Variations of UV-*B* radiation in Tomsk in 2003–2007

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The results of the UV-*B* radiation monitoring carried out with UVB-1 pyranometer and Brewer spectrophotometer (MKIV No. 049) at the TOR station of IAO SB RAS (Tomsk) in 2003–2007 are presented. It is shown that main contribution into the annual income of UV-*B* radiation falls on the warm season with maximum in June. There is a spring increase of daily income in the annual-average behavior of UV-*B* radiation in April with a subsequent attenuation to the beginning of May, as well as fluctuations (10–15-day period) in daily income with typical peaks during summertime. Maximal variability in spectral behavior was observed in a 295–310 nm range, (Haggis band), which varies from year to year.

Introduction

Ultraviolet radiation (UVR) plays an important role in many photochemical and chemical-biological processes occurring in the Earth's atmosphere and on its surface, takes part in the climate formation, influences the planet's biosphere. The level and variations of the near-ground ultraviolet radiation are determined by astronomical (zenith angle of the Sun) and some other factors: changes in the total ozone content, the cloudiness, albedo of the underlying surface, aerosol optical thickness, the presence of different air admixtures, which have absorption lines in the ultraviolet range. The contribution of each of these factors is variable and depends on physical-geographical and climatic peculiarities of the region. The network of ground-based monitoring of UV radiation,[1] existing now in Russia, as well as satellite measurements[2–5] do not allow the control for its variations on the regional level.

There are numerous evidences of regional peculiarities in the income of UV-*B* radiation.[6–8] Based on measurements of near-ground erythematous ultraviolet radiation (EUVR) around five large cities of Siberian region (Novosibirsk, Tomsk, Gorno-Altaisk, Krasnoyarsk, and Irkutsk), spatial mesoscale inhomogeneity in the distribution of UV radiation was found,[9] formed under the effect of atmospheric factors (cloud regime, aerosols, total ozone content) as well as circulation processes and regional physical-geographical peculiarities. The authors of the cited work note that mean relative variations of UV radiation in the considered regions reach ± 15–20%.

At the same time, it follows from some works[10–12] (ground-based measurements) that variations of UVR, related with regional peculiarities, can be significant. Some peculiarities in UVR variation at the Eastern Siberia (asymmetry in the seasonal behavior of UVR, seasonal behavior of variation coefficients of UVR, short-time increases), assessed from the data of ground-based measurements of the direct UVR in individual ranges of the ultraviolet spectrum (296–346 nm) were noted.[13,14]

Stations of monitoring of UV-*B* radiation in Western Siberia are absent, although such data are necessary for a number of applications: bioclimatology, medicine, building climatology, and so on. In this paper we present our results of five-year monitoring of UV-*B* radiation in the region of the Tomsk city.

Instrumentation

In October of 2002, the radiation block of the instrumentation complex (TOR-station) of the Institute of Atmospheric Optics[15] was equipped with a computerized ultraviolet pyranometer UVB-1 (Yankee Environmental Systems, Inc., USA) capable of measuring the total intensity of UV-*B* radiation in a wavelength range 280–320 nm. Measurements were carried out hourly round-the-clock. For one measurement cycle of 10 minutes parameters have been read with a frequency of 1 Hz. The final computer-recorded result was obtained from averaging of 600 single values and calculating the root-mean-square deviation. The results then were recorded to hard disk for storing in the database.

Measurements of the total ozone content (TOC) with the spectral photometer Brewer MKIV No. 049 started in September, 2003, in cooperation with Central Aerological Observatory, and since January, 2004, regular measurements of UVR in the range 290–325 nm with a step of 0.5 nm started. The technical maintenance and calibration of the spectral photometer relative to the secondary standard during the measurement period were made in August, 2003 and 2005 at the Scientific-Production Corporation "Typhoon"; the next calibration is planned for August, 2008. The spectral photometer Brewer MKIV measures the total UVR with a spectral accuracy of (0.006 ± 0.002) nm. During 5 min and 25 s the

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photometer performs a double scanning (forward and backward), such obtaining two values at each wavelength. The final result is the spectrum obtained from arithmetic mean values. The available software allows obtaining integral values in a given wavelength range, therefore, cutting the upper boundary of the spectrum to 320 nm, it is possible to compare the obtained data with the data of the pyranometer UVB-1.

Measurement results

Average values of the daily income of UV-*B* radiation are shown in Fig. 1 for each day of all years of the considered period with subsequent smoothing through the sliding averaging over five days, as well as maximal and minimal values of the daily values (they characterize the possible inter-day variability of the considered parameter), are presented in Fig. 1.

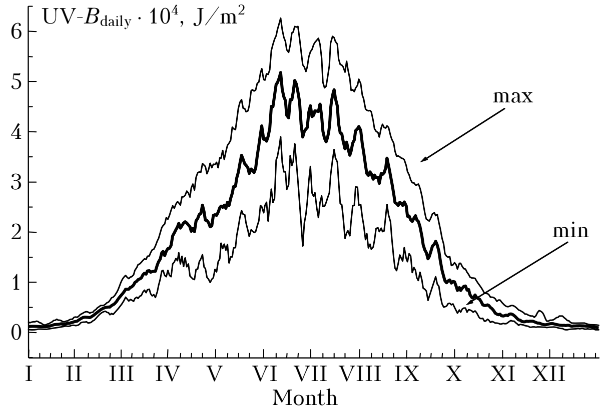

Fig. 1. Annual mean variations of daily income of UV-*B* radiation, as well as their maximum and minimum values.

The following peculiarities were observed in the mean annual behavior of UV-*B* radiation: spring increase of the income in April with subsequent decrease to the beginning of May; oscillations of the UV-*B* radiation values with periods of 10–15 days and characteristic peaks (which are twice longer than the duration of the natural synoptic period) in summer.

Similar regularities were noted independently by other researchers[9] from analysis of the satellite data on erythematous UV radiation in 1979–1992 and 1996–2003 for different regions of Siberia: Novosibirsk, Tomsk, Krasnoyarsk, Irkutsk, and Gorno-Altaisk. It was marked that spring maximum in Tomsk is best pronounced.

Maximal income of UV-*B* radiation in the considered period was observed between May and September, which is 78% of the annual magnitude. Inside this period, maximal income of UV-*B* radiation was observed in June. Sharp drops were observed quite often in the inter-day variability of UV-*B* radiation daily sums. For example, from June 1, 2005 to June 12, 2005 the amplitude of variations of the daily sums was 50.77 kJ/m^2. The variation coefficient of daily sums in warm season was 44%. However, this value included variations caused by astronomical factors as well (the annual behavior of Sun elevation and the length of light day).

In order to eliminate the effect of these factors, we used the ratio of daily sums to the mean values for each day of the considered period. The variation coefficient of the ratio, characterizing the greater variability of UV-*B* radiation daily sums due to weather conditions, is 31%. The histograms of the daily sum repetition during warm season, when the underlying surface is homogeneous, are shown in Fig. 2*a*.

It is seen that the major percentage of the daily sum repetition is composed in the range 30–60 kJ/m^2, and 40% of daily sums in June fall on 50–60 kJ/m^2 range. Daily sums in September vary in the range 0–40 kJ/m^2 with maximum within 10–20 kJ/m^2 (48%).

The UV-*B* radiation income in the cold season (January–April and October–December) was 22%. From November to February it did not exceed 10 kJ/m^2 and in other months lied in range 0–40 kJ/m^2 (Fig. 2*b*).

Of interest is the estimate of extreme UV-*B* radiation daily sums for all months in 2003–2007. These data are presented in Table 1. The absolute maximum of daily sums for warm season was observed on June 12, 2005 (67.75 kJ/m^2), and minimum – on September 30, 2003 (3.66 kJ/m^2).

Monthly sums of the UV-*B* radiation for 2003–2007 are presented in Fig. 3*a*, and its seasonal sums are in Table 2.

It is seen that the flux of UV-*B* radiation under conditions of the Western Siberia changes during a year almost 70-fold, mainly due to the astronomical factor. Inter-annual variability of monthly sums observed in the considered period is also shown in Fig. 3*a* [$\delta = ((y_i - y_{mean})/y_{mean}) \cdot 100\%$], where y is the considered parameter. Variations in the income of UV-*B* radiation are quite large and can reach ± 25–45%. The income of UV-*B* radiation in warm season varies within ± 10% of the mean value. At the same time, the decrease in the radiation income (–17%) was recorded in May and June, 2007, and the maximal monthly sum for the considered period – in July, 2007. The variations in the cold season are more significant (± 45% in December). It should be noted that the income of ultraviolet radiation in April is practically constant, except for 2004.

The reasons, which could lead to such UV-*B* radiation variations can be changes in the TOC or AOT, as well as in optical thickness of clouds and cloud fraction. The aerosol content in the atmosphere in the considered period varied weakly, and the mean value of AOT at a wavelength of 550 nm was 0.173 ± 0.004.[16,17] The total ozone content and cloud fraction are principal factors among the aforementioned ones.

Yearly variations of TOC in the considered period show typical for Tomsk annual behavior with the maximum in February–March and the minimum in October–November. The maximal total cloud fraction is observed in autumn and winter, the repetition of cloudy weather is 75%, and the mean cloud fraction is 0.8. The continuous cloud cover (especially in lower level) is the main factor affecting the income of UV-*B* radiation.[18,19]

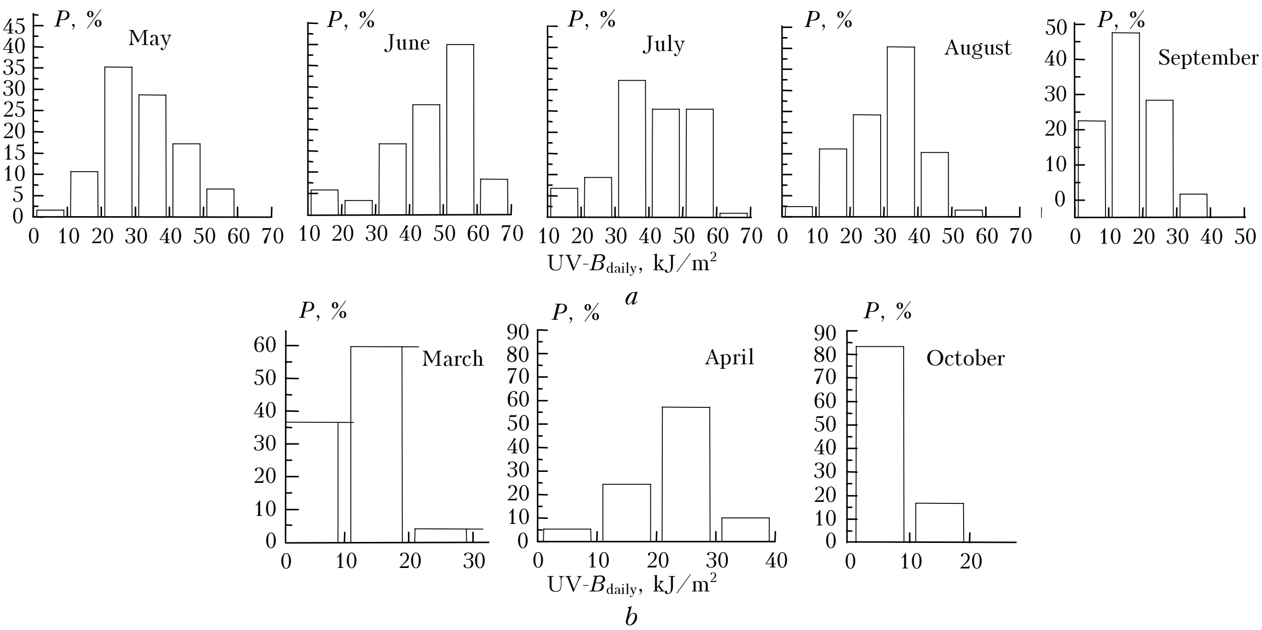

Fig. 2. Repetition of daily sums of UV-*B* radiation: warm season (*a*), cold season (*b*).

Table 1. Mean and extreme daily sums of UV-*B* radiation in 2003–2007, kJ/m^2

Month	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Average	1.541	4.300	11.739	21.456	32.050	46.724	40.320	30.724	16.163	6.464	2.573	1.314
Max	3.204	9.152	23.597	37.186	56.877	65.750	61.318	50.528	30.948	16.133	5.886	4.173
Min	0.517	1.315	4.458	6.448	5.981	12.259	11.236	8.754	3.663	0.317	0.874	0.358
Date of max	29 2003	28 2006	28 2003	29 2006	31 2006	**12** **2005**	13 2005	2 2004	6 2006	2 2005	24 2002	6 2002
Date of min	11 2005	10 2006	7 2004	8 2005	11 2006	14 2006	24 2006	29 2006	**30** **2003**	18 2003	29 2003	9 2006

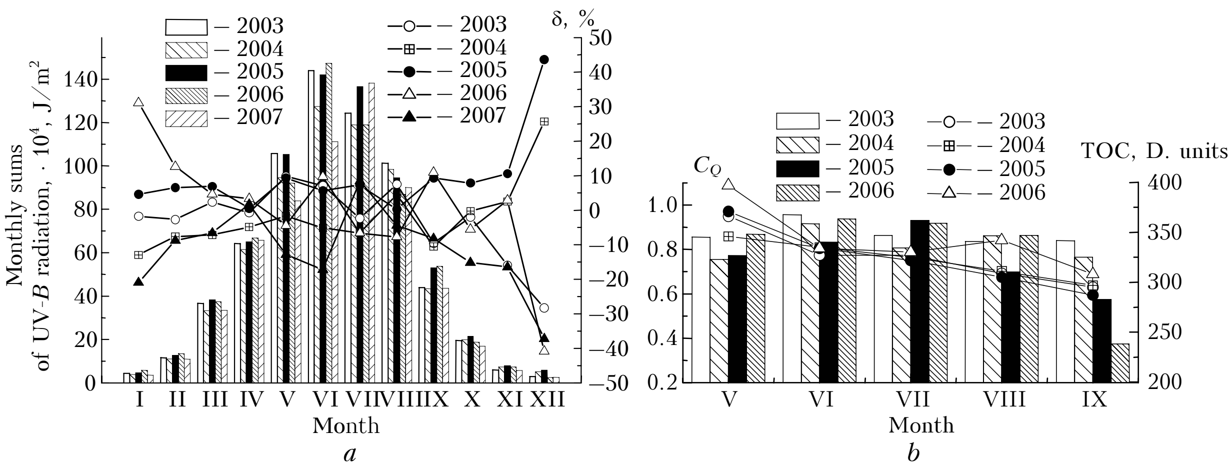

Fig. 3. Annual behavior of UV-*B* radiation.

Table 2. Seasonal sums of UV-*B* radiation, MJ/m^2

Year	Winter	Spring	Summer	Fall
2003	0.200254	2.064798	3.695229	0.692870
2004	0.177613	1.894151	3.448233	0.704733
2005	0.224228	2.051854	3.729654	0.822971
2006	0.250513	1.962814	3.521474	0.798616
2007	0.167585	1.830639	3.393237	0.661752

N o t e . For winter, December data are taken from the previous year, January and February data – from the current year.

We estimated anomalies in UV-*B* radiation for warm season (May–September), characterized by homogeneous conditions of the underlying surface:

1) through taking into account cloudiness, using the ratio $A_i(C_Q) = C_{Q\,i,j}/C_{Q\,i,j-1} - 1$, where $C_Q = Q/Q_0$ is the characteristic of UV-*B* radiation transmittance by clouds, Q is the UV-*B* radiation in the presence of clouds, and Q_0 is the UV-*B* radiation at clear sky and at the same Sun elevation as Q. The values of C_Q at the Sun elevation greater than 18° were used;

2) through taking into account the TOC, using the value of the radiation amplification factor (RAF) accepted to be 1.1; $A_i(\mathrm{TOC}) = \mathrm{TOC}_{i,j}^{\mathrm{RAF}} / \mathrm{TOC}_{i,j-1}^{\mathrm{RAF}} - 1$ [$A_i(C_Q)$, $A_i(\mathrm{TOC})$ is the variability of UV-*B* radiation due to cloud fraction and ozone, respectively, i is the month, j is the year].

Absolute values of the TOC (http:// toms.gsfc. nasa.gov/ozone/ozone_v8.html) and transmittance of UV-*B* radiation by clouds measured in the considered warm period are shown in Fig. 3*b*. It is seen that an increase of TOC was observed in May and August, 2006 as compared to previous years. The value of UV-*B* radiation transmittance by clouds has the maximum in June. High values of UV-*B* radiation in June, 2006 in comparison with July, 2005 are caused only by increase of C_Q (by 15%) due to decrease of the repetition of the dense cloudiness. Decrease of UV-*B* radiation in August, 2006 in comparison with August, 2005 is determined not only by increase of ozone (by 13%) but also by increase of C_Q (by 23%).

All aforementioned data were obtained with the pyranometer UVB-1, which provided for total over spectrum magnitude of the UV-*B* radiation. The spectral photometer Brewer in the instrumentation complex allowed the analysis of ultraviolet radiation variations in smaller intervals. These data are shown in Fig. 4, from which it follows that main variations in the UV-*B* radiation income in the annual behavior are observed in a wavelength range 295–310 nm, i.e., in the ozone absorption band. This confirms the importance of accounting for the total ozone content when interpreting the data on UV-*B* radiation. When considering this dynamics in different years, the effect of other factors becomes evident, therefore, this will be the subject of our further investigations.

Conclusions

Based on the analysis of variations of the income of UV-*B* radiation in Tomsk from the data of ground-based measurements in 2003–2007, the following conclusions can be drawn.

The warm season makes principal contribution into the annual sum of the UV-*B* radiation income with maximum in June; the variation coefficient of daily sums is 31%.

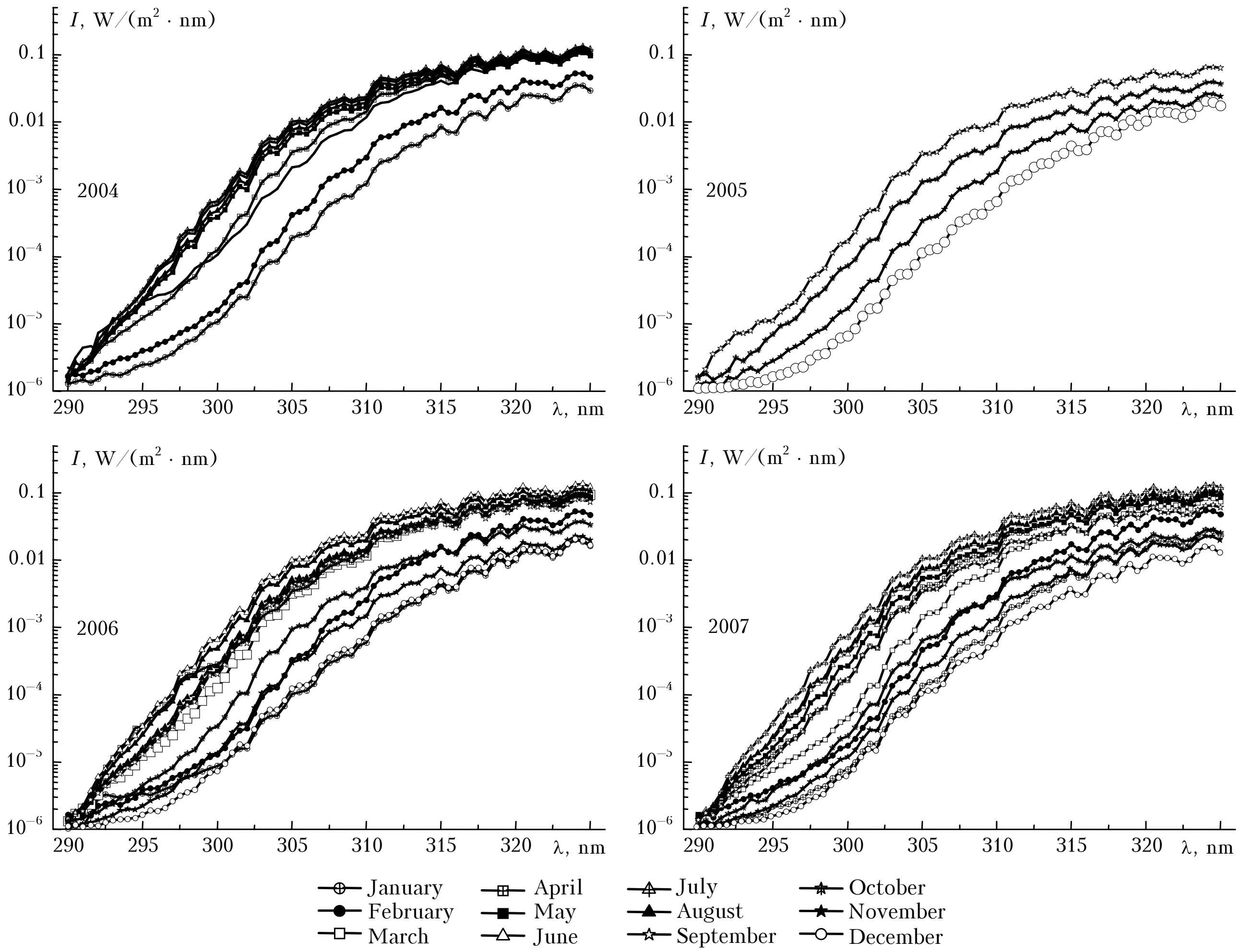

Fig. 4. Monthly mean distribution of UV-*B* radiation intensity in different years.

The annual behavior of the UV-*B* radiation is characterized by spring increase in the daily income in April with subsequent decrease to the beginning of May, as well as by the daily income oscillation with a period of 10–15 days with characteristic peaks (summer).

The inter-annual variability of the monthly income of UV-*B* radiation is quite large and can reach ± 25–45%.

The most variability in spectral behavior is observed within 295–310 nm (Haggins band), which varies from year to year.

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