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Characteristics of the Erythemal Ultraviolet-B (EUV-B) Irradiance in Anmyeon (Korea Global Atmosphere Watch Center)

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Abstract

We have examined seasonal and annual means of clear-sky solar noon and daily erythemal ultraviolet-B irradiances measured in Anmyeon. The intensity of the EUV-B irradiance is mainly dependent on solar zenith angle (SZA) and total ozone amounts on clear day conditions. The daily maximum occurs near solar noon time and the highest monthly accumulated EUV-B is seen in July in Anmyeon. The maximum daily variation occurs in June and July due to precipitation and clouds. The 7-year trend of EUV-B irradiance shows that it is slightly increasing. Additionally, we could confirm that aerosol effects such as Asian Dust decreases the EUV-B irradiance reaching the ground surface by 35% to 60%. For more than 45% of the summer days, EUV-B irradiacne was high enough that the UV index registered higher than category Extremely High. This information will be very important for evaluation of the UV index for prevention of both skin cancer and ecosystem damages as well as to understand UV climatology over the Korean Peninsula.

Key words : Erythemal ultraviolet-B irradiance, UV index, Solar zenith angle, Total ozone

1. INTRODUCTION

The increase in surface ultraviolet radiation caused by the decrease in the stratospheric ozone causes human damage by stimulating skin cancer, cataracts and DNA damage as well as changing atmospheric environment through photochemical reactions (Herman *et al.*, 1996). Therefore, although the surface ultraviolet radiation represents a relatively small proportion of the incoming solar radiation at all wavelength bands, it is a very important wavelength band from biological and environmental points of views.

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Ultraviolet radiation can be divided into three biologically relevant radiation types UV-A, UV-B and UV-C (WHO, 1994; Tevini, 1993). Radiation in the form of UV-A, a 320~400 nm wavelength band, is barely absorbed by the ozone layer and reaches the earth layer regardless of the ozone layer fluctuations. This form of radiation is a great help in vitamin D formation in the human body. The wavelength band of the radiation classed as UV-C is 100~280 nm. These wavelengths are very harmful to plants and animals. But never reaches the earth surface because it is completely absorbed by the present ozone layer and other oxygen-related absorption gases. In contrast, the radiation of UV-B, with wavelengths of 280~320 nm, has strong and deleterious effects on animals and plants, as well as on humans, and its radiation level at the ground surface is greatly affected by variations in the ozone layer.

Research related to increases in the surface ultraviolet radiation and its relationship to total ozone in the ozone layer has been receiving increased attention in recent years (Hong and Choi, 2006; Kim *et al.*, 2005; Song *et al.*, 2005; Cho *et al.*, 1998; Weiler and Penhale, 1994; Madronich *et al.*, 1991). Factors that influence of the levels of surface ultraviolet radiation include the total ozone (McKenzie *et al.*, 1991), clouds, aerosols and the surface albedo, while geometrical elements such as the solar zenith angle and the distance between the Sun and the Earth also have effects.

Thus, in this study, it was of interest to analyze the seasonal and annual variations in the surface ultraviolet radiation using the Erythemal ultraviolet-B irradiance data collected over the past several years. In section 2, we briefly describe the data processing used in present study. In section 3, results of the characteristics and a case study of the effects of weather conditions on Erythemal ultraviolet-B irradiance are presented. In conclusion, a summary and discussion are given in section 4.

2. DATA AND METHODOLOGY

2.1 Erythemal ultraviolet-B (EUV-B) radiation

The Erythemal ultraviolet-B irradiance, which has wavelengths of 280 ~ 320 nm, is known to be especially harmful to the human body or to other living organisms. A weighted value of spectral function is used to assess the biological effects according to the kind of organism because ultraviolet radiation has different effects on different organisms depending on the wavelength (Madronich *et al.*, 1991; action spectrum). The erythemal weighted ultraviolet-B radiation (hereafter called EUV-B) that is integrated from the UV-B domain is expressed as follows:

$$\mathrm{EUV-B} = \int_{280\,\mathrm{nm}}^{320\,\mathrm{nm}} E(\lambda) W(\lambda) d\lambda \qquad (1)$$

where the $E(\lambda)$ is the ultraviolet radiation intensity by wavelength ($Wm^{-2}\ nm^{-1}$) and the $W(\lambda)$ is CIE (Commission Internationale de L'Eclairage) erythemal action spectrum. The erythema action spectrum is only one of many action spectra observed in nature, with similar slope and wavelength range. The McKinlay-Diffey erythema action spectrum is 21 mJ/cm^2 to induce minimal skin redness. The intensity of weighted UV-B radiation has a unit of Wm^{-2} (Cho *et al.*, 2001).

The EUV-B irradiance data used in this study was collected from January 1999 to December 2006. The UV-Biometer (Solar Light Co., Model 501) measures ultraviolet radiation automatically every 10 minutes at the Korea Global Atmosphere Watch Center (KGAWC, No. 47132) in Anmyeon (36.32°N, 126.19°E, MSL 45.7 m). The Minimal Erythemal Dose (MED) (hereafter called MED) is extensively used as a measurement unit of the skin damage by sunlight. A reading of 1 MED is the minimal level of the ultraviolet radiation sufficient to produce erythema on skin within 24 hours after exposure. As measured by the UV-Biometer, 1 MED corresponds to 210 Jm^{-2} at the horizontal level (Solar Light, 1993).

For analysis of seasonal and annual variations in the ultraviolet radiation, the data processing program converted the 144 MED observation values measured daily into EUV-B irradiance data. The EUV-B irradiance reading having a maximum value was chosen as a daily representative value. Data from a clear-sky was selected to generate a curve line of the daily EUV-B irradiance that fit well in cosine curved form (Song *et al.*, 2005). The UV-Biometer, which measures the EUV-B irradiance, was calibrated twice a year by Solar Light Co. in USA.

2.2 UV index

The World Meteorological Organization (WMO) has been investigating UV irradiance by various methods and in various regions including Canada, Finland, New Zealand, Sweden and America to establish a global standard UV index. For UV index forecast predictions, the total ozone around the solar noon is measured and then, based on the predicted ozone and the EUV-B irradiance, a UV index forecast is projected.

In this study, we calculated UV index by the empirical equation (2) (METRI, 1998), expressed as follows:

$$\text{UVI}=K\int_{280\,\text{nm}}^{320\,\text{nm}} E(\lambda)W(\lambda)d\lambda \quad (2)$$

where the K is 40 and the UV index 1 corresponds to 25 mWm^{-2} in the EUV-B irradiance flux density averaged 10 minutes around the solar noon time (Long *et al.*, 1996). Using this method, we calculated the UV index from the EUV-B irradiance data from Anmyeon. Table 1 describes UV index (UVI) range used in Korea Meteorological Administration. The UV index is classified into 5 classes according to the EUV-B irradiance intensity, which indicates the average erythemal dose occurrence time in case of an average person.

3. RESULTS AND DISCUSSION

We examined seasonal and annual variation characteristics of the harmful surface ultraviolet radiation and performed a case analysis about characteristics of the EUV-B irradiance and effects of Asian dusts, using the EUV-B irradiance data measured in Anmyeon from 1999 to 2006.

3.1 Annual and seasonal variation

The annual variation of the daily accumulated EUV-B irradiance measured in Anmyeon is shown in Fig. 1. The main feature in Fig. 1 is an obvious seasonal variation, in that most of the EUV-B irradiance occurred in the summer season. This is strongly related to solar zenith angle (SZA) and the total ozone amount. The EUV-B irradiance also decreased relatively due to effects of the rainy season in June. The seasonal variation of EUV-B irradiance from January 1999 to December 2006 in Anmyeon is shown in Fig. 2. In the box graph, the EUV-B irradiance along the bottom line indicates 5-, 10-, 25-, median, 75-, 90-, and 95-percentiles. On the whole, the EUV-B irradiance shows a maximum in summer, followed

Table 1. UV index range used in KMA.

Categories	UVI range	Average time to burn
Extremely high	≥9	Less than 20 minutes
High	7.0~8.9	Around 30 minutes
Moderate	5.0~6.9	Around 60 minutes
Low	3.0~4.9	Around 100 minutes
Very low	0.0~2.9	2~3 hours or more

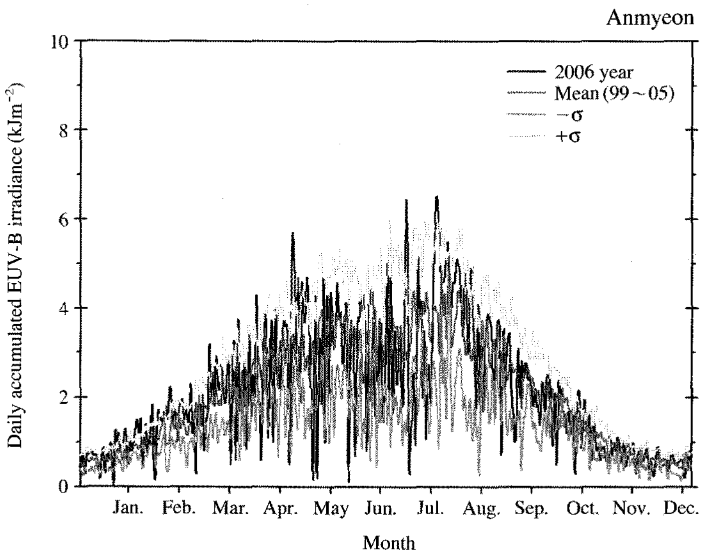

Fig. 1. The annual variations in daily accumulated EUV-B irradiance in Anmyeon.

by spring, autumn and winter.

3.2 Comparison of the EUV-B irradiance and total ozone amount

Fig. 3 shows the comparison of the EUV-B irradiance and total ozone in Anmyeon. The total ozone amount data were obtained from TOMS satellite data (http://jwocky.gsfc.nasa.gov). As mentioned above, the EUV-B irradiance is high in the summer season and lower in the winter season, while the total

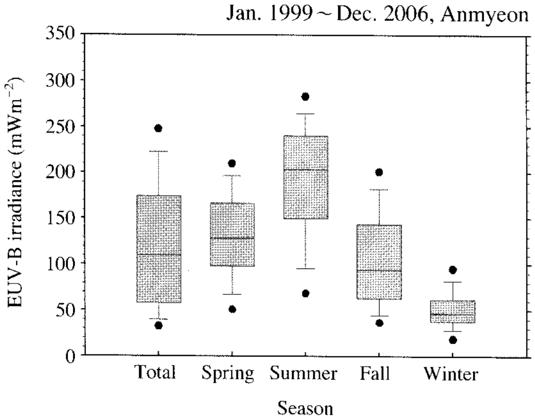

Fig. 2. Seasonal variations in the EUV-B irradiance in Anmyeon. The solid line indicates the median.

ozone amount shows as being higher in the spring season. The seasonal variation of the EUV-B irradiance also depends strongly on the solar zenith angle, but this can also be affected by the variation in the total ozone amount. For example, although the solar zenith angle of the vernal and the autumnal equinox are the same, the EUV-B irradiance is different for each season, because the total ozone amount is larger in March than in September. Therefore, the EUV-B irradiance reaching the earth surface is greater in September than it is in March. As shown in Fig. 4, which documents the annual variation of the EUV-B irradiance and total ozone amount for all sky conditions in Anmyeon. The 7 year trend for EUV-B irradiance shows it to be slightly increasing ($Y=0.0005X+114.63$), while the trend of total ozone amount shows it to be slightly decreasing ($Y=-0.0065X+323.02$). That is to say, the EUV-B irradiance is increasing by about 0.18 mWm^{-2} per year and the total ozone amount is decreasing by about 2.4 dobson unit (hereafter called DU) per year. A DU is the most basic measure used in ozone research. 1 DU is defined to be 0.01 mm thickness at standard temperature and pressure. Ozone layer thickness is expressed in terms of DU, which measure what its physical thickness would be if compressed in the

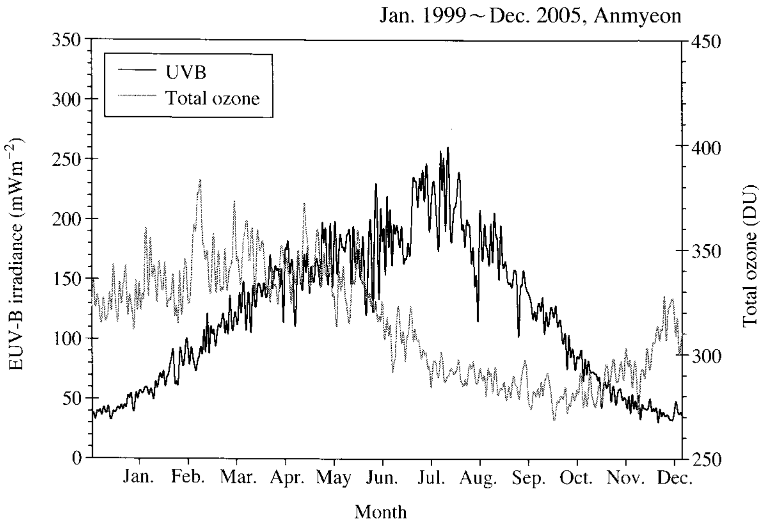

Fig. 3. The annual variations of the EUV-B irradiance and total ozone in Anmyeon.

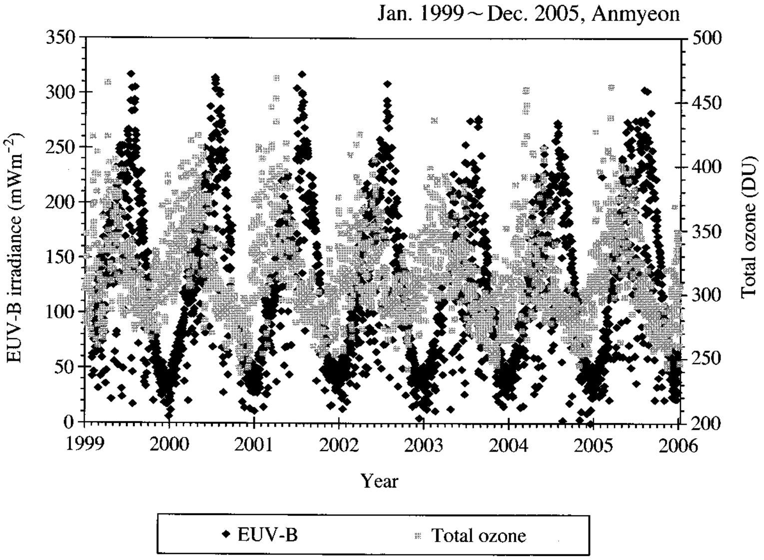

Fig. 4. Time series of the EUV-B irradiance and total ozone in Anmyeon.

Table 2. Seasonal and annual mean EUV-B radiation and total ozone amount (January 1999～December 2005, Anmyeon).

	Spring	Summer	Autumn	Winter	Annual
Total ozone (DU*)	344	308	285	321	315
Daily accumulated mean (MED**)	11.7	16.4	8.5	4.5	10.3
Number of observation day	644	644	637	726	2651
Standard deviation (MED)	5.4	7.1	5.0	1.8	4.8

*A dobson unit (DU) is the most basic measure used in ozone research. 1 DU is defined to be 0.01 mm thickness at standard temperature and pressure.

**A MED is the minimal level of the ultraviolet radiation sufficient to produce erythema on skin within 24 hours after exposure.

Earth's atmosphere.

Table 2 shows the seasonal and annual means of the daily accumulated EUV-B irradiance and total ozone. The total ozone analyzed using TOMS satellite data shows a maximum 344 DU in the spring season and a minimum 285 DU in the autumn season with an annual mean of 315 DU. The daily accumulated EUV-B irradiance shows a maximum of 16.4 MED in the summer season and a minimum of 4.5 MED in the winter season, with standard deviations larger in the summer season (7.1 MED) than in the winter season (1.8 MED).

3.3 Case study

Aerosol particles interact with solar radiation through absorption and scattering processes. Under natural conditions, the major aerosol effects on UV radiation result from differences in the aerosol amounts, as expressed by the aerosol optical depth, and from differences in the absorption properties of the aerosols (Reuder and Schwander, 1999; Weihs and Webb, 1997). Aerosol optical depth (hereafter called AOD) is a quantitative measure of the extinction of solar radiation by aerosol scattering and absorption between the point of observation and the top of the atmosphere. It is a measure of the integrated columnar aerosol load and the single most important parameter for evaluating direct radiative forcing. AOD can be determined from the ground through measurements of the spectral transmission of solar radiation through the atmosphere using rather simple and relatively inexpensive instruments pointed directly at the sun called sunphotometer. AOD is not directly measurable, but rather must be retrieved from observations of atmospheric spectral transmission. The solar irradiance I at a given wavelength can be expressed as $I=I_0 \exp(-m\delta)$ with I_0 the extraterrestrial (top-of-the-atmosphere) irradiance of the sun, m the air mass and δ the total optical depth. The air mass equals 1 for a vertical path and is roughly proportional to 1/cos z with z the zenith angle of the sun during the observation. The total optical depth δ at a given wavelength is composed of several components such as scattering by gas molecules, δ_R (Rayleigh scattering), extinction by aerosol particles, δ_A, absorption of trace gases, δ_G, like ozone, and possible cloud contamination. Thus, the AOD can be obtained from the total optical depth by subtracting modelled estimates of the other components $\delta_A=\delta-\delta_R-\delta_G$.

UV radiation reaching the ground decreases if the scattering and absorption properties of the atmospheric aerosols above increases. Krzyscin and Puchalski found variations of 20~30% in erythemally weighted UV daily radiant exposure in response to aerosols. According to research reports, special cases with significantly higher decreases in UV radiation due to tropospheric aerosols may be associated with heavy pollution, desert dust or heavy biomass burning (Acosta and Evans, 2000; Kylling *et al.*, 1998; Burrows, 1997; Mims III, 1996).

Fig. 5 shows the variations of the EUV-B irradiance with weather conditions. We selected Case I and Case II in order to analyze the variation in the EUV-B irradiance with weather conditions. The

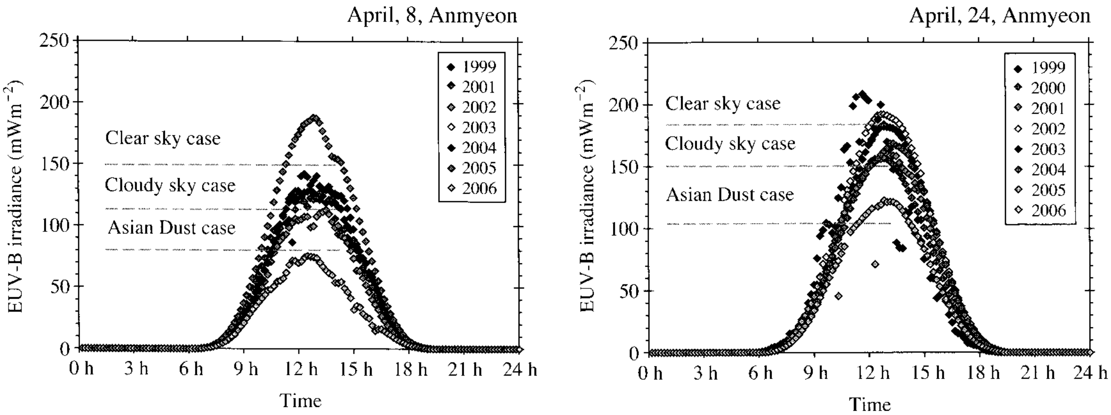

Fig. 5. The variation in the EUV-B irradiance with weather conditions (Clear-sky, Cloudy-sky and Asian Dust case).

Table 3. Description of weather conditions with Case I and Case II.

	Weather condition	Cloudiness (tenth) (cloud type)	PM10 mass concentration ($\mu g/m^3$)	Aerosol Optical Depth (AOD)	EUV-B irradiance attenuation
Case I (April, 8)	Clear sky	0	50~70	0.4~0.5	–
	Cloudy sky	5~8 (Stratus)	50~70	–	20~30%
	Asian Dust (2002)	0~1	530	1.2	41%
	Asian Dust (2006)	0	800	1.95	60%
Case II (April, 24)	Clear sky	0	50~70	0.4~0.5	–
	Cloudy sky	2~3 (Cirrus)	50~70	–	10~15%
	Asian Dust (2006)	0	250	0.8	35%

Case I was April, 8, 2002 through 2006 as the Asian dust case, and the Case II was April, 24, 2006. Case I was analyzed for variation trends in the EUV-B irradiance with weather conditions for the date April, 8, from the year 1999 to 2006. The April, 8, 2005 data show a typical clear-sky day, with EUV-B irradiance of 188 mWm^{-2}. At this time of year, the average cloudiness of a cloudy sky day was 5 ~ 8 out of 10, with 10 being of year full cloud cover. The EUV-B irradiance under these partially cloudy conditions decreased by 20 to 30% compared to a clear sky day. However, for the Asian Dust Case in the years 2002 and 2006, irradiance decreased by 41 to 60% compared with a clear sky day. AOD at this time was 1.2 to 1.95 at 500 nm.

For Case II, the effects were less than those seen in Case I, due to differences in intensity of the Asian Dust and cloudiness. The rate of the EUV-B irradiance attenuation was 35% and AOD 0.8 at 500 nm, respectively (Table 3).

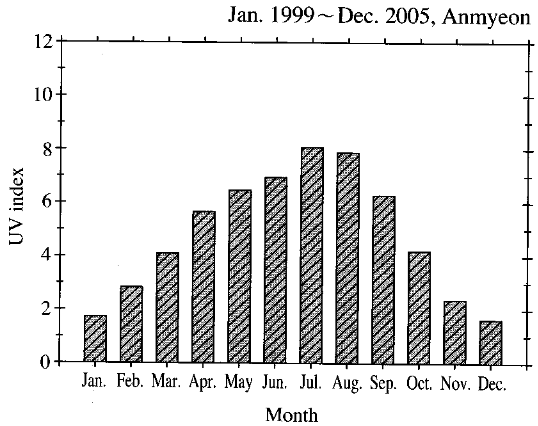

Fig. 6. The variation of monthly mean UV index.

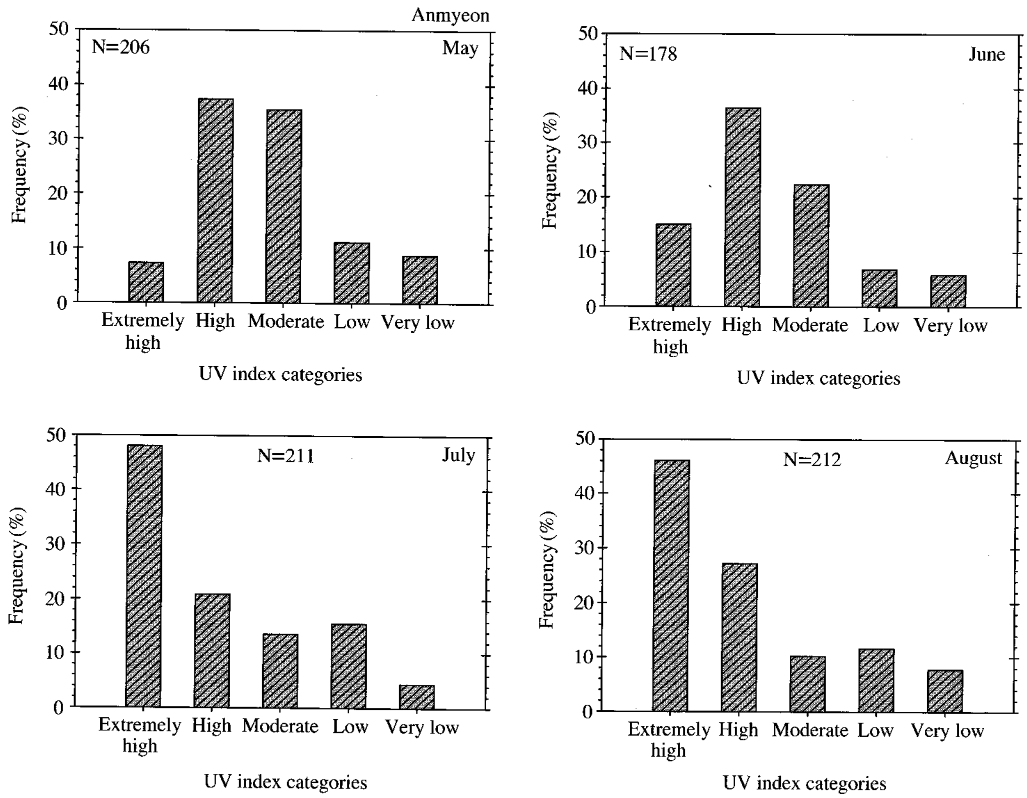

Fig. 7. Frequency distribution of UV index from May to August (1999 ~ 2005).

3.4 Variations in UV index

We calculated the hourly and daily mean of the EUV-B irradiance data measured every 10 minute from Anmyeon sites. We then calculated the UV Index (hereafter called UVI) using the data from noon to at 1 p.m., at which time the EUV-B irradiance is the strongest. The monthly variation is shown in Fig. 6. In general, the UVI measured below UVI 7 from October to April of the next year and measured over UVI 7 from June to August. A UVI of 7 means that a minimum erythemal dose can occur after about 30 minutes of outside activity. July and August show maximum UVI during the year, while January and December show minimum UVI.

Fig. 7 shows a frequency distribution of UVI categories from May to August that UVI appear high throughout the year. The frequency distribution of UVI in May showed that more than 30% of the UVI measurements were in the High and Moderate classes and about 7% were classed as Extremely High. More than 45% of the measurement for July and August were classified as Extremely High, with another 20% classed as High and Moderate. Thus, we have to always take precautions for ultraviolet radiation in summer season as because the most Extremely High UVI days occur in the months of July and August.

4. SUMMARY

The main feature of the daily accumulated EUV-B irradiance was that it showed an obvious seasonal variation, with a high EUV-B irradiance occurring in the summer season. The EUV-B irradiance also decreased relatively due to effects of the rainy season in June. The EUV-B irradiance is high in the summer season and lower in the winter season, while the total ozone amount is high in the spring season. The seasonal variation of the EUV-B irradiance depends on the strong solar zenith angle and total ozone amount. The EUV-B irradiance has increased by about 0.18 mWm^{-2} per year and the total ozone amount has decreased by about 2.4 DU per year.

For the variation of the UVI from May to August, the frequency distribution of UVI in May showed that more than 30% of the UVI measurements were in the High and Moderate classes and about 7% were classed as Extremely High. More than 45% of the measurement for July and August were classified as Extremely High, with another 20% classed as High and Moderate.

In the variations of the EUV-B irradiance with weather conditions, the EUV-B irradiance under cloudy conditions decreased by 20 to 30% compared to a clear sky day. However, for the Asian Dust Case in the years 2002 and 2006, irradiance decreased by 41 to 60% compared with a clear sky day. For Case II, the effects were less than those seen in Case I, due to differences in intensity of the Asian Dust and cloudiness.

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