Journal of Environmental Sciences Vol.5, No.4, pp. 416–426, 1993 ISSN 1001-0742

Effect of ozone variation on the ultraviolet radiation at some places in China

Xiong Xiaozhen, Wang Gengchen

Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing 100029, China

Abstract — Results of numerical simulation of UV-radiation and UVB-radiation incident at the ground for different seasons and geographical regions in China are presented. The change of UVB incident at sea level due to ozone content depletion of 5% are evaluated too. All these computations are carried out after taking into accounts of Rayleigh scattering, aerosol scattering and absorption, ozone absorption and so on. The monthly mean daily sums of ultraviolet radiation in UVB (285–325 nm) and UV (285–400 nm) in different sea-level elevation by integrating with zenith angle and wavelength. It is estimated that in summer, the monthly mean daily sums of UV have little change with the latitude increase, while UVB decreases significantly; in winter, the monthly mean daily sums of both UV and UVB decrease obviously with the increase of latitude. Supposing the ozone amount depletion of 5%, the increase ratio of UVB radiation is greater in high latitude than that in low-mid latitude, and lower in summer than that in winter. So the influence of ozone depletion to biosphere may be greater in the north of China than that in south.

Keywords: ozone; UV; UVB; monthly mean daily sums.

1 Introduction

Ozone is an important trace gas in the atmosphere. Solar radiation absorbed within the atmosphere drives the photo-chemical process and maintains the ozone layer, and it is just the absorbed solar energy that determines the structure of the stratospheric temperature field, imposes on the circulation, and shields the biosphere from harmful solar ultraviolet. The depletion of stratospheric ozone caused by human activities may lead to increase of UV radiation incident at the ground, and the increase of ozone content near the ground is very harmful to biosphere.

The ultraviolet radiation incident at the ground depends on a large of factors, such as the extraterrestrial solar irradiance (Thekaekara, 1974), the transmittance of solar irradiance through the atmosphere, and underlying surfaces. So the changes of the sun-earth distance and ground reflectivity have to be considered first;

and we also have to take into accounts of the effects of Rayleigh scattering, scattering and absorbing of aerosol, absorbing of ozone and other trace gases, extinction of clouds and so on.

In the past years, several computations have been made for spectral distribution of the direct and scattered solar components for various atmospheric models and surface conditions (Halpern, 1974; Cuthis, 1974; Green, 1974; Nack, 1974; Dave, 1976; Shinhirne, 1978), most of these results are presented in the form of tables or figures for a specific solar zenith angle. Although the clouds pose tremendous effects on the ultraviolet radiation incident at the ground, most of the calculations (Harlpern, 1974; Nack, 1974; Shinhorne, 1978; Frederic, 1988; Frederick, 1989; Frederick, 1990) just consider uniform-homogeneous cloud layers, and assumed cloud types, cloud droplet size distribution. However, as the variation of cloud thickness, cloud height, droplet size distribution, cloud cover and so on exert influence a lot on the spectral composition of radiation, so the cloud is a more complicated, variable and uncertain parameter for calculating the transfer of UV and UVB passing through the atmosphere. In this paper, we just highlight the effects of ozone depletion on the UVB radiation incident at the ground, and calculate UV-radiation and UVB-radiation incident at the ground and its variation with ozone depletion in clear sky in China. Considering the computational speed and accurate, the delta-eddinton approximation method are used to solve the transfer equation, and by Gauss quadrature formula over solar angle, and simpthon quadrature formula over wavelength to give out the monthly mean daily sums of UV and UVB radiation in clear sky in summer (July) and winter (Jan.) and the variation of UVB with ozone depletion of 5%. On basis of these, when an action spectrum of ultraviolet radiation is given (Robert, 1983; Cole, 1986), it is very easy to calculate biological effects and evaluate the so called "UV damage" due to ozone depletion. As ground pressure is on behalf of the length of air in the column of atmosphere, and in some way it can represent the magnitude of Rayleigh scattering of atmospheric molecules, so we select the ratio of ground pressure change as an amplifier factor of optical depth of Rayleigh scattering.

2 Computational procedure of model

There are a number of methods that can be used to solve the equation of the transfer of UV and UVB radiation through the atmosphere. In this paper, we use the delta-eddington approximation method (Joseph, 1976), which is computationally rapid and accurate.

The azimuthal averaged the equation of radiance in plane-parallel atmosphere is:

$$\mu \frac{dI(\tau,\ \mu)}{d\tau} = I(\tau,\mu) - \frac{\omega}{2} \int_{-1}^{1} I(\tau,\mu') P(\mu,\mu') d\mu' - \frac{\omega}{4\pi} \pi F_0 P(\mu, -\mu_0) \exp(-\tau/\mu_0). \quad (1)$$

The phase function can be approximated:

$$P(\cos\theta) \cong P_{\delta-edd}(\cos\theta) = 2f\delta(1-\cos\theta) + (1-f)(1+3g'\cos\theta), \quad (2)$$

here,

$$g' = \frac{g-f}{1-f}, \quad (2a)$$

$$f = g^2. \quad (2b)$$

The deduction refers Joseph (Joseph 1976), f is the fractional scattering into the forward peak and g is the asymmetry factor of the truncated phase function.

By use of eddington approximation:

$$I(\tau,\mu) = I_0(\tau,\mu) + I_1(\tau,\mu)\mu \quad (-1 \leqslant \mu \leqslant 1). \quad (3)$$

Where τ is the optical depth, and μ is the cosine of the zenith angle. Diffuse irradiance can be computed from I_0 (τ, μ) and I_1 (τ, μ), that is:

$$F(\tau)^{\uparrow\downarrow} = 2\pi \int_0^{\pm 1} (I_0(\tau,\mu) + \mu I_1(\tau,\mu)) \mu d\mu = \pi(I_0(\tau) \pm \frac{2}{3} I_1(\tau)). \quad (4)$$

Where $\mu > 0$ corresponds to $F\uparrow$ and $\mu < 0$ corresponds to $F\downarrow$.

I_0^i and I_1^i can be computed from Equations (1), (2) and (3). Then within each layer of non-conservative atmosphere there are:

$$I_0^i(\tau) = A_i \exp(-k_i\tau_i) + B_i \exp(+k_i\tau_i) + \alpha_i \exp(-\tau_i/\mu_0),$$

$$I_1^i = P_i(A_i \exp(-k_i\tau_i) - B_i \exp(+k_i\tau_i)) + \beta_i \exp(-\tau_i/\mu_0), \quad (5)$$

where,

$$k_i^2 = 3(1-\omega_i)(1-\omega_i g_i)/(1-\omega_i f_i)^2,$$

$$P_i = \sqrt[2]{\frac{3(1-\omega_i)}{(1-\omega_i g_i)}},$$

$$\alpha_i = -\frac{3\omega_i F_0 \mu_0^2 (1-f)(1-\omega_i g_i + \frac{g_i}{1+g_i})}{4[1-\mu_0^2 k_i^2 (1-W_i f_i)^2]},$$

$$\beta_i = \frac{3\omega_i F_0 \mu_0 (1-f_i)[1+3(1-\omega_i)\mu_0^2 \frac{g_2}{1+g_i}]}{4[1-\mu_0^2 k_i^2 (1-W_i f_i)^2]}. \quad (6)$$

As the radiance between layers must be continuous, so there are boundary conditions as follows:

$$I_0^i(\tau_i) = I_0^{i+1}(\tau_i), \qquad (i=1,\ 2,\cdots N),$$
$$I_1^i(\tau_i) = I_0^{i+1}(\tau_i),$$

$$F\uparrow(\tau_N) = as[F\downarrow(\tau_N) + \mu_0 \pi F_0 \exp(-\tau_N/\mu_0)]. \quad (7)$$

Now there are $2N$ unknown constants and $2N$ equations altogether, and they forms a closed equations, so they can solved. Then the solar radiation incident at the ground can be written as follows:

$$F^{tot} = F_{dir}^{\downarrow} + F_{dif}^{\downarrow} = \mu_0 \pi F_0 \exp(-\tau_N/\mu_0) + \pi[A_N(1-\frac{2}{3}P_N)\exp(-k_N\tau_N) + B_N(1$$
$$+\frac{2}{3}P_N)\exp(k_N\tau_N) + (\alpha_N - \frac{2}{3}\beta_N)\exp(-\tau_N/\mu_0)] = \mu_0 C_1 \exp(-\tau_N/\mu_0)$$
$$+ C_2\exp(-k_N\tau_N) + C_3\exp(k_N\tau_N) + C_4\exp(-\tau_N/\mu_0), \quad (8)$$

where,

$$C_1 = \pi F_0, \qquad C_2 = \pi A_N(1-\frac{2}{3}P_N),$$

$$C_3 = \pi B_N(1+\frac{2}{3}P_N), \qquad C_4 = \pi(\alpha_N - \frac{2}{3}\beta_N). \quad (9)$$

The daily sums of UV and UVB is obtained by integration in zenith angle and in the wavelength. Integration in zenith angle is completed by the method of Gauss quadrature formula. Integration in the wavelength is completed by the method of

Simpthon quadrature formula for UVA (325−400 nm), and as for UVB, owing to large variation of absorption coefficient over the small spectral wavelength region, the integration can be made by approximation method suggested by Hunt *et al.* (Hunt, 1969) and by Yamamoto (Yamamoto, 1970).

3 Atmospheric model

The atmospheric model used for our numerical simulation is one-dimensional, plane-parallel atmosphere with nonhomogeneity restriction in the vertical direction. Ozone profile and other mixed gas profiles for the model atmosphere are given by McClatchey (McClatchey, 1970).

Aerosol model, as developed by Shettle and Fenn (Shettle, 1976), there are different size distribution and vertical profile for boundary layer, upper troposphere, stratosphere and mesosphere. For the boundary layer (below 2 km) 10 models have been defined which describe the aerosols in rural, urban, and maritime environments with several surface meteorological visibilities between 2 and 50 km. In this paper, the urban and rural environments with visibility 23 km are selected. For the upper troposphere two aerosol models defined for spring-summer condition and fall-winter conditions respectively are all chosen. In the stratosphere (up to 30 km) there are models for background, moderate, high, and extreme volcanic conditions for each seasonal models, and in this paper, only the model for background condition are used. For the upper atmosphere (above 30 km), as the aerosols is considered to be meteoric dust, so a model for background condition is used.

The size distribution for stratospheric aerosol models are represented by a modified Gamma distribution:

$$\frac{dN}{dr} = n(r) = Ar_{\alpha}\exp(-br_{\beta}). \tag{10}$$

The parameters are given in Table 1.

The size distribution for other models are represented by the sum of two log-normal distribution:

$$\frac{dN(r)}{dr} = \sum_{i=1}^{2}\left(\frac{Ni}{\ln(10)r\sigma_i\sqrt[2]{2\pi}}\right)\exp-\left[\frac{(\log r-\log r_i)^2}{2\sigma_i^2}\right], \tag{11}$$

where $N(r)$ is the cumulative number density. The parameters defining the size distribution are given in Table 1.

Table 1 Size distributions (normalized to 1 particle/cm³)

		Log-normal				
Type of aerosol	$N1$[1]	$r1$	σ_1	$N2$	$r2$	σ_2
Rural	0.9999975	0.005μ	0.475	2.5e−6	0.5	0.475
Urban	0.9999975	0.005μ	0.475	2.5e−6	0.5	0.475
Tropospheric	1	0.005μ	0.475	–	–	–
Meteoric dust	1	0.03μ	0.5	–	–	–

	Modified		gamma	
	A	α	β	b
Background stratospheric	324	1	1	18
Fresh volcanic	341.33	1	0.5	8

1. $N1+N2=1$

The aerosol refraction index of $1.5-0.01\,i$ is chosen for all models, this value of refraction index corresponds to background aerosol for continental condition (Hanel, 1978). The size range is from 0.1 to 10μm.

The whole atmosphere is divided into 21 plane parallel layers, the optical depth of the layer i is:

$$\tau_i = \tau_i^r + \tau_i^A + \tau_i^{03}. \tag{12}$$

Where τ_i^γ is the optical depth of scattering by molecules, and τ_i^{03} is the optical depth of ozone absorption, τ_i^A is the optical depth due to aerosols scattering and absorption, which is calculated by Mie scattering theory. As pressure at the ground changes from P_0^m (pressure of the model atmosphere) to P (the observed pressure), then

$$\tau_i^\gamma = \frac{\tau_i^{\gamma m} P_0}{P_0^m}. \tag{13}$$

Where $\tau_i^{\gamma m}$ is the optical depth of model atmosphere molecules scattering, which is calculated by Rayleigh scattering theory.

As the total amount of ozone changes from H_m^{03} (cm-atm) (the ozone amount of the model atmosphere) to H^{03} (cm-atm) (observed ozone amount), then

$$\tau_i^{03} = \frac{\tau_i^{03m} H^{03}}{H_m^{03}}, \tag{14}$$

where τ_i^{03m} is the depth of ozone absorption of model atmosphere.

4 Results

In order to investigate ultraviolet radiation distribution in China, several typical districts are selected to calculate the monthly mean daily sums of UV and UVB radiation. The pressure at ground surface is taken as an average of ten years ground pressure observed at meteorological station; the ozone amount is interpolated on basis of observed data of the year 1985; the albedo of ground surface is carefully selected by the types of the surface, vegetation and so on (Konderageve, 1972).

In summer, variation of monthly mean daily sums of UVB and UV as a function of latitude and height are plotted in Fig. 1 and Fig. 2, respectively. From Fig.1 and Fig.2, it can be seen that at the same sea level elevation, ultraviolet radiation changes little with latitude, and in latitude of 36° N, there exists a maximum; UVB radiation decreases significantly with the increase of latitude. From Table 2, it can be seen that from south to north in China, the monthly mean daily sums of the UV radiation in July have little difference, which result in the decrease of zenith angle and the increase of sunshine time as latitude increase. The monthly mean daily sums of the UVB radiation exist a decreasing trend from south to north, which results in the increase of ozone amount.

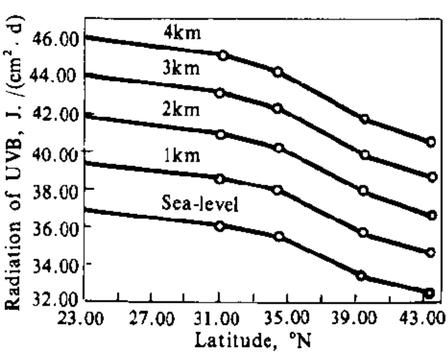

Fig.1 The variation of monthly mean daily sums of UVB-radiation with latitude and height in July

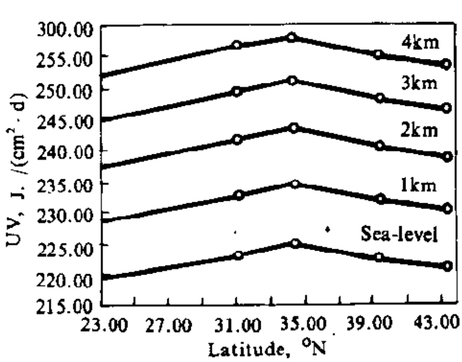

Fig. 2 The variation of monthly mean daily sums of UV-radiation with latitude and height in July

Fig.3 and Fig.4 show variation of monthly mean daily sums of UVB and UV with latitude and height in Jan. It can be seen that at the same sea level elevation, UV radiation and UVB decreases with latitude significantly. Because of sea level elevation changes a lot in different districts in China, and because of the zenith angle and the sunshine time decreasing as latitude increases, the monthly mean daily sums of UV radiation in Guangzhou are almost twice than that in Beijing, and its UVB is almost three and half than that in Beijing. The ratio of monthly mean daily sums of UVB radiation in Jan. to that in July is 0.45 in Guangzhou, and 0.15 in Beijing. The ratio of UV radiation in Jan. to that in July is 0.52 in Guangzhou, and 0.25 in Beijing. It shows that with latitude increasing, the annual variation of UVB and UV radiation increases a lot. Fig.5 gives the ratio of UV at sea level in Jan. to July, for comparison the ratio of UVB is also given in Fig.5. It is obvious that the annual variation of UV is bigger than that of UVB.

Table 2 The monthly mean daily sums of UV and UVB radiation in different places in China in clear sky in summer and winter

(unit: $J/(cm^2 \cdot d)$)

Station, lat., long	Elevation, m	UV (Jan.)	UVB (Jan.)	UV (July)	UVB (July)
Erlianhaote (43.39°N, 110°E)	965.9	45.3	3.4	230.1	34.8
Beijing (39.48°N, 116°E)	32.3	55.3	4.9	222.2	33.5
Zhengzhou (34.43°N, 113°E)	111.4	71.8	7.3	225.9	35.9
Shanghai (31.1°N, 121°E)	8.6	83.6	9.5	223.1	36.1
Guangzhou (23.08°N, 113°E)	7.6	113.8	16.1	219.3	36.8

Fig. 6 and Fig.7 give the increase ratio of the monthly mean daily sums of UVB radiation in different latitude and height with ozone depletion of 5% in winter and summer, respectively. It can be seen that if ozone amount is decreased by 5% from the value of 1985, the increased ratio of UVB is bigger in high-latitude than that in low-latitude, and the increased ratio of UVB is larger in winter than that in summer. For example, in summer in Guangzhou districts, UVB increases by 3.1% with ozone depletion of 5%, and in winter the value becomes to 3.6%. In

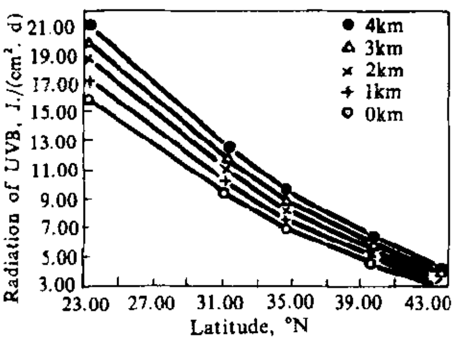

Fig.3 The variation of monthly mean daily sums of UVB-radiation with latitude and height in Jan.

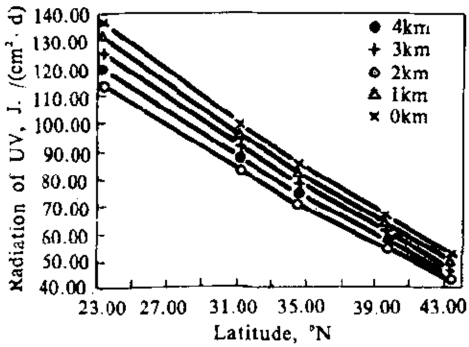

Fig.4 The variation of monthly mean daily sums of UV-radiation with latitude and height in Jan.

summer of Beijing district, UVB increases by 3.3% with ozone depletion of 5%, while in winter the value becomes to 5.4%.

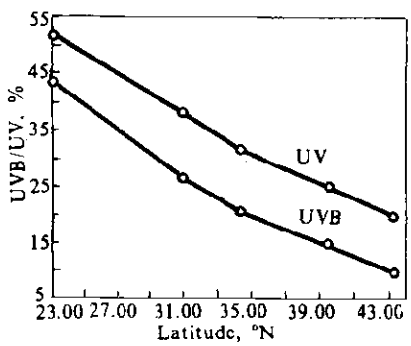

Fig.5 Variation of the ratio of monthly mean daily sums of UVB and UV radiation at sea-level in Jan. to that in July with latitude

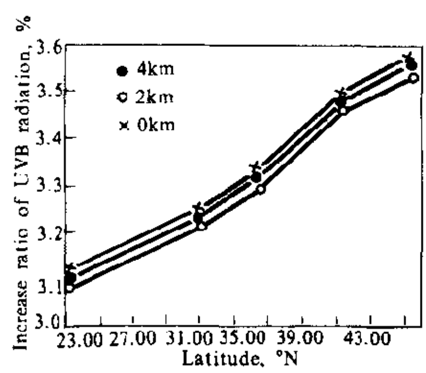

Fig.6 The increase ratio of monthly mean daily sums of UVB-radiation with ozone depletion 5% in July

If the action spectrum of UV-radiation $E(\lambda)$ is given, the biologically effective influence rate F_{BE} is:

$$F_{BE}=\int_{\lambda} E(\lambda)F(\lambda)d\lambda. \tag{15}$$

Where $F(\lambda)$ is the radiation flux incident at the ground. As the ozone depletion, F_{BE} can written as:

$$F_{BE}=\int_{\lambda} E(\lambda)F(\lambda)A(\lambda)d\lambda. \quad (16)$$

Where $A(\lambda)$ is the increased factor of radiation flux due to ozone depletion. It is obviously that a little change of $F(\lambda)$ may have a large influence on the F_{BE}. Considering the radiation flux incident at the ground and the increase of radiation $A(\lambda)$ due to ozone depletion, the increased ratio of biologically effective influence rate F_{BE} caused by ozone depletion is greater in high-latitude. However, as UVB flux incident at the ground in south of China is much more strong than that in north, so, with the depletion of atmospheric ozone, damage of the inereased UVB to biosphere in south districts in China may be more dangerous.

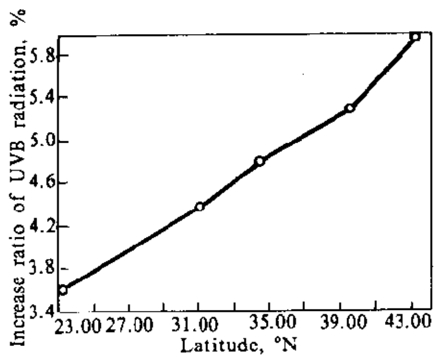

Fig.7 The increase ratio of monthly mean daily sums of UVB-radiation at sea-level with ozone depletion 5% in Jan.

References

Colle CA, Forges PD, Davis RE. Photo Chem Photobiol, 1986; 43:275
Cutchis P. Science, 1974; 184:13
Dave JV, Halpern P. Atmosphere Environment, 1976; 10:547
Frederick JE, Lubin D. J Geophys Res, 1988; 93:3825
Frederick JE, Snell HK, Haywood EK. Photochem Photobiol, 1989; 50:443
Frederick JE, Snell HK. J. Clim, 1990; 3:373
Green AES, Sawada T, Shettle EP. Photochem Photobiol, 1974; 19:251
Hanel G, Bullrich K. Beitr Phys Atmos, 1978; 51:129
Halpern P, Dave JV, Braslau N. Science, 1974; 186:1204
Hunt GE, Grant IP. J. Atmos Sci, 1969; 26:963
Joseph JH, Wiscombe WJ, Weinman JA. J. Atmos Sci, 1976; 33:2452
Kondramyev KYa. Radiation process in the atmosphere, Geneva, WMO, 1972; 19
Mcclathey RA. Atmospheric optical charateristics, translated by Institute of Atmospheric Physics, Chinese Academy of Sciences 1970; 2
Nack ML, Green AES. Appl Opt, 1974; 13:2405
Robert DR. Physiol Plant, 1983; 58:360
Shettle PE, Robert WF. Electromagnetic wave propogation panel symposium, Lyngby, Denmak, October 27–31, 1975, AGARD-CP-183

Shinhirne JD, Green AES. Atmos Environ, 1978; 12:2449
Thekaekara PM. Appl Opt, 1974; 13:518
Yamamoto G, Tanaka M, Asano S. J. Atmos Sci, 1970; 27:283

(Received July 14, 1992)

SYMPOSIUM ANNOUNCEMENT AND CALL FOR PRESENTATIONS

1st International Symposium on

Ecosystem Health and Medicine: New Goals for Environmental Management

June 19–22, 1994 · Ottawa Congress Centre
Ottawa, Ontario, Canada

New Goals for Environmental Management is a timely theme for the 1st International Symposium on Ecosystem Health and Medicine. Ecosystem health and medicine is increasingly being seen as a necessary approach to environmental management.This emerging transdisciplinary field bridges the social, health and ecosystem sciences in fostering new systematic methodologies for the diagnosis, prognosis and treatment of ecosystems under stress. This Symposium provides an exciting opportunity for professionals working in ecosystem science and management, medical and health sciences, environmental ethics and law and ecological economics to take part in the development of integrated approaches to the evaluation, monitoring and rehabilitation of environmental health at the ecosystem and landscape levels. The program will include invited speakers from the medical, ecosystem science and policy interfaces as well as contributed presentations.

Major Symposium themes Include:

- Approaches to Assessing Ecosystem Health
- The Human Health/Ecosystem Health Interface
- Environmental Management and Policy

For Symposium Information and Guidelines for Presentations (Submission Deadline-February 1, 1994) contact: Mr. Remo Petrongolo, Symposium Manager, Office of Continuing Education, 159 Johnston Hall, University of Guelph, Guelph, Ontario, CANADA, NIG 2W1, Tel. (519) 824-4120 ext. 3064, FAX (519) 767-0758.