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Effect of atmospheric aerosols on UV-B radiation reaching the ground

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Abstract — Solar ultraviolet radiation reaching the ground can be reduced due to light scattering of atmospheric aerosols. Aerosol pollution has led to the decrease in biological active UV-B radiation by about 45% and 10% in city and rural areas, respectively. In populated areas, effect of aerosol scattering on UV-B radiation may offset the increased amount of UV-B caused by ozone depletion, but in clean areas such as two poles, ozone depletion may have great damage effects on ecosystems.
Keywords: atmospheric aerosol; UV-B radiation; ozone reduction.

INTRODUCTION

The solar ultraviolet radiation is attenuated by several processes as it propagates through the atmosphere. The most important of these is absorption by ozone located in the stratosphere and troposphere. However, scattering by molecules, aerosols and especially by clouds is also significant. A long-term change in the abundances of any of the absorbers or scatterers will lead to a variation in ultraviolet irradiance.

It is reported that global ozone concentrations have decreased by 1% －3% (WMO, 1990). The depletion of ozone layer may lead to the increase in biological active UV-B radiation (280－320nm) at the surface of the Earth, which is known to have damage effects on living organisms (NRC, 1984). But recent report showed a decreasing trend of UV-B radiation in the United States (Scotto, 1988). The causes of the contradiction are nuclear, but it is believed that environmental factors such as atmospheric aerosol, cloud cover and tropospheric ozone may be the main contributors (Scotto, 1988; Bruhl, 1989; WMO, 1990).

Atmospheric aerosols have been increasing since the industrial revolution especially in the past two decades. Model calculation indicated that the amount of UV-B radiation in the Northern Hemisphere has decreased by a range of about 6% to 18% since the industrial revolution, primarily due to scattering of solar radiation contributed by aerosols. This is larger than the currently estimated increase of UV-B due to stratospheric ozone depletion at NH mid-latitudes (Liu, personal communication). So aerosol scattering may play a greater role in polluted areas. In this work, we discussed aerodol contributions in city and rural atmosphere to the change of UV-B radiation at the ground and compared different effects of ozone depletion and increase in aerosol concentration on UV-B radiation.

METHODS

Green and his colleagues have developed equations for the spectrum of UV irradiance, based on surface, aircraft and satellite measurements of UV and on certain theoretical considerations (Green, 1974; 1980; 1982; 1983). This parameterization model is relatively simple than any other methods and proved good prediction of UV irradiance (Wang, 1993). The total downward irradiance at any wavelength is the sum of direct and diffuse components, where the latter consists of photos which have been scattered one of more times. The direct spectral irradiance at the ground may be placed in the basic form based on Beer's Law.

$$D(\lambda, \theta) = \cos\theta H(\lambda) \exp - \sum_i \tau_i / \mu_i , \tag{1}$$

where $H(\lambda)$, θ, and τ_1, τ_2, τ_3, τ_4 denote the extraterrestrial solar spectral irradiance, the solar zenith angle, and the optical depths for Ray length scattering, aerosol scattering and absorption, and ozone absorption, respectively, μ_1, μ_2, μ_3, and μ_4 represent generalized cosine functions which are appropriate to the air, aerosol, and ozone in view of the roundness of the Earth. The expressions of these functions are in the form

$$\mu_i = \left(\frac{\mu_i^2 + t_i}{1 + t_i} \right)^{1/2} \tag{2}$$

where $\mu = \cos\theta$ and t_i are small characteristic numbers which depend upon the altitude distribution of species (Green, 1980).

Diffuse light is a major component of the total irradiance in the UV, in many cases exceeding direct sunlight. Green and the Florida group developed several approaches to model the diffuse irradiance. They considered the ratio of diffuse to direct irradiance as a function of wavelength and defined

$$M(\lambda) = S(\lambda, 0^\circ) / D(\lambda, 0^\circ) , \tag{3}$$

as the ratio of diffuse to direct irradiance for overhead sun (solar zenith angle zero) and

$$\delta(\lambda, \theta) = S(\lambda, \theta)/S(\lambda, 0^{\circ}) \ , \tag{4}$$

as the ratio, as a function of wavelength, of diffuse irradiance at solar zenith angle θ to that for $\theta=0^{\circ}$. These auxiliary functions are represented by fairly complex polynomial functions which reoptimized to fit the results of radiative transfer calculations. Once adequate representations of the auxiliary functions $M(\lambda)$ and $\delta(\lambda, \theta)$ are obtained, the iiradiance of diffuse solar UV - B radiation can be calculated from

$$S(\lambda, \theta) = \delta(\lambda, \theta)\ M(\lambda)D(\lambda,0^{\circ}) \ , \tag{5}$$

The detailed formulae of $M(\lambda)$ and $\delta(\lambda, \theta)$ are given elsewhere (Green, 1982; 1983).

The input parameters needed to calculate solar spectral irradiance in Green's model are column ozone, air pressure and relative humility at the ground, and aerosol level Column ozone was measured at Xianghe Ozone Observation Station in Beijing. Air pressure and relative humility were measured at Beijing Meteorological Observation Station. Aerosol level can be determined from optical depth (Wang, 1993). We used the formulae proposed by Zhao *et al.* (Zhao, 1986) to correlate optical depth (τ_a) and observed surface visibility (V).

$$\tau_a = \left(\frac{3.912}{V} - 0.0116\right)\frac{0.55}{\lambda}\ [H_1 \exp - Z/H_1 - \exp - 5.5/H_1) \\ + 16.27 \exp\ -5.5/H_1] \ , \tag{6}$$

where $H_1 = 0.886 + 0.0222\ V.V,\ Z,$ and λ represents visual range, altitude and wavelength, respectively. Here we chose wavelength of 550 nm.

RESULTS AND DISCUSSION

In the past two decades, air quality in Beijing has greatly decreased due to fossil fuel burning. Observed surface visibility as a characteristic of aerosol pollution has shown decrease trend in Beijing. We chose two sites stationed at remote and city area as representative of rural and city aerosol pollution levels, in which the average visual ranges in the past decade were 32 ± 10 and 12 ± 4 km. The two visibility were the averages of ten-year data measured at 8:00 and 14:00 in clear sky at corresponding station. Based on observations in the remote station we chose 70 km as the natural background value f visibility for Beijing. By comparing the difference of UV-B radiation at different aerosol levels, we can know the effects of aerosol pollution on UV-B, which are attributed mostly by anthropogenic activities .

Fig. 1 shows the ratio of UV irradiance at polluted aerosol level to that at background condition for local noontime as a function of wavelength. The decrease of surface UV-B radiation varies from 7% at 280 nm to 11% at 320 nm for aerosol loading of 32 km visual range. For city aerosol pollution with 12 km visibility, the decrease of surface UV-B radiation is greater, which is 23% at 280 nm and 31% at 320 nm. For UV-A, the decrease of solar radiation change little with wavelength for two aerosol levels, which are at about 11% for rural area and 31% for city case. The ratio of daytime integrated UV-B radiation on the ground between polluted atmosphere and background level is illustrated in Fig.2. The UV-B radiation for rural area is reduced by about 10%, while for city area the decrease of UV-B caused by aerosol pollution is approximately 45%. This shows that the reduction of UV-B by aerosols is much greater in heavily populated urban areas than that in rural areas.

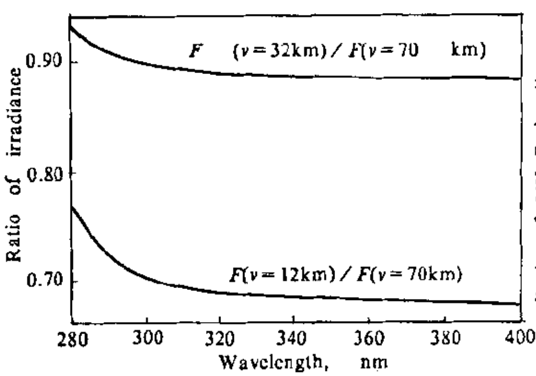

Fig. 1 Ratio of UV irradiance at noontime for 12 km and 32 km visual ranges to that for 70 km visibility as a function of wavelength

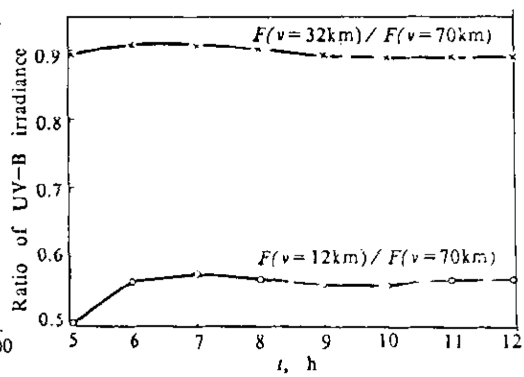

Fig. 2 Ratio of daytime UV-B irradiance for 12 km and 32 km visual ranges to that for 70 km visibility

We have known that reduction of global ozone layer may lead to the increase in UV-B radiation reaching the ground. And it has been reported that ozone layer over Beijing has decreased by about 5% in the last decade (Wei, 1991). Our calculation on UV-B radiation in Beijing demonstrated that biologically effective UV-B radiation would increase at average of 1.4% per year from 1980 to 1989 providing that other environmental factors including aerosol level kept constant (Wang, 1993). However, reduction of UV-B by aerosol scattering shown above indicates that aerosol can decrease UV-B to great content. Surface measurements of UV-B radiation in the United States also suggested that increase in aerosol concentration may have greater role than expected (Scotto, 1988). Here, we made comparison of effects between ozone layer and aerosol on UV-B radiation reaching the ground.

Fig.3 shows the ratio of daily UV-B irradiance for ozone layer depletion or for increase in aerosol thickness to that for present level of column ozone and aerosol. Effect of ozone depletion on UV-B is greater than that of aerosol. When ozone depletion and aerosol pollution changes less than 5%, aerosol scattering may balance ozone absorption. This means that UV-B radiation reaching the ground would not increase a lot and have little damage effects on living organisms. This case is referred to populated areas with aerosol pollution where atmospheric aerosols, though with detrimental effects to health and visibility, can reduce UV-B radiation and this is of benefit to the health. When ozone depletion is much larger, the increase amount of UV-B at the surface caused by ozone reduction surpasses greatly the decreased amount of UV-B due to aerosol and adverse effects of UV-B is much concerned. This is the case in two poles of the Earth, especially in Antarctic area, where aerosol level changes little, and ozone hole is the greatest in the world. So, UV-B radiation in Antarctic area may cause eye damage to researchers who visit there for extended periods of time and to Antarctic life in winter seasons when ozone concentration may be reduced by 40% (Frederick, 1989; WMO, 1990).

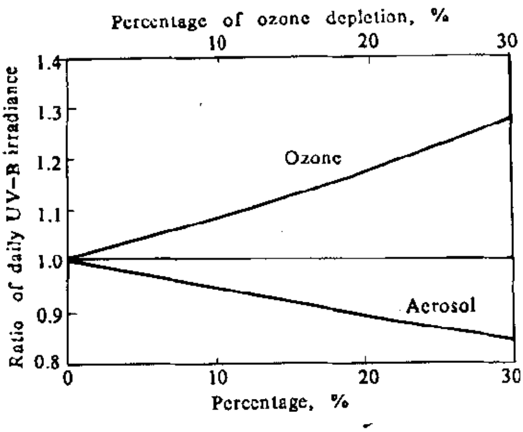

Fig. 3 Ratio of daily UV-B irradiance for ozone depletion and aerosol pollution to that for present ozone and aerosol level

In conclusion, aerosol scattering decreases the UV-B radiation at the surface of the Earth. Aerosol pollution in urban and rural area can reduce daily UV-B irradiance by about 45% and 10%, respectively. In populated areas, UV-B radiation changes little due to balanced effects of aerosol scattering and ozone absorption, while in clean areas, such as polar zones, UV-B radiation may have great damage effects on living organisms due to ozone depletion.

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