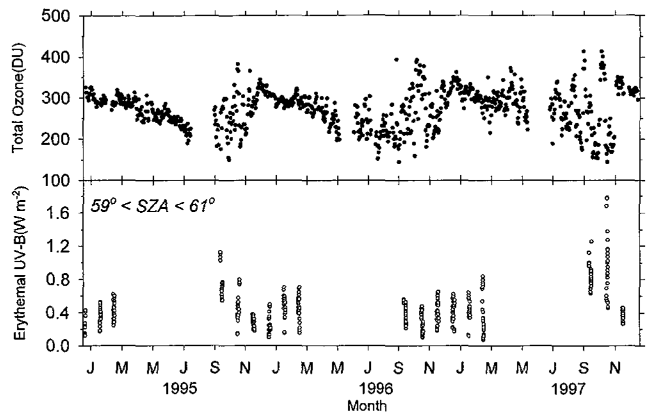

Fig. 8. Time series of total ozone and erythemal UV-B radiation for 59°~61° of solar zenith angle at King Sejong station (1995. 1~1997. 12).

usually in the UV-B. RAF is defined as the relative fractional change in irradiance with fractional change in total ozone (Booth and Madronich, 1994).

When solar zenith angles are 60° and 70°, Fig. 9(a) and (b) show linear regression analyses on the same coordinates for total ozone and erythemal UV-B radiation supposing that total ozone is constant all through the day although measured times of them don't coincide with each other. As a result, at solar zenith angle of 60° and 70°, each RAF showed 1.7 and 2.3. These are larger than values with 0.9 and 1.2 in Seoul (37.5°N, 126.9°E) located on the northern mid-latitude for the same zenith angles, and values with 1.04~1.20 in Toronto of Canada (Cho *et al.*, 1998). This means that erythemal UV-B radiation at King Sejong station is more affected by variation of total ozone than that in other locations on the northern hemisphere. These results give us a suggestion that various factors such as aerosol except total ozone which affect the variation of erythemal UV-B radiation are relatively smaller at King Sejong station.

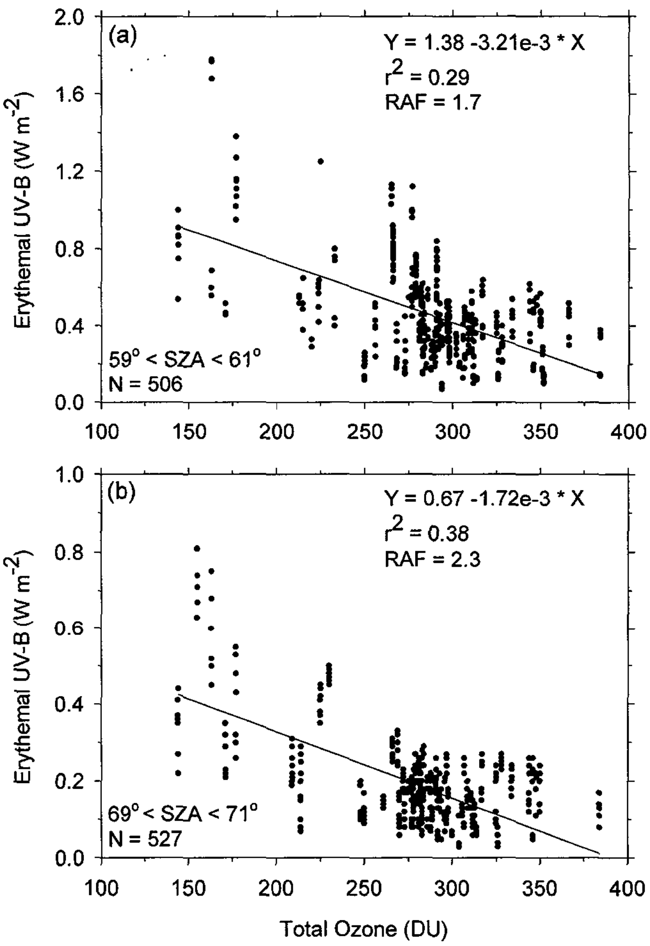

Fig. 9. Correlation of total ozone and erythemal UV-B radiation for (a) 60° and (b) 70° of solar zenith angle (1995. 1~1997. 12).

Concluding Remarks

To understand variations of surface harmful UV radiation and stratospheric ozone, and their relationships, measurements made from King Sejong station since 1994 have defined the ultraviolet radiation environment of the region. Also, we have analyzed satellite data which are downloaded from NOAA and NASA over the station. As we know, although UV-B is only a few percent of UV radiation, the increase of UV-B radiation with ozone depletion can affect badly both the human body and ecosystem, and in fact, numerous influences are partially coming out with various aspects about this field.

Because stratospheric ozone depletion over the Antarctic was spreaded wide and deepened, it became an important matter of primary and common interest. As a conclusion of this study, however, King Sejong station located on the spatial boundary of the typical ozone hole area was not yet affected directly and continuously until now by ozone hole which occurs periodically in the Antarctic. Nevertheless, according to data analyses, UV-B radiation was increased by 13% with decreasing of total ozone by 10% at King Sejong station up to date from the late 1970s. This means that King Sejong station is affected indirectly or can be influenced largely as the occasion demands by the ozone depletion.

The current radiation measurement program at King Sejong station provides vital information about the radiation environment with the variation of total ozone. However, because results in this study are on short time scales at the station, there is a need to collect data for a long time and analyze in more quantitative and qualitative way.

Acknowledgements

This work was supported by grant to Bang Yong Lee from KORDI (PP9800107). We would like to thank Ms. Hyo-Jung Kwon and Mr. Myeong Joon Kim for their kind assistance in data processing. Total ozone were provided by NASA Goddard Space Flight Center and NOAA of U.S.A.

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Received 6 January 1999
Accepted 10 April 1999