Specific features of the UV radiation spectrum at the ground level in Irkutsk

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The peculiarities of the solar UV radiation spectrum at the ground level are investigated. The degree of influence of the variation of atmospheric parameters, such as the total ozone content (TOC), atmospheric pressure, and aerosol, on the variability of the ground-level UV radiation in the region of 300 to 350 nm has been studied in Irkutsk. The most significant of them were determined in separate bands of the selected range on different time scales. Functions of spectral responses of direct midday UVR to variations of the atmospheric parameters by 1% about their mean values for Irkutsk were constructed. These functions can be used to assess the influence of actual changes under atmospheric conditions. It is pointed out that the aerosol and cloud state are the factors that determine the overall UVR level. The effect of pressure fluctuations on UVR variability is insignificant; however, under conditions of optical stability of the atmosphere, which can persist for several days, the influence of pressure variations on UVR can become predominant. TOC and the Sun's zenith angle govern the spectral composition. It was found that at the wavelengths longer than 320 nm the spectral structure of the UVR variation coefficient coincides with the system of Huggins bands in the ozone absorption spectrum, and for the wavelengths shorter than 320 nm, it coincides with the typical spectral patterns of the extra-terrestrial solar UV spectrum. It was ascertained that small-scale structure of the ground-level spectrum is determined by the structure of the extra-terrestrial solar UV spectrum, while the overall spectral variation is determined mainly by the large-scale spectral behavior of the ozone absorption coefficient.

Some peculiarities in the spectral composition of UV radiation near the ground surface were studied earlier both theoretically[1] and using experimental data.[2] The task of this study was to continue these investigations in order to reveal the effect of different parameters of the atmosphere on the variability of the near-ground UV radiation in the range from 300 to 350 nm (Ref. 3). Let us determine the most important of them in separate bands of the selected range and show which of these parameters determine the structure of the near-ground spectrum of different spectral scales.

Variations of some atmospheric parameters that most significantly affect UV radiation, such as TOC, atmospheric pressure, and aerosol show different influence on the variability of the near-ground UV radiation, and this influence is spectrally dependent. The strength of the effect of each of them can be different in different regions of the planet, because always there are various regional peculiarities in the state and dynamics of the atmosphere.

Let us consider the behavior of UV radiation spectra in Irkutsk (Eastern Siberia). Let us determine the strength of the effect of each parameter on the UV radiation by means of the Bouguer formula

$$\ln I_\lambda = \ln I_{\lambda 0} - \alpha_\lambda X \mu - \frac{P}{P_0} \beta_\lambda m - \delta_\lambda m_1 , \quad (1)$$

where I_λ is the intensity of the near-ground direct solar UV radiation; $I_{\lambda 0}$ is the intensity of the direct UV solar radiation at the top of the atmosphere, α_λ is the ozone absorption coefficient; X is the total ozone content; μ is the optical mass of ozone along the direction toward the Sun; β_λ is the optical thickness of the Rayleigh atmosphere; m is the optical mass of the atmosphere along the direction toward the Sun; P is the atmospheric pressure, P_0 is the atmospheric pressure at the sea level, δ_λ is the optical thickness of atmospheric aerosol or the aerosol extinction coefficient, m_1 is the aerosol optical mass. Let us take partial derivatives of expression (1) with respect to a certain parameter. The following formulas are obtained:

at the change of TOC

$$(\Delta I_\lambda / I_\lambda)_X = -\alpha_\lambda \mu \Delta X, \quad (2a)$$

at the change of atmospheric pressure

$$(\Delta I_\lambda / I_\lambda)_P = -\frac{\beta_\lambda m}{P_0} \Delta P, \quad (2b)$$

at aerosol variations

$$(\Delta I_\lambda / I_\lambda)_b = -m_1 \lambda^{-a} \Delta b, \quad (2c)$$

$$(\Delta I_\lambda / I_\lambda)_a = m_1 b \lambda^{-a} \Delta a, \quad (2d)$$

where notation of the partial derivative is replaced by Δ, subscripts in the left part of the equations are the parameters the variation of which causes the variations of the near-ground direct UV radiation. The effect of aerosol variations is divided into the response to variations of the turbidity coefficient b and to the change of the aerosol Angström parameter a supposing that the aerosol optical thickness (AOT) obeys the Angström law $\delta_\lambda = b\lambda^{-a}$ (λ measured in micrometers).[4] The value b approximately presents the content of large

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aerosol particles, and the parameter a characterizes the value of the relative content of fine aerosol fraction as compared with the coarse fraction.[5]

It follows from Eqs. (2a) and (2b) that the effect of variations of TOC and pressure (ΔX and ΔP) on the relative variations of UV radiation ($\Delta I_\lambda / I_\lambda$) depends on the optical mass, it is maximum in winter and minimum in summer. This means that only the optical mass in formulas (2a) and (2b) is a variable, that corresponds to the varying amplification coefficient of the effect of variations of TOC and pressure on the relative variations of UV radiation.

The spectral responses of the direct noon UV radiation on May 29, 2001 on the variations of the atmospheric parameters by 1% about their mean values for Irkutsk are shown in Fig. 1*a*.

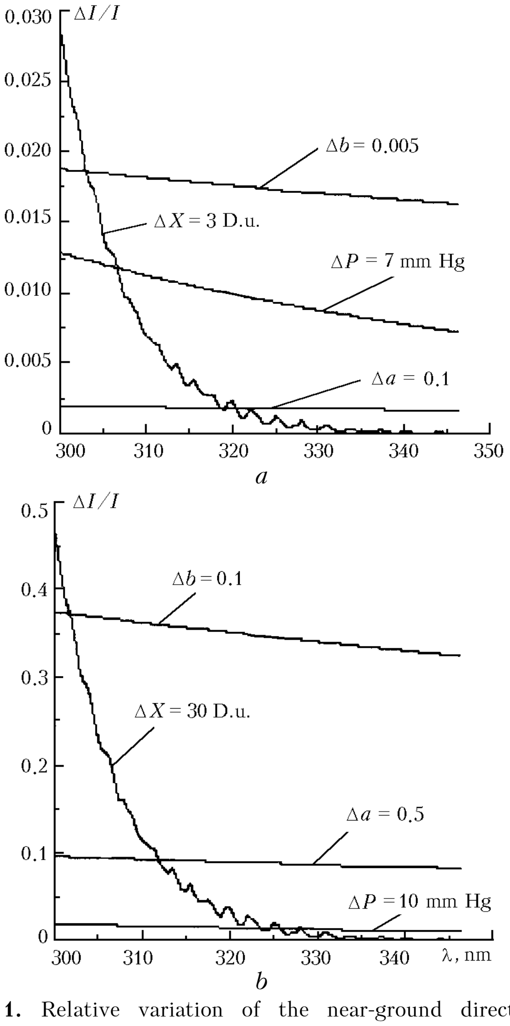

Fig. 1. Relative variation of the near-ground direct UV radiation at variations of different parameters of the atmosphere.

As for the aerosol variation, one can only conditionally say about percent variation and mean values of its parameters, because they are strongly variable.[5,6]

The plots shown in Fig. 1*a* present the response of the UV radiation to the 1% variation of the atmospheric parameters, so one can call them the weighted variations. One can say the same about Fig. 1*b* but only if the atmospheric parameters have been replaced by the "typical" deviation during a year from the mean values in Irkutsk.

Variations of haze and cloudiness effect most strongly over all spectrum, that is mostly pronounced on a year scale (Fig. 1*b*). Variations of pressure, though being at the second place by the effect they show on the variability of UV radiation (see Fig. 1*a*), but such an effect is insignificant on a year scale (see Fig. 1*b*). Nevertheless, under conditions of optically stable atmosphere, which can be kept during several days, the effect of pressure variation on the UV radiation may become dominant. The variations of the product of TOC by the ozone optical mass, which can be called the ozone effective content, are responsible for the change of the shape of spectrum. The role of variations of that or another parameter at different realizations of the change of the state of the atmosphere can significantly vary, that leads to different combinations of the curves presented in Fig. 1.

Let us determine the wavelength (at $m = \mu$), such that at shorter wavelengths the contribution of ΔX to the relative variation of the UV radiation is greater than the contribution coming from ΔP, and vise versa at $\lambda > \lambda_0$, by equating Eqs. (2a) and (2b) with each other:

$$\lambda_0 = \left(\frac{\Delta P}{\alpha_\lambda P_0 \Delta X} \frac{8\pi^3 H}{3N} (n^2 - 1)^2 \frac{6 + 3p}{6 - 7p} \right)^{1/4} .$$

Here N is the number of molecules in a unit volume (Loschmidt number); n is the refractive index; H is the height of the homogeneous atmosphere; p is the coefficient of the optical anisotropy of molecules. At a change of pressure and ozone by 1% λ_0 = 306.5 nm. The contribution ΔX at $\lambda >$ 325–330 nm is negligible as compared with the contribution from variations of other atmospheric parameters.

In addition to the variations of atmospheric parameters, formulas (2c) and (2d) include their absolute values, and, as they can take the value in a wide range (a can change in the limits from 0 to 4, and b can vary from 0.04 to 1 and greater),[4] their effect can change from negligible (especially the effect of Δa) to the prevalent one. The aerosol parameters on the above mentioned day were $b = 0.051$ that is practically minimum possible value for Irkutsk, $a = 0.973$, that is close to the mean value. It is seen from Fig. 1 that the effect of TOC variations begins to be apparent at the wavelengths shorter than 320 nm with sharp increase in the shortwave range. Perhaps, the most significant is the effect of variations of the turbidity of the atmosphere. Variations of this parameter lie in a wide range, however, such variations practically do not affect the variation of the spectrum shape, at least, they cause no peculiarities. The same refers to the effect of pressure variations, with the only difference, that it is significantly weaker, and the relative range of pressure variations is lower.

The amount of direct UV radiation in the limits of the wavelength range under study measured by means of the instrumentation used in Irkutsk is determined accurate to 12–16% depending on the wavelength and conditions of recording.[3] In this connection, it is possible to reliably reveal the effect of variations of the atmospheric parameters on the relative variations of UV radiation only under condition that this effect leads to deviations of UV radiation by the value greater than the measurement error. For example, the response of the direct UV radiation to the annual variation of pressure in Irkutsk, according to calculated data, is not more than 2% (see Fig. 1*b*), so it is impossible to check it experimentally using the aforementioned instrumentation, in this case one can say only about the estimates. The response of UV radiation to variations of other atmospheric parameters can be revealed from the experimental data and coincides with calculated estimates accurate to 15–20%.

The following was done to demonstrate the selectivity of the effect of different external conditions on the income of near-ground UV radiation. The spectra measured during a year were normalized to unity at 345 nm wavelength and then averaged over months and year. The wavelength $\lambda = 345$ nm was selected for normalizing the spectra, because the effect of variations of the state of the atmosphere and the parameters themselves is minimum at it, that is seen from Fig. 1. The results of such averaging are shown in Fig. 2. The monthly and annual mean spectra are shown here.

It is seen from Fig. 2 that the Sun elevation determines the shortwave boundary of the radiation coming to the Earth surface. Let us define λ_{min} as λ at which 1% of I_{345} reaches the Earth surface. It was obtained for Irkutsk, that the minimum λ_{min} is equal to 300 nm in June and July, and the maximum $\lambda_{min} = 308$ nm in December and January, and the annual mean $\lambda_{min} = 303$ nm.

The behavior of the near-ground UV radiation at weakly variable Sun elevation but significant variations of the effect of the state of the atmosphere due to great optical path is shown in Fig. 2*b*. The variability of the normalized daily spectra during a month is less than that during a year, and its maximum value is displaced to longer waves.

One can show the spectral variations more clear, if constructing the annual and monthly plots of the variation coefficients (Fig. 3). These coefficients are defined as the ratio of the variance to the mean value of radiation at a certain wavelength.

According to these plots, there is a wavelength range where UV radiation varies most strongly depending on the conditions of recording.

The range of 305 to 323 nm undergoes the greatest relative variations on the temporal scale of a year, and the radiation at $\lambda = 312$ nm undergoes maximum variations. This range for the monthly scale is 310 to 330 nm with maximum at $\lambda = 318$ nm. The difference in the spectral distribution is related to the effect of Sun elevation during a year.

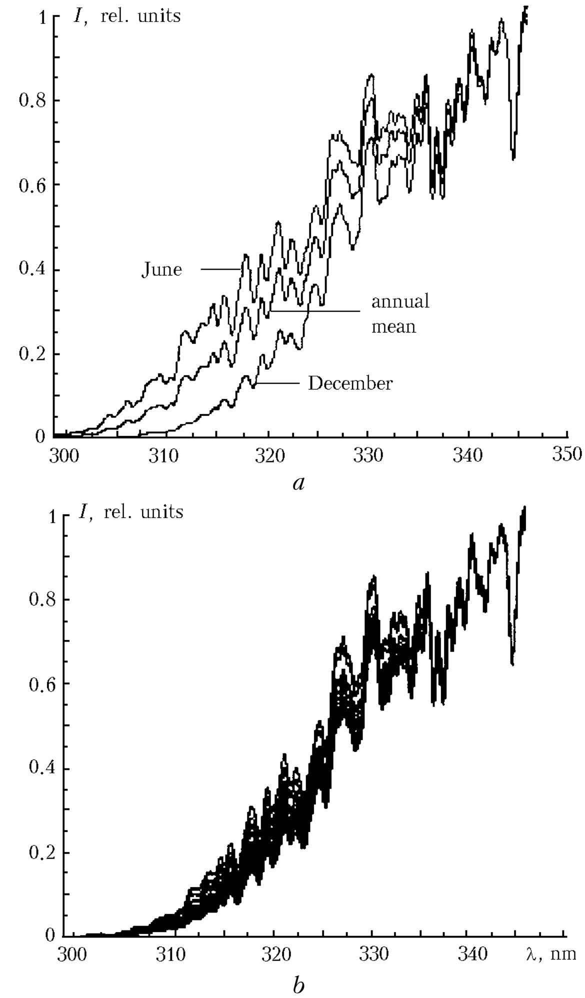

Fig. 2. Normalized monthly mean spectra for year 2000 (*a*) and daily for February, 2000 (*b*).

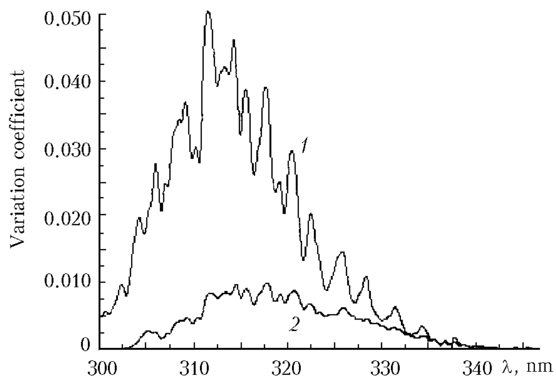

Fig. 3. Variation coefficient of the near-ground direct UV radiation: annual mean for year 2000 (*1*) and February, 2000 monthly mean (*2*).

The essential excess of the annual variation coefficients over the monthly ones is quite natural, because the range of variations of all parameters during a year is significantly wider than during a month. This peculiarity is seen in the annual curve, which is related to different character of the absorption by ozone. There are two absorption bands of ozone in the UV spectral range: the Hartley band (180 to 340 nm) and the Huggins band system (320 to 366 nm). The Hartley band consists of small diffuse peaks on strongly continuous background, the band center is at the wavelength of $\lambda = 255$ nm. The so-called Huggins band system superposes the longwave side of this band. This system is significantly weaker than the Hartley band, but its maxima are pronounced better.[7] Local extrema of the curve *1* at $\lambda > 320$ nm coincide with the extrema of the ozone absorption, which lie in the Huggins band system. The decrease of the variation coefficients is caused by a sharp decrease in the ozone absorption in this spectral range. Local extrema of both curves at $\lambda < 320$ nm coincide with the positions of the peaks of the extraterrestrial solar spectrum and repeat to a certain degree its shape. The shortwave decrease of the variation coefficients is caused by very strong absorption of radiation in this range by ozone. In this connection, the amount of ozone, which absorbs this radiation is not that significant as in the more "soft" ultraviolet. It is for this reason that the curve *2*, showing the degree of variability of UV radiation in February at significant optical mass, decreases to zero at $\lambda < 308$ nm.

Let us reveal now the factors that govern the spectral behavior of the near-ground UV radiation shown in Fig. 2. Let us plot in Fig. 4 all terms included in formula (1): the logarithm of the annual mean near-ground UV spectrum, the logarithm of the extraterrestrial solar UV spectrum with the same spectral resolution 0.2 nm (Ref. 8), the ozone absorption coefficient at the annual mean TOC of 354 Dobson units and $\mu = 2$ (that corresponds to the Sun elevation angle of 37°),[9] the absorption coefficient of the Rayleigh atmosphere at mean pressure of 723 mm Hg (Ref. 7), and the aerosol absorption coefficient at $b = 0.1$ (moderate and high transparency) and $a = 1$.

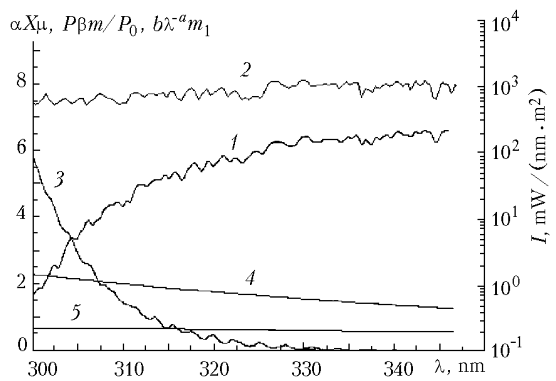

Fig. 4. The effect of extraterrestrial UV spectrum (*2*), ozone absorption (*3*), scattering by the Rayleigh atmosphere (*4*), and aerosol scattering (*5*) on the shape of the spectrum of the near-ground UV radiation (*1*).

It is well seen that small-scale spectral features in the spectrum of the near-ground UV radiation are determined by the corresponding lines of the extraterrestrial solar spectrum. The principal spectral behavior is due to the strong absorption by ozone. Aerosol practically does not affect the spectrum shape, in the frameworks of the used model, however, it should be studied in a more detail, because this atmospheric component is very variable in the total content, particle size distribution, chemical composition, and spatial distribution. Having in mind these properties, aerosol can essentially affect the UV radiation, especially in industrial areas, like Irkutsk.

Results. The effect of variations of the parameters of the state of the atmosphere (TOC, atmospheric pressure, and aerosol) on the variability of the near-ground UV radiation in the range of 300–350 nm in Irkutsk has been revealed. The most significant factors are determined in different bands of the selected range. The limits of variations of the wavelength of the shortwave boundary of the near-ground UV radiation during a year are determined. The coincidence of the spectral structure of the variation coefficient of UV radiation with the Huggins band system in the ozone absorption spectrum at $\lambda > 320$ nm, and with the characteristic spectral peculiarities of the extraterrestrial solar UV spectrum at $\lambda < 320$ nm has also been revealed. It was also found, which factors govern the structure of the near-ground spectrum on different spectral scales.

Acknowledgments

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