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Biologically effective ultraviolet radiation in Beijing area

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Abstract — Ozone layer depletion implies the enhancement of solar ultraviolet radiation at the earth's surface. However, aerosol contributes to the scattering of solar radiation and leads to the reduction of UV-B radiation on the ground. In this paper, the model calculation shows that due to effects of atmospheric ozone and aerosol UV-B radiation in Beijing in the past decade has decreased with the annual change rate of 0.7%, which is probably approximate to the measured values. The effects of three scenarios for long-term changes in atmospheric ozone and aerosol concentrations on UV-B radiation reaching the ground in Beijing are also discussed.

Keywords: UV-B biological effect; ozone; aerosol; Beijing.

INTRODUCTION

There is increasing concern about the destruction of the ozone layer which filters solar ultraviolet radiation (Titus, 1986). The spectral regions of primary interest for biological damage centered on the UV-B at wavelengths from 280 to 320 nm (Frederick, 1988). It is predicted that an 1% reduction in the amount of ozone layer will lead to an increase of approximately 2% in UV-B radiation (Cutchis, 1974). Enhancement in UV-B radiation may have adverse effects on animals (including human beings) and plants, such as increase in incidences of skin cancers, decrease in agricultural crop yields and reduction of marine productivity (Titus, 1986).

Ozone column has decreased by 5% over Beijing in the last decade (Wei, 1991). The model calculation showed that biologically effective UV-B radiation increased at average rate of 1.4% per year from 1980 to 1989 on condition that other environmental factors remained unchanged (Wang, 1993). However, light extinction of atmospheric aerosol as an important element in light radiation significantly decrease UV-B radiation reaching the ground (Wang, 1993) and this may not be ignored. In the report we discussed UV-B radiation at the surface due to both ozone reduction and increase in aerosol thickness in Beijing area.

MODEL AND DATA INPUTS

Green's parameterization model for UV-B irradiance was adopted whose principles and formulae were discussed in detail elsewhere (Green, 1982; 1983). The model was used by several researchers for predicting UV irradiance and proved good prediction (Bjorn, 1985; Rundel, 1986; Wang, 1993). Inputs for the model are ozone column, air pressure and relative humidity at ground level, aerosol level and ground cover. Ozone concentrations were measured at Xianghe Ozone Observation Station (39°46'N, 107°00'E). Aerosol level can be determined from observed surface visibility (Wang, 1993). Air pressure, relative humidity and visual range were measured at Beijing Meteorological Observation Station (39°56'N, 116°17'E). Doda and Green (1980; 1981) have proposed UV wavelength-dependent expressions for various ground covers and used them in the model. Here we chose green farmland case in which albedo is about 4% in UV-B wavelength range.

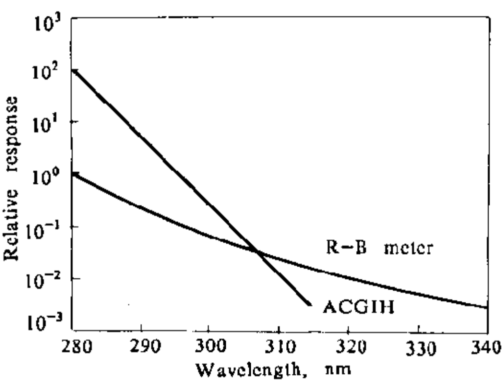

Fig. 1 Action spectrum for ACGIH and sensitivity curve of the Robertson-Berger (R-B) meter

Biological response to UV-radiation depends on the convolution over wavelength of solar radiation with an action spectrum, in which the action spectrum measures the relative sensitivity of an organism to damage by sunlight of varying wavelengths. We refer to this convolution as the biologically effective radiation dose. The calculation adopted the action spectrum for ACGIH and response curve of the photosensitive meter [Robertson-Berger(R-B) meter], which are illustrated in Fig. 1. R-B meter is a standard weighting function often adopted as a measure of biologically damaging radiation (Lubin, 1989), ACGIH was published as human sensitivity for safe working environments by American Conference of Governmental Industrial Hygienists (ACGIH, 1978). It is an envelope curve for minimal spectral exposures causing erythema, photoconjunstivities and so on.

RESULTS AND DISCUSSION

Biologically effective UV-B radiation dose at different seasons

Fig.2 shows the biologically effective UV-B dose for local noon at the fifteenth of January, April, July and October for clear sky condition as function of wavelength.

It can be seen that UV-B dose is highest in July, while the lowest in January. At the range of shorter UV wavelengths (< 305 nm), UV-dose in October is greater than that in April; at the range of 305-320nm the UV-dose in April is greater. This is owing to the different effect of ozone obsorption and aerosol scattering. It is reported that ozone column is greatest in April, lowest in October in Beijing (Wei, 1991). Aerosol levels in winter and spring are greater than those in summer and autumn Wang, 1989; Qiu, 1986). UV irradiance increases greater at the shorter UV-B wavelengths when ozone concentration decreases. Effect of aerosol on UV-B irradiance on the ground is greater than that of ozone absorption at the longer wavelengths (Wang, 1993). So, in April more ozone in the atmosphere prevents UV radiation at short wavelength reacting the ground.

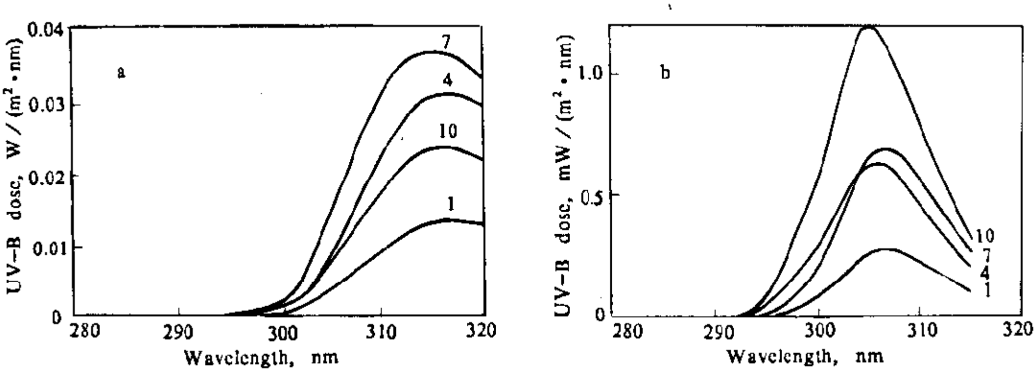

Fig. 2 UV-B dose reaching the ground at nootime of the 15th of January, April, July,and October as function of wavelength
a. R-B meter; b. ACGIH

The integrated UV-B dose at different time in a day are shown in Fig.3. Biologically effective radiation for R-B meter decreases as July, April, October and January by turn from 9:00 to 15:00. In early morning and late afternoon UV-dose in October is more than that in April. For ACGIH, the UV-dose in July is highest, lowest in January. In the period of 11:00 – 13:00, UV-dose in April is greater than that in October, while for the rest of hours the situation is reversed. Table 1 shows the ratios of total UV radiation per day in April, July and October to that in January. For R-B meter UV-dose in July is in the first place and the second is what in April, which is similar to the change of UV irradiance at different seasons. But for ACGIH, UV-dose in October is in the second place. Therefore, from what have been discussed above, we know that for different action spectrum, change trends of UV-B dose at different seasons are not the same.

Table 1 Ratios of daily UV radiation in April, July and October to that in January

Month	4	7	10
UV irradiance	2.37	3.09	1.85
R-B UV-dose	2.36	3.24	1.93
ACGIH UV-dose	2.23	3.99	2.34

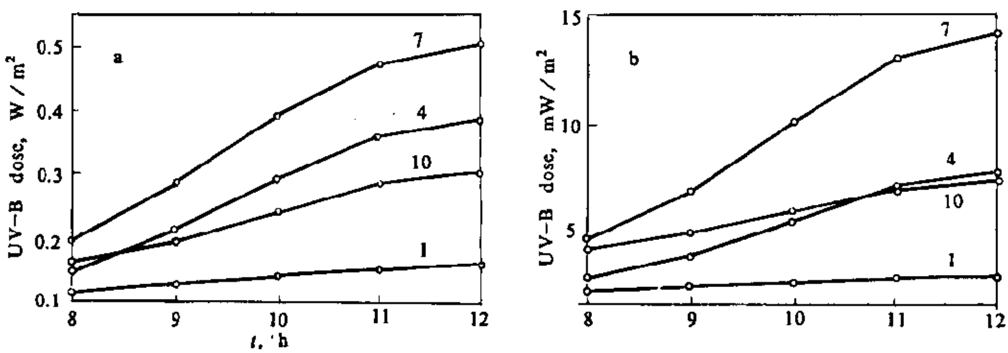

Fig. 3 Variation of daytime UV-dose at the 15th of January, April, July and October
a. R-B meter; b. ACGIH

2. Annual change of UV-dose from 1980 to 1989 in Beijing

It is predicted that UV-B radiation at the surface of the earth would increase when ozone layer decreased. Fig. 4 illustrates the annual variation of ozone column in Beijing in the past decade. The data demonstrate that the ozone layer changed slightly from one year to another with an evident negative shift of 0.5% per year. Wang *et al.* (1993) made calculation on UV-B radiation and concluded that the annual change rates of biologically effective ultraviolet radiation varied from 0.8% to 1.8% with the average of 1.4% from 1980 to 1989 provided that aerosol average was adopted. But recent report of surface measurements of biologically effective ultraviolet radiation in the United States from 1974 to 1985 showed a negative shift with average rate of 0.7% per year for eight stations(Scotto, 1988). In Beijing, the measured total solar irradiance also shows a similar change tendency (Fig.5). Scotto *et al.* (1988) believed that the role of physical and meterological factors in the troposphere may be greater than expected, and that there may be prevailing conditions that diffuse solar energy and thus reduce the amount of UV-B radiation reaching the ground.

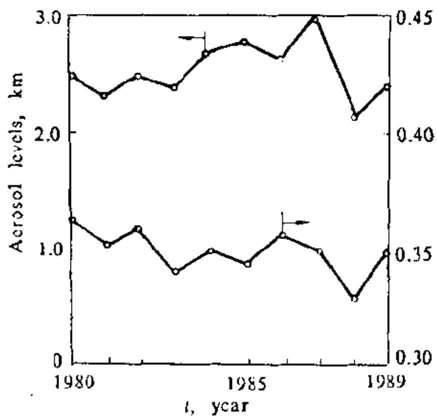

Fig. 4 Annual variation of ozone layer and aerosol concentrations in Beijing from 1980 to 1989

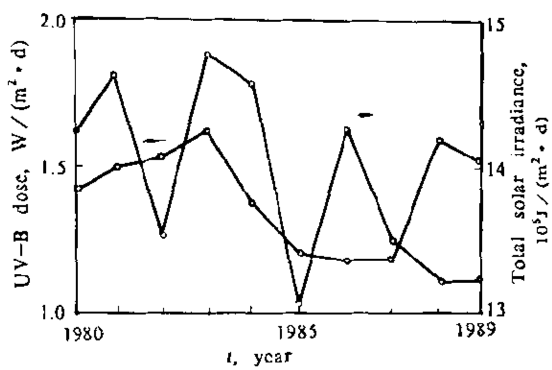

Fig. 5 Total solar irradiance trend and computed annual UV-dose variation for R-B meter in Beijing from 1980 to 1989

Light scattering by atmospheric aerosol decreased UV-B irradiance (Wang, 1993). Model calculation indicated that decrease of UV-B due to the increase of aerosol concentration in the air may be offset to the increase of UV-B attributed to ozone reduction (Wang, 1993). In Beijing, with the development of industry atmospheric aerosol arising from fuel burning and photochemical reaction increased in the last decade (Fig. 4). From 1980 to 1987 aerosol levels increased a little, which was opposite to the ozone change. So increase in aerosol column must be considered in the calculation of UV-B irradiance. Fig.5 demonstrates annual change of the biologically effective UV radiation for R-B meter from 1980 to 1989. At first, UV radiation increased slightly, then it fell down rapidly, and at the end it went up to the level of 1982 – 1983. Regression analysis was used to obtained an estimate of the average annual percentage change of −0.7. This result was compared with the measured total solar irradiance at the same period and the annual change rates of measured UV-B radiation in the United States (Table 2). It can be seen that the computed UV-B trend is close to the measured data. The calculated trend, though, is not statistically significant, it accounts in part for the measured UV data. And it also suggests that meteorological and environmental factors such as cloud cover, localized sources of air pollution and increase in tropospheric ozone play a greater role in attenuating UV-B radiation than that was previously suspected.

Table 2 Comparison of UV-B radiation annual change rates (%)

Beijing (39.7°N) UV-B	TSI*	Oakland (37.7°N) UV-B	Philadelphia (39.9°N) UV-B	Average of eight stations in USA UV-B
−0.7[1]	−0.9[2]	−0.7[3]	−0.4[1]	−0.7

TSI*: total solar irradiance;

1. not significant; 2. $P \leq 0.01$; 3. $P \leq 0.05$

3. Effects of future changes of aerosol level and ozone layer on UV-B radiation

It is commonly known that depletion of ozone layer is partly due to chemical compounds CFCs, which are emitted entirely from anthropogenic sources. The Montreal protocol has made limitations on their productions and emissions, however, their effects on ozone layer will still exist for a long time. Model calculation predicted that global ozone reduction would continue in the next century. Meantime, atmospheric aerosol may also be changed owing to air pollution or pollution administration and control. In order to understand UV-B radiation in the future, we performed long-term predictions based on following scenarios (Table 3).

World Meterological Organization made eight UNEP scenarios to predict ozone change from 1960 to 2060 based on global policies that would curtail the use of CFCs controlled under the Montreal Protocol (WMO, 1990). Model calculation showed that at 40°N, annual ozone concentrations would decrease 2% −10% by 2060. We assumed a average of 5% reduction of ozone layer over Beijing in the future, For aerosol, we chosen three levels as follows:

(1) Visibility is 4km, which represents the serious case in Beijing in 1970s (Su, 1986).

(2) Visibility is 12km, kept as present condition.

(3) Visibility is 25km, which is the best level of the last decades appeared in 1960s (Qiu, 1986).

Fig. 6 shows the average annual ratios of UV-B dose for R-B meter of three scenarios to the present UV-dose as function of wavelength. In all threescenarios the UV-dose at shorter wavelengths changes greater than those at longer wavelengths. Scenarios B and C indicate the increase of UV radiation. The increased ratio varies from 0.01 at 320 nm to 6.7 at 280 nm in scenario B. The ratios in scenario C are greater, which

Table 3 Three scenarios of changes of future ozone column and aerosol levels

Scenario A: Ozone column reduced by 5%, visibility decreased to 4km
Scenario B: Ozone column reduced by 5%, visibility kept as present 12km
Scenario C: Ozone column reduced by 5%, visibility increased to 25km

change from o.27 at 320 nm to 7.6 at 280 nm. In scenario A the UV-B radiation shows an increase at the wavelengths shorter than 288 nm, whereas it decreases at wavelengths greater than 288 nm to the most by 60% at 320nm.

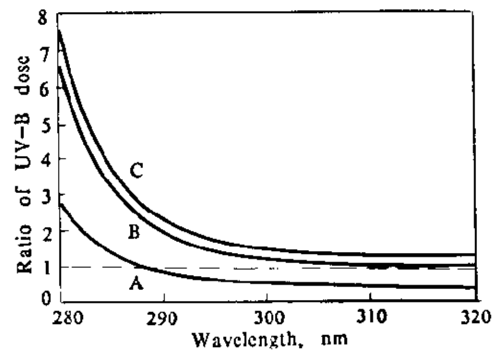

Fig. 6 Ratios of average annual UV-dose for R-B meter at local noon computed for the year future to those at present in scenarios A, B, and C in Beijing

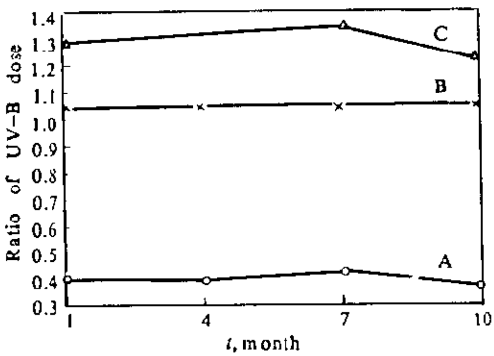

Fig. 7 Variation of daytime integrated UV-dose for R-B meter with months, vertical scale gives the ratios of UVdose computed for the year future to those at present in scenarios A, B, and C in Beijing

The integrated daily UV-dose in different seasons were computed and the ratios of daily UV radiation for R-B meter in three scenarios to those of today's level are shown in Fig.7. UV-dose in scenario A is decreased by 60%, more than the degrees of UV radiation increased in scenario B and C, in which UV-dose are increased by about 4% and 30%, respectively. In scenario A and C the UV-dose changes greatest in July, lowest in October. In scenario B, the ratios of UV-dose in different seasons are close.

CONCLUSIONS

UV-B radiation on the ground in Beijing changes with season. The computed annual variation of UV-B radiation in the period of 1980 to 1989 is −0.7% due to combined effects of atmospheric ozone and aerosol. The scenarios of long-term changes in ozone layer and acrosol level lead to different projections for solar ultraviolet radiation at the earth's surface in Beijing. In the scenario of decrease in ozone concentrations, the daily UV-B radiation is increased by about 4%. In the scenario of decrease in ozone layer and aerosol column, the daily UV-B radiation varies by a factor 0.2 or more with season. In a scenario of ozone depletion and increase in aerosol level, the daily UV-B radiation shows a decrease of 60% or so.

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