Separation of direct ultraviolet radiation from data measured with a spectrophotometer having wide entrance aperture

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The contribution from direct and scattered ultraviolet radiation (295–345 nm) is estimated based on measurements with a spectrophotometer having a fixed entrance aperture (central angle of 32°). It is shown that in a certain range of the sun elevation angles and in some wavelength region, it is possible to separate out direct ultraviolet radiation (UVR) component from recorded signals. The procedure of separating the direct UVR is applied to processing and analyzing the daily near-noon values of UVR recorded in Irkutsk in 1998–2000. The experimental data on the annual UVR variation amplitude in Irkutsk (the sun elevation angle from 14 to 60°) are compared with calculated values of annual variation amplitudes of direct and scattered UVR. It is concluded that the observed variations in the recorded UVR correlate to a greater extent with variations of direct radiation. The proposed method of separating the direct UVR is intended for monitoring and investigation of long-term (such as interseasonal and interannual) UVR variations.

Introduction

In some problems, in studying the surface ultraviolet radiation (UVR), it is needed to have a device capable of recording the direct solar radiation for a long time. The design of such devices is rather complex because of the presence of servo systems, and for solution of some problems it becomes necessary to apply a device with a static arrangement of the entrance optical system.

In this paper, we consider the possibility of and conditions for separating the direct UVR from data measured with a spectrophotometer having a fixed entrance aperture. The results of observation of the surface UVR in Irkutsk (52°N, 102°E), Eastern Siberia, are presented. A specific feature of the observation site is connected with the stable Siberian High characterized by anomalously low values of the total ozone column (TOC) observed in some periods.[1–4]

Instrumentation and measurement technique

Daily measurements of the near-noon UVR in the wavelength region from 295 to 345 nm have been conducted in Irkutsk since fall of 1998. The main measurement instrument is a spectrometer comprising of the KSVU-12 (LOMO) system and an IBM AT computer. The spectrometer layout is shown in Fig. 1. The sun and sky radiation incident on a quartz ground glass passes through a filter and comes to the entrance slit of an MDR-12 monochromator. Having passed through a monochromator, the dispersed radiation comes to a FEU-100 PMT, where it is amplified. Then it is converted by a 12-bit ADC and recorded by a computer. Simultaneously, a reflecting diffraction grating is turned, thus providing for scanning over the selected wavelength region. The quartz ground glass is needed to provide for continuous presence of the direct solar radiation in the monochromator entrance slit. The visible radiation scattered inside the monochromator is excluded by a UFS-5 absorption filter installed in front of the entrance aperture.

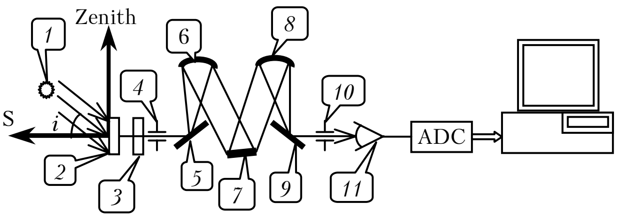

Fig. 1. Spectrometer layout: sun and sky *1*, quartz ground glass *2*, UFS-5 filter *3*, entrance slit *4*, collimator mirrors *5* and *9*, spherical mirrors *6* and *8*, beam-turning diffraction grating *7*, exit slit *10*, and PMT *11*.

The radiation incident on a fixed vertical quartz ground glass plate oriented in the south direction is recorded. The angular halfwidth of the optical system field of view is $\alpha \approx 32°$. The spectral resolution in spectral scanning is about 0.2 nm, the scanning step is 0.02 nm, the scanning rate is ~ 0.33 nm/s. The stability of the measurement system is controlled every day with a reference light source and all measured data are corrected against this calibration. For absolute calibration of the system, a 200-W tungsten ribbon lamp with a quartz window was used. In this paper we describe a procedure for separating out the direct UV radiation from the recorded signal. Therefore, the Bouguer line method can be additionally applied to converted experimental

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data to refer the measured radiation to tabulated values of extraterrestrial radiation at the studied wavelengths. For this purpose, we drew the dependences of the logarithm of converted values of the measured radiation on the optical mass of the atmosphere. After extrapolation of the obtained straight lines, the value of the function at the zero optical mass was set equal to the tabulated value of the extraterrestrial radiation at this wavelength.

Usually, in drawing Bouguer straight lines, one day is used for measurements with different optical masses m (Ref. 5). We applied this procedure on a half-year time scale with the equivalent range of optical mass variation. For applying the Bouguer method, we took clear days with highest atmospheric transmittance. In such an approach, we can speak about some equivalency of the Bouguer law obtained from one-day and half-year measurements. The difference consists in time scales of atmospheric stability.

Calculation and analysis of the results

If UVR is measured at a randomly oriented plate by a device with a finite entrance aperture (that is, from some part of the sky), the device always records both direct and a certain portion of the scattered radiation, and the level of scattered radiation depends on the angular sensitivity of a receiver and the position of a source.

The measurements in Irkutsk were conducted as the sun passed the system optical axis at the same time (12:30 of local (winter) time). The used scheme of measurements required estimation of the contributions from the direct S and scattered D radiation to the recorded signals and determination of the technique for signal processing for their further analysis.

Since the sensitivity of the receiving system depends on the angle of radiation arrival, the recorded radiation can be presented in the general form as follows

$$J_{\mathrm{rec}} = Sk(i,\phi) + \int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \int_{0}^{\frac{\pi}{2}} D(\theta,\varphi)\, k(\theta,\varphi)\, \mathrm{d}\theta\, \mathrm{d}\varphi \;, \qquad (1)$$

where i is the sun elevation angle; ϕ is the sun azimuth with respect to the device axis; J_{rec} is the radiation level recorded by the device; θ and φ are the angles determining the direction from the device axis to a sky point; $k(i, \phi)$ and $k(\theta, \varphi)$ are the coefficients of device angular sensitivity in the direction to the sun and to a given sky point, respectively; $D(\theta, \varphi)$ is the radiation scattered from a given direction. If measurements are always conducted at the same time, then $k(i, \phi)$ does not depend on ϕ, therefore the variable ϕ is omitted and hereinafter we consider the coefficient $k(i)$.

Since the receiving optical system has a finite angular aperture, only a part of the scattered sky radiation is recorded. This part is determined by the geometric coefficient F_g defined as a fraction of the coelosphere visible in the device field of view. This scattered radiation comes from the sky part lying before the entrance window within the halfwidth of the angular aperture. For the direct and scattered radiation and their ratio, theoretical and experimental data are available for different sun elevation angles and different atmospheric transmittance.[6,7] Using these data, in Eq. (1) we can represent the scattered radiation through the direct one applying the coefficients $d(i) = D/S(i)$ (the ratio of the radiation scattered from the whole coelosphere to the direct radiation) and $\delta(i)$ (dependence of the brightness of the sky portion viewed by the device on the angle between the sun and the sighting axis i). Thus, the second term in the right-hand side of Eq. (1) can be estimated as

$$\int_{-\frac{\pi}{2}}^{\frac{\pi}{2}} \int_{0}^{\frac{\pi}{2}} D(\theta,\varphi) k(\theta,\varphi)\, \mathrm{d}\theta\, \mathrm{d}\varphi = SF_g \delta(i)\, d(\lambda, i)\;. \qquad (2)$$

From Eqs. (1) and (2) we can determine the direct UVR:

$$S(\lambda, i) = \frac{J_{\mathrm{rec}}(\lambda, i)}{k(i)\left\{1 + \dfrac{F_g \delta(i)\, d(\lambda, i)}{k(i)}\right\}}\;. \qquad (3)$$

To use Eq. (3), we should first determine the coefficients $k(i)$, $\delta(i)$, $d(\lambda, i)$, and F_g for our device. The values of the direct radiation and the radiation scattered from the coelosphere in the UV region at different sun elevation angles, the surface albedo A, and the atmospheric turbidity were taken from Ref. 6 and used for determination of the coefficient $d(\lambda, i)$. The coefficient $k(i)$ was determined experimentally for a point source. The device sees a half of the sphere segment with the central angle α, because the input window is oriented vertically and the lower part of this segment is below the horizon. Based on stereometric equations, $F_g = \sin^2(\alpha/4)$. The coefficient F_g was calculated from the data for a point source and found to be equal to 0.02. For estimates, the coefficient $\delta(i)$ was taken equal to unity at $i = 15–30°$ and 0.5 at $i = 45–60°$.

The parameter $F_g \delta(i)\, d(\lambda, i)/k(i)$ characterizes the relative contribution of the scattered radiation at the unit contribution of the direct radiation to the measured one. In the case $F_g\, \delta(i)\, d(\lambda, i)/k(i) \ll 1$, Eq. (3) transforms into

$$S(\lambda, i) = J_{\mathrm{rec}}(\lambda, i)/k(i). \qquad (4)$$

In some problems, when the accuracy of separating out the direct and scattered components from the total radiation recorded is not critical, Eq. (3) or its approximation (4) can be used for estimating the direct radiation. Such problems can arise when studying seasonal and interannual variations of the surface UVR, trends, and possible dependence on the solar activity.[4,8] We have assessed conditions, under which the

Table 1

Sun elevation angle, deg	S, mW/(m^2·nm)		D, mW/(m^2·nm)		k	d		$F_g\,\delta(i)\,d(\lambda, i)/k(i)$	
	309 nm	344 nm	309 nm	344 nm		309 nm	344 nm	309 nm	344 nm
15 (A=0.7)	0	59	7	163	0.95	–	2.76	>>1	0.06
30 (A=0.7)	17	246	51	307	0.56	3	1.25	0.11	0.04
45 (A=0)	50	388	73	280	0.28	1.46	0.72	0.05	0.03
60 (A=0)	83	475	101	311	0.17	1.22	0.65	0.07	0.04

approximation (4) can be used. Table 1 gives the estimates of $F_g\,\delta(i)\,d(\lambda, i)/k(i)$ at high atmospheric transmittance and TOC equal to 300 D.u. for different values of the sun elevation angles at two wavelengths of 309 and 344 nm. It follows from Table 1 that the contribution of the scattered UVR at the wavelength of 344 nm is smaller than 6% at the noon sun elevation angle from 15 to 60°, and at the wavelength of 309 nm it varies within 7–11% for the sun elevation angles from 30 to 60°. This means that the device largely records the direct radiation. The contribution of the scattered radiation to $J_{rec}(\lambda, i)$ becomes significant only in the shortwave part of the spectrum at the minimum sun elevation angle at noon at the observation site.

The UVR values obtained by the above method were compared with the calculated values of the direct and scattered radiation[6] at the sun elevation angle $i \sim 30$–60°. Table 2 gives the ratios of calculated (direct and scattered)[6] and measured radiation $J_{rec}(\lambda, i)/k(i)$ at fine weather with the highest atmospheric transmittance for two sun elevation angles of 30 and 60°. The calculated values are given for two values of the coefficient of atmospheric turbidity $b = 0.025$ and 0.05 (Ref. 6).

Table 2

Wavelength, nm	Calculation		Measurement
	$S(60°)/S(30°)$	$D(60°)/D(30°)$	
309	4.9	2 (b = 0.025)	6
	5.5	2.1 (b = 0.05)	
344	1.9	1.01 (b = 0.025)	2.5
	2.1	1.06 (b = 0.05)	

It follows from Table 2 that the dynamics of measured radiation better agrees with the calculated direct radiation, than with the scattered one. This confirms the conclusion that the measured radiation comprises largely of the direct one and only a small fraction of radiation scattered by the whole coelosphere.

Conclusions

A method is proposed for separating out the direct UV radiation from data measured with a device having a wide angular aperture.

This method can be used to study long-term UVR variations. It allows the use of instrumentation without a complex servo system to trace the sun. It also extends the device dynamic range, because the maximum of the angular sensitivity is directed at the minimum intensity of the direct radiation at a given azimuth.

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