Influence of the total ozone variations on the change of the UV-*B* solar radiation level

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In this paper we consider the influence of the total ozone variations on the change of the level of UV-*B* solar radiation at the ground in midlatitudes of the Northern hemisphere. We have analyzed the spectrum of radiation. It has been established that correlation between relative deviations of the diurnal doses of UV-*B* radiation and of the total ozone from the standard ones is statistically significant even for the confidence probability of 0.99. We have investigated the influence of smoothing by a sliding mean as well as of averaging over 10 days, a month, and a year on the level of correlation. It is shown that in studying the influence of solar UV-*B* radiation with the wavelengths shorter than 315 nm on the biosphere of the middle- and high-latitude regions with high total ozone content, the series of data on TOC can adequately substitute the missing data of long-term series radiation measurements.

Introduction

The level of solar radiation including the UV-*B* range (from 295 up to 315 nm) is known to have a pronounced annual behavior with the maximum in summer months in the Northern hemisphere. Clearly, biological objects that have formed the appropriate protective mechanisms in the course of evolution have adapted to these regular variations. At the same time, essential deviation from the standard, especially, during rather long-term time interval, can lead to a significant negative consequences. Increase in solar UV-*B* radiation dose leads to destruction of DNA, proteins and membranes of living cells and causes the changes in photosynthesis, growth, development, and morphogenesis, transport of substances and respiration of plants.[1–3]

Specifically biological activity of the UV radiation is caused by capture of the high-energy quantum by molecules that can lead to their excitation up to ionization and dissociation.[4] While affecting the Earth biosphere, the UV-*B* radiation is a climate-forming factor as well.

Nevertheless, up to the present time, there is a problem in acquiring valid data on solar UV radiation level from space-based platforms while the series of ground-based observations are often fragmentary, exceeding at best, a decade at some stations. For this reason, sometimes, the available data yield quite contradictory results.[5]

As known, long-term variations of the ground solar UV-*B* radiation level, under conditions of clean atmosphere, are largely controlled by the total ozone content (TOC), mainly due to absorption in the ozonosphere and the radiation attenuation increases with the decreasing wavelength of solar radiation.[5–7]

By absorbing solar UV radiation over the same wavelength range as the molecules of living cells, ozone preserves the living organisms from hard UV radiation. Its disturbing action can exceed the capabilities of protective mechanisms and lead to failure of the physiological, biochemical, and macromolecular processes. There is a connection between the changes in TOC and parameters characterizing biological objects. It is of principle importance that the monitoring of the TOC field has been performed for about half a century as compared with instrumented observations of the UV radiation and the obtained data on TOC are quite reliable.

Statement of the problem

Certainly, the ground UV-*B* radiation level depends not only on the state of the ozonosphere. An important role in formation of the UV radiation field belongs to the heliogeophysical and meteorological factors, in particular, to the atmospheric circulation processes, cloud and aerosol atmospheric condition, underlying surface albedo, continentality, orographic conditions, the Sun elevation angle.[5,8,9] However, data on the influence of total ozone oscillations on the variations of solar UV-*B* radiation caused by variations of the above-mentioned parameters are rather contradictory. Thus the studies of the UV-*B* radiation conducted from 1991 to 1997 in Saloniki (Greece; 40.6°N) showed that the long-term variations of solar radiation with the wavelengths shorter than 320 nm observed at the ground level were mainly governed by the total ozone.[5] However, according to data obtained during the campaign "Second experiment on studying the stratosphere of Arctic and midlatitudes of Europe (SESAME)" in March of 1995, the variation in erythemal radiation doses (300–320 nm), caused by overcast, can be compared with variations conditioned by TOC oscillations. The cloud effect for Saloniki is recognized to be the priority one and exceeds the effect of ozone[10] by three to four times.

As far as we relate the change in bioparameters not to variations of the UV-*B* radiation level directly,

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but to the TOC variations, it is necessary to know for sure, how valid this substitution is. The problem is in revealing the wavelength range of the solar UV-*B* radiation within which the effect of total ozone dominates, and in establishing the time interval, out of which the influence of such significant factors as overcast and atmospheric aerosol can be considered weak.

Such an approach is also conditioned by a certain resistance of most living organisms to the short-term attacks of the increased UV-*B* radiation doses. Therefore, only long-term attack of hard solar UV radiation being the consequence of cumulative effect[11] can produce irreversible effects. Simultaneously, the dependence of correlation should be established on the geographical factor, mainly, on the latitude determining both the spectral distribution of solar radiation and the state of the ozonosphere.

It should be shown finally that there is a high correlation between the TOC variations and variations of the biologically active UV-*B* radiation that allows using the long-term series of the TOC data as a valid parameter for investigation of the short-wave solar radiation effect on the change of bioparameters. In its turn, it will confirm the validity of reconstructions and forecasts of the changes in the ozonosphere based on data on bioindicators.

Selecting the observation series. Analysis of the UV radiation spectra

In our investigation we have used primarily the biological objects from the regions located in the middle and subarctic latitudes of the Northern hemisphere. Unfortunately, there is no any station in Russia, where rather long-term continuous series of observations on solar UV-*B*-range radiation were carried out. Therefore, to solve this problem, we have chosen the series of ground observations of the daily radiation doses (D) at $\lambda = 295$, 300, 305, 310, and 315 nm compiled in Edmonton (Canada; 53.55°N; 114.10°W) and Kagoshima (Japan; 31.58°N; 130.565°E)[12] that quite cardinally different in their latitude, continentality, and climate conditions. Edmonton was chosen because geographically it is similar to regions in the South of Western Siberia. A series of TOC diurnal values for Edmonton was obtained from the TOMS data.[13] For Kagoshima, we have used the diurnal ground TOC measurement data.[12] In order to carry out the correlation analysis using the Origin software, the time series have been formed for Edmonton and Kagoshima covering the periods from July 25, 1996 to December 31, 2004 and from January 01, 1991 to December 31, 2001, respectively.

The oscillations of both TOC and solar ground UV-*B*-radiation dose have a pronounced annual behavior that was determined from the average daily data by use of the FFT-filter smoothing. Figure 1 shows, as an example, the annual mean behaviors, or the climatic norm of the TOC and UV-*B* radiation at 305-nm wavelength for Edmonton and Kagoshima over the observation period from July 25, 1996 to December 31, 2001 with the well seen nonsynchronism. Besides, one can clearly see the difference between the total ozone of the two climatic zones, especially in winter–spring months (Fig. 1*a*).

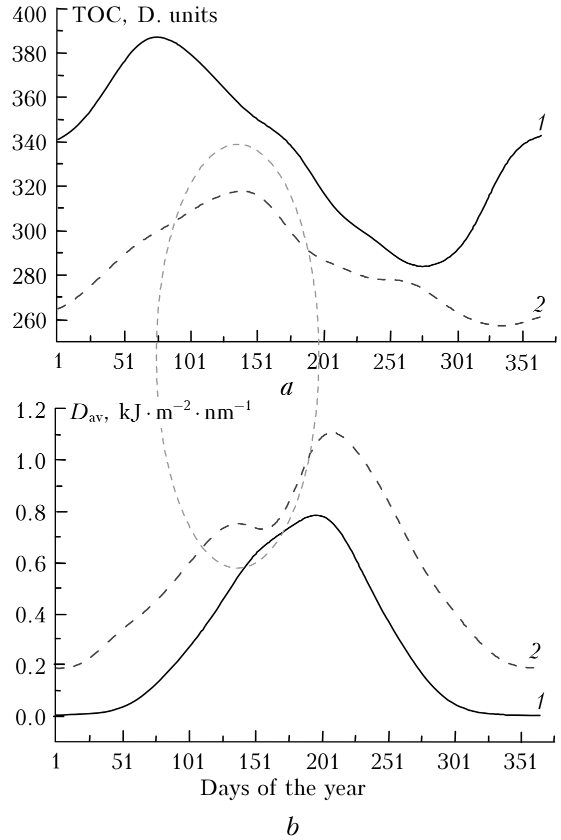

Fig. 1. Annual mean variations of TOC and UV-*B* radiation at $\lambda = 305$ nm over the period from July 25, 1996 to December 31, 2001 for Edmonton (curve *1*) and for Kagoshima (curve *2*). The area corresponding to the maximum level of the total ozone in Kagoshima is marked with oval.

Ozone content in Edmonton is by 18.6%, on the average, higher than in Kagoshima. A significant difference connected with latitude regional features is also observed in situation of the TOC climatic maxima. The total ozone maximum in Edmonton occurs in March–April, while in Kagoshima from the middle of April until the middle of June.

The radiation spectrum also depends on the observation site. However, the positions of maxima in the annual behaviors coincide, since the highest values of diurnal radiation doses are observed irrespective of radiation wavelength and latitude location during summer solstice (Fig. 1*b*). The peculiarity in the annual mean radiation dose (curve *2* outlined area) is caused by the climatic ozone maximum characteristic of this period.

Table 1 and Fig. 2 present the results of quantitative analysis of the spectrum of the solar UV-*B* radiation. Table 1 shows the daily mean total radiation doses during the year and the periods from June–August until December–February at the wavelengths of 295, 300, 305, 310, 315 nm, and a fraction of radiation energy corresponding to every wavelength.

Table 1. Daily mean total doses of UV-*B* radiation for summer (June–August) and winter (December–February) and the fraction of radiation at the particular wavelengths

Observation period	D, kJ·m^{-2}·nm^{-1}			Wavelength, nm	Radiation fraction, %		
	Year	Summer	Winter		Year	Summer	Winter
Edmonton							
July 25, 1996 – December 31, 2001	3.4238	7.0554	0.5587	295	0.008	0.013	–
				300	0.456	0.653	0.028
				305	8.150	9.836	2.098
				310	21.362	22.608	14.271
				315	70.015	66.891	83.603
Kagoshima							
July 25, 1996 – December 31, 2001	4.8831	7.2341	2.5511	295	0.056	0.0842	0.016
				300	1.032	1.332	0.525
				305	11.797	13.211	8.999
				310	23.380	23.826	22.375
				315	63.735	61.547	68.085

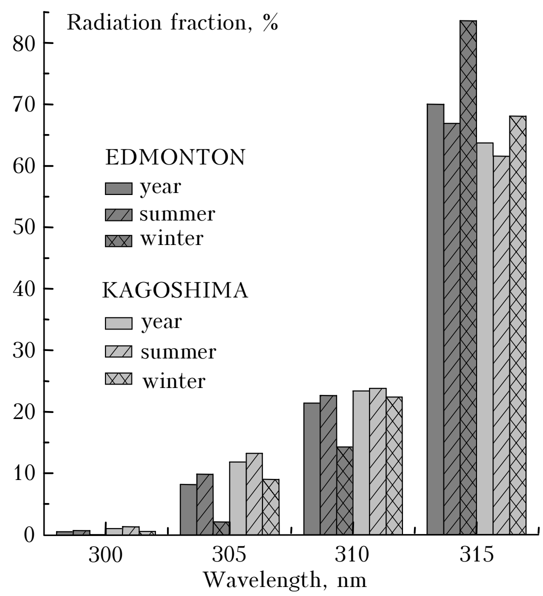

Fig. 2. Wavelengths distribution of the daily mean dose of solar UV-*B* radiation for summer (June–August) and winter (December–February) over the observation period from July 25, 1996 to December 31, 2001.

The histogram in Fig. 2 demonstrates the differences in spectra of the solar UV-*B* radiation and energy redistribution depending on the latitude and season of the year. The most considerable changes are typical for the energy spectrum at higher latitudes.

The main difference between spectra of solar radiation in the regions studied takes place mainly in winter. On the whole for a year, the total mean daily dose in Edmonton is by 42.6% lower than in Kagoshima. If the difference is minimum in summer and makes 2.5%, in winter it reaches 356.6%.

In summer in Edmonton, a fraction of UV radiation at the wavelength of 295 nm makes only 0.008% of the total dose, and from the middle of October and until the end of February it was not recorded at all, but the fraction of radiation at the wavelength of 315 nm considerably increases. In Kagoshima, the fraction of radiation at the wavelength of 295 nm is also negligible and makes about 0.084% of the total sum in summer and 0.016% in winter. Although, the main fraction of solar radiation of the UV-*B* range falls in the wavelength of 315 nm, total radiation dose at the wavelengths of 300, 305 and 310 nm is rather significant and makes about 30.0% of the daily mean total radiation dose in Edmonton and 36.2% in Kagoshima. In summer, this fraction increases making already 33.1 and 38.4%, respectively. At the same time, the negligibly low fraction of radiation at the wavelength of 295 nm both over the year and over a season, even for low latitudes of the midlatitudes allows one to ignore the radiation at this wavelength. Note that irrespective of the region, the daily mean spectra of radiation over a year are close to these in summer.

Results of correlation analysis

In analyzing the influence of daily and monthly mean TOC oscillations on the change of the UV-*B* radiation the annual behavior was eliminated, because of the essential time shift, from the considered series, which then were normalized and expressed in relative units (relative deviations) by the formula

$$I_i(t) = \left[X_i(t) - \bar{X}_i(t)\right] / \bar{X}_i(t), \qquad (1)$$

where $X_i(t)$ is the current series value, $\bar{X}_i(t)$ is the climatic norm corresponding to the given value.

Estimation of the statistical significance was made using the Student's t-criterion.

Results of correlation analysis of the series of relative deviations of the daily doses of the UV-*B* radiation at the wavelengths of 300, 305, 310, and 315 nm, as well as of the TOC are presented in Table 2.

Correlation coefficients (R) at the confidence level $\beta = 0.95$ are given for the entire observation period, warm (April–September) and cold half-years (October–March). Table 2 points out the confidence intervals of correlation coefficients (Δr) and the values of R necessary for achieving the statistical significance at the level of 0.95, the confidence level ($r_{\min}$), for the corresponding sample (N). For $N > 50$, the confidence interval of R was calculated by the formula

$$\Delta r = t_\beta \frac{1 - r^2}{\sqrt{N}}, \quad (2)$$

where the quantile $t_\beta = 1.96$ (for $\beta = 0.95$).[14]

Inessential difference between the time series under investigation for the observation period and number of data allows comparing the results obtained for the chosen regions.

The results obtained show very high negative correlation between the series of relative deviation in daily TOC and UV-*B* radiation values in Edmonton at all wavelengths for all periods. Figure 3 presents the time series of relative deviations of the UV radiation at the wavelength of 305 nm (Fig. 3*a*) and TOC (Fig. 3*b*).

Considerable short-term bursts of UV radiation doses have been recorded in winter–spring period. Their occurrence is always connected with the short-term decrease in the total ozone, which could take place due to the winter–spring changes in the stratosphere.

For Kagoshima, in the wavelength interval from 300 to 310 nm, the correlation between the series is also quite high, essentially exceeding $r_{\min}$, although at the wavelength of 315 nm, $|R| < r_{\min}$ through the entire year and in the warm half-year as well. Irrespective of latitude, the values of R in the warm half-year at the corresponding wavelength are somewhat lower in the absolute value, than in the cold one. Another situation is observed only for Edmonton at the wavelength of 300 nm, where $|R|$ is higher in the warm half-year that may be connected with the measurement errors in the short-wave UV radiation range in winter. On the whole, as far as it moves into the long-wave region, we can observe the decrease of the correlation between the series analyzed.

In climatology, in investigating the correlation between the parameters, the methods of series smoothing are widely used, in particular, the method of sliding average, which is a filter allowing to suppress the high-frequency oscillations while to isolate the long-period ones better. Use of the sliding average gives a chance for revealing the main tendencies in the series under investigation.[15] Since there is a considerable correlation between the TOC and UV-*B* radiation series analyzed, this technique would allow reducing the factor of aerosol and cloud effect on variations of the UV-*B* radiation. However, in this case, it is necessary to solve the problem on the proper choice of a smoothing interval.

The smoothing procedure over the range of 300–315 nm yields different results directly dependent on the region. Figure 4 presents variation in correlation coefficient module ($|R|$) as a function of the smoothing interval for the entire observation period. Change in $|R|$ for the warm and cold half-years in Edmonton and in Kagoshima is presented in Fig. 5.

Irrespective of the region, the smoothing over three and five points leads to the increase in absolute value of R in both warm and cold periods, moreover, $|R|$ for Edmonton series remains higher by the module than that in Kagoshima.

Table 2. Correlation coefficients and confidence intervals of the series of relative deviations of the daily values of the UV-*B* radiation dose and TOC

Edmonton ($R \pm \Delta r_{0.95}$)			
Wavelength, nm	Full period (07.25.96–12.31.04)	Warm half-year (April–September)	Cold half-year (October–March)
300	**−0.673 ± 0.020**	**−0.743 ± 0.023**	**−0.646 ± 0.030**
305	**−0.666 ± 0.020**	**−0.611 ± 0.033**	**−0.713 ± 0.025**
310	**−0.548 ± 0.025**	**−0.473 ± 0.041**	**−0.617 ± 0.031**
315	**−0.377 ± 0.032**	**−0.356 ± 0.046**	**−0.415 ± 0.042**
N	2896	1410	1486
$(r_{\min})_{0.95}$	−0.094	−0.098	−0.097
$(r_{\min})_{0.99}$	−0.097	−0.099	−0.099
Kagoshima ($R \pm \Delta r_{0.95}$)			
Wavelength, nm	Full period (01.01.91–12.31.01)	Warm half-year (April–September)	Cold half-year (October–March)
300	**−0.488 ± 0.025**	**−0.400 ± 0.039**	**−0.565 ± 0.031**
305	**−0.310 ± 0.029**	**−0.250 ± 0.044**	**−0.368 ± 0.039**
310	**−0.179 ± 0.032**	**−0.148 ± 0.046**	**−0.210 ± 0.043**
315	−0.084 ± 0.032*	−0.070 ± 0.047*	**−0.098 ± 0.045**
N	3613	1753	1860
$(r_{\min})_{0.95}$	−0.092	−0.097	−0.097
$(r_{\min})_{0.99}$	−0.096	−0.098	−0.098

N o t e . Statistically significant correlation coefficients for the confidence probability equal to 0.95 are printed in a bold type. The values of correlation coefficients below $r_{\min}$ for the confidence probability equal 0.99 are denoted by * symbol.

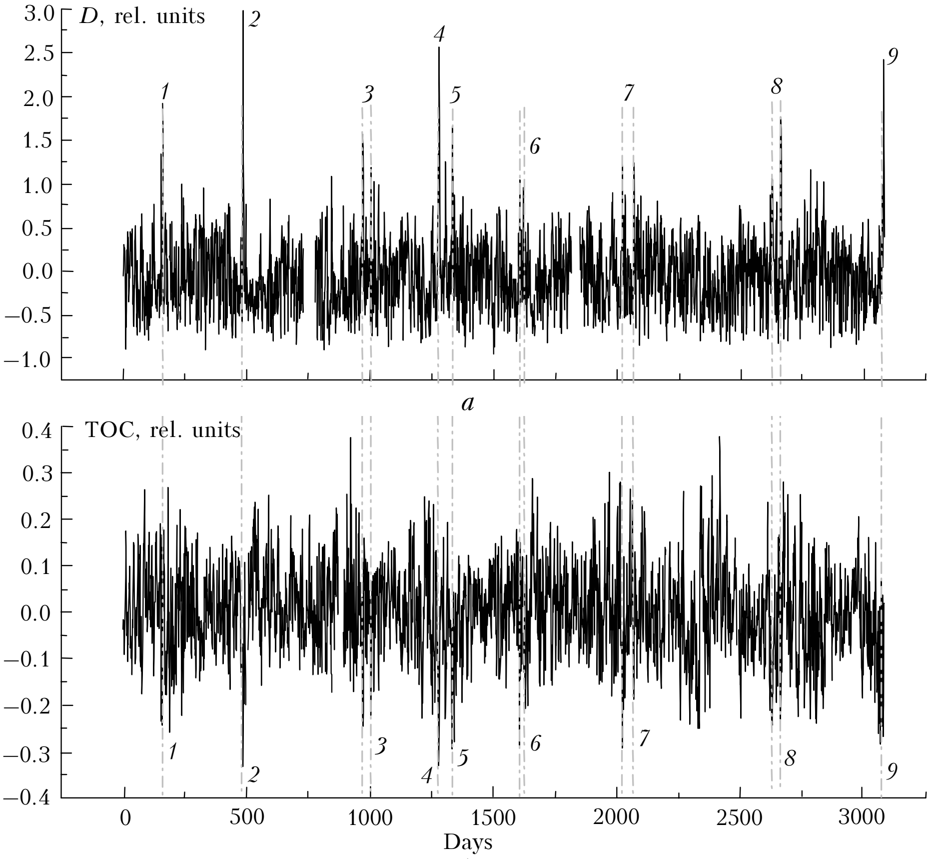

Fig. 3. Time series of relative deviations of the daily values of UV-B radiation dose at the wavelength of 305 nm and of the total ozone in Edmonton.

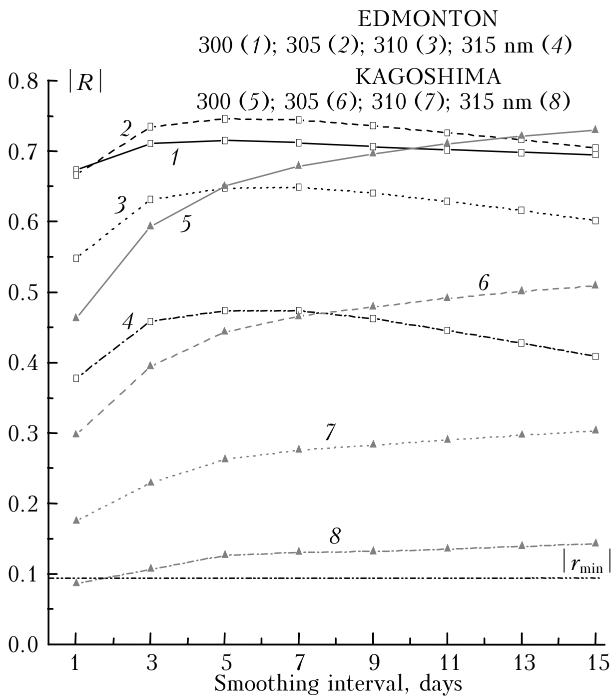

Fig. 4. Dependence of $|R|$ of series of relative deviations for the diurnal values of UV-B radiation dose at the wavelength of 300, 305, 310, 315 nm and of TOC for Edmonton and Kagoshima on the smoothing interval for the entire observation periods.

The correlation coefficients of full normalized TOC and D series for Edmonton increase by the module if smoothed over 3 to 7 points (at the wavelength of 300 nm – over 3 to 5 points) (see Fig. 4). Further extension of the smoothing interval leads to the reduction of correlation. For the warm period (Fig. 5*a*), the smoothing interval extension leads to the increase in $|R|$. Some decrease in correlation in smoothing over more than five points is observed only at the wavelength of 315 nm. For the cold half-year, smoothing over three or five points leads to the correlation increase, however, smoothing over seven and more points causes the gradual reduction in $|R|$, although, certainly, its values remain very high.

Thus, reduction in $|R|$ if smoothing by sliding average of the full series of TOC deviations and radiation dose over more than seven points is connected with the decrease in correlation level in cold half-year. Note that for the cold time of a year, the smoothing procedure almost does not affect $|R|$ for the series of TOC deviation and radiation dose at $\lambda = 300$ nm.

For Kagoshima, the difference in R absolute values between the cold and warm half-years (Fig. 5*b*) essentially reduces owing to the increase in wavelength. This may be connected with reduction in TOC effect on radiation level over the range from 310 to 315 nm and amplification of aerosol–cloud effect. The $|R|$ of TOC relative deviations and UV-B

radiation doses over the range from 300 to 315 nm increases depending on expansion of the smoothing interval both for the full observation period and for the warm and cold half-years (see Figs. 4 and 5*b*). For the whole observation period and for the warm half-year, when smoothing by three points at λ = 315 nm, correlation of normalized TOC and D series exceeds r_{min}, moreover, $|R|$ in warm time of the year becomes even higher than in cold period. However, smoothing by more than nine or eleven points already does not lead to the significant correlation increase.

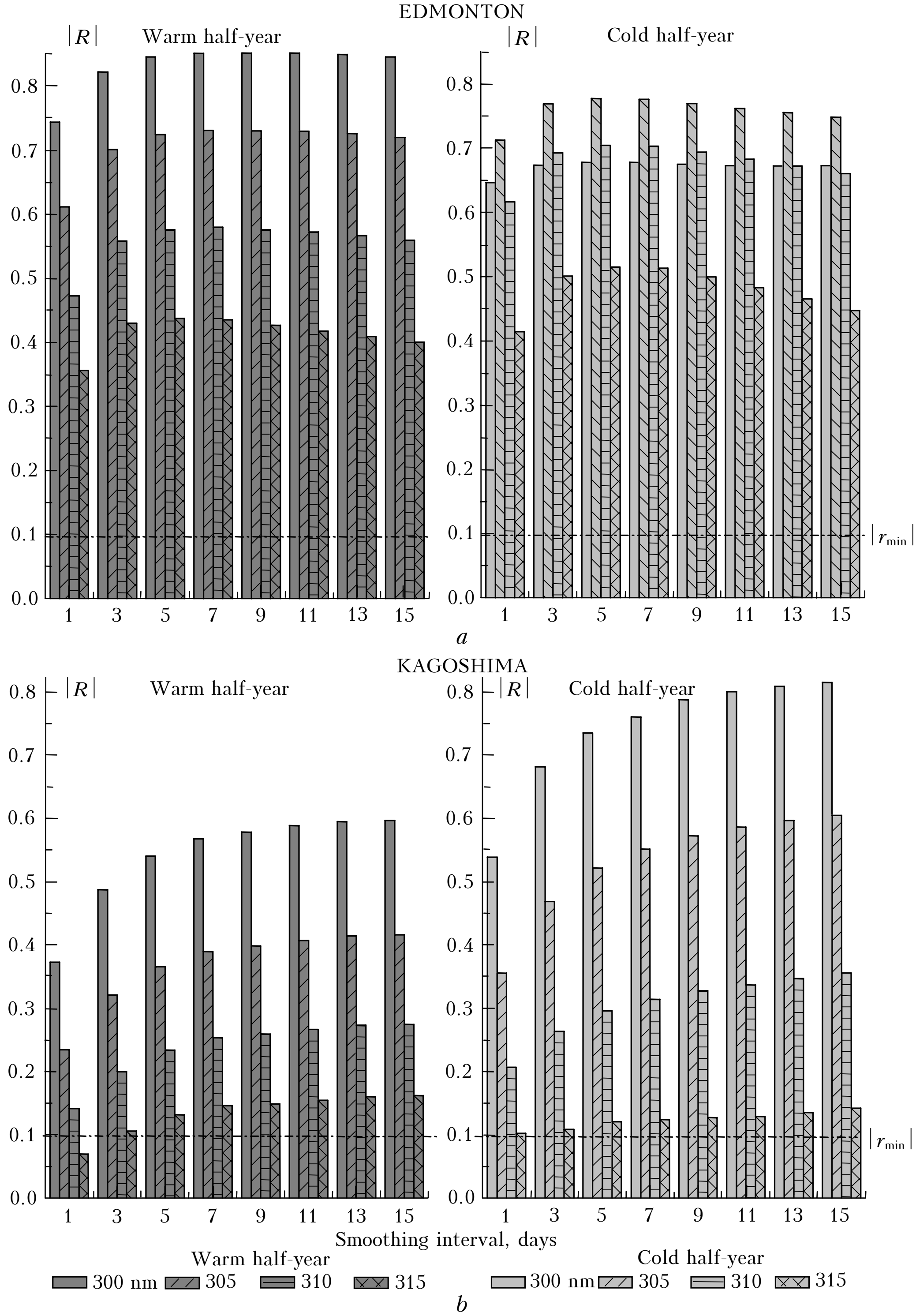

Fig. 5. Change in $|R|$ for the series of normalized deviations in daily values of UV-*B* radiation dose at the wavelength of 300, 305, 310, and 315 nm and TOC in Edmonton and Kagoshima depending on the smoothing interval for warm and cold half-years.

Therefore, the smoothing over five or seven days in the correlation analysis is optimal for the regions located at the latitude of Edmonton, while for Kagoshima the optimum is from nine to eleven days. Just these time intervals correspond to the periods of synoptic scale oscillations, cyclones, anticyclones, and fronts.[16] Averaging and, hereby, weakening the influence of meteorological processes on the ground UV radiation, the procedure of smoothing over the synoptic period allows one to reveal more significant correlation between variations of the UV-B radiation and ozonosphere that is especially important for the regions with relatively low total ozone and high radiation dose.

Let us consider the correlation between the series of normalized deviation averaged over 10 days (the period of the order of the synoptic scale) of daily observations, normalized series of monthly mean deviations (over the entire observation period, warm and cold half-years), annual mean TOC values, and corresponding series of the UV-B radiation dose.

The results of this analysis are presented in Table 3.

To determine the confidence interval at $N < 50$ a corrected formula was used

$$\Delta r = t_{\beta} \frac{1 - r^2}{\sqrt{N - 2}}. \quad (3)$$

For the entire observation period when averaging the series of daily relative deviations of TOC and UV-B radiation dose over 10 days, very high negative correlation is observed, although, some regional features, certainly, can take place and absolute values of R for Kagoshima are somewhat lower, than for Edmonton. The correlation decreases with the increasing wavelength that is more clearly seen in southern latitudes. Thus, the influence of TOC variations on the change in UV-B radiation, if averaged over the synoptic period, is the major factor in the regions of high latitudes and, at least, over the range of 300–305 nm, in low latitudes of the temperate zone of the Northern hemisphere.

Largely, the latitude dependence of R is seen for the normalized series of monthly mean TOC, as well as for the annual mean values of the UV-B radiation dose. The northern regions of temperate zone conserve high negative correlation between both the series of monthly mean relative deviations, and annual mean data, although, the dependence of R on wavelength is also clearly seen, $|R|$ decreases with the increasing wavelength.

The same regularity is also observed in southern regions. However, in the case of averaging the TOC and D series over a month and a year as well as for the normalized series of daily data, relatively low TOC weakens its influence on the UV radiation level at the wavelengths longer than 310 nm. Therefore, for radiation at the wavelengths of 315 nm, and for the warm half-year for the case of averaging over a month at the wavelengths 310 nm, $|R| < r_{\min}$. It is worthy to note that because of the complete lack of data on radiation dose of UV-B range during two months (June and July) the year of 1993 is omitted from analysis of the time series of the annual average values for Kagoshima. An attempt to calculate the annual mean values of the investigated parameters over 10 months leads to the strong distortion of the series, since for the given region, this period corresponds to maximum UV-B radiation doses, and also the climatic TOC maximum occurs in June.

Table 3. Correlation coefficients and confidence intervals for the case of series (averaged over 10 days) of relative deviations of the daily, monthly mean, and annual mean values of TOC and UV-*B* radiation dose

Edmonton ($R \pm \Delta r_{0.95}$)					
Wavelength, nm	Averaging by 10 days (07.25.96–12.31.04)	Averaging by month (08.1996–12.2004)			Averaging by year (1997–2004)
		Full period	Warm half-year	Cold half-year	
300	**−0.734 ± 0.053**	**−0.76 ± 0.08**	**−0.73 ± 0.13**	**−0.77 ± 0.11**	**−0.80 ± 0.29***
305	**−0.740 ± 0.052**	**−0.68 ± 0.11**	**−0.61 ± 0.18**	**−0.70 ± 0.14**	**−0.81 ± 0.28***
310	**−0.639 ± 0.068**	**−0.55 ± 0.14**	**−0.48 ± 0.22**	**−0.57 ± 0.19**	**−0.81 ± 0.28***
315	**−0.459 ± 0.091**	**−0.30 ± 0.18**	**−0.32 ± 0.26***	**−0.30 ± 0.25***	**−0.77 ± 0.33***
N	287	100	49	51	8
$(r_{\min})_{0.95}$	−0.122	−0.20	−0.28	−0.28	−0.70
$(r_{\min})_{0.99}$	−0.152	−0.26	−0.37	−0.36	−0.82
Kagoshima ($R \pm \Delta r_{0.95}$)					
Wavelength, nm	Averaging by 10 days (01.01.91–12.31.01)	Averaging by month (01.1991–12.2001)			Averaging by year (1991–1992, 1994–2001)
		Full period	Warm half-year	Cold half-year	
300	**−0.720 ± 0.050**	**−0.73 ± 0.08**	**−0.56 ± 0.17**	**−0.81 ± 0.08**	**−0.73 ± 0.31***
305	**−0.499 ± 0.077**	**−0.50 ± 0.13**	**−0.38 ± 0.21**	**−0.59 ± 0.16**	**−0.69 ± 0.34***
310	**−0.296 ± 0.094**	**−0.28 ± 0.16**	−0.24 ± 0.23*	**−0.34 ± 0.21**	**−0.64 ± 0.41***
315	**−0.140 ± 0.101***	−0.12 ± 0.17*	−0.14 ± 0.24*	−0.12 ± 0.24*	−0.60 ± 0.44*
N	360	130	64	66	10
$(r_{\min})_{0.95}$	−0.105	−0.17	−0.25	−0.24	−0.62
$(r_{\min})_{0.99}$	−0.141	−0.23	−0.32	−0.32	−0.75

See note to Table 2.

Let us note that irrespective of the region for the series of relative deviations of the monthly mean values of TOC and radiation dose, the absolute values of R in cold half-year remain higher for the same wavelength, except for the wavelengths of 315 nm, than in the warm one.

Conclusion

It has been established that the share of biologically active radiation of the UV-B range makes up about 30.0 to 38.4% depending on the geographical region and time of a year. The fraction of radiation at the wavelength of 295 nm is negligible, and in the northern latitudes during the cold half-year is not recorded at all.

It is shown that in regions with high total ozone statistically high negative correlation exists between the series of relative deviations of the diurnal values of TOC and UV-B radiation dose at the wavelengths shorter than 315 nm, even for a confidence probability equal to 0.99. For the regions in the southern latitudes with lower total ozone that high correlation exists between the series of normalized TOC and solar UV radiation dose at the wavelengths shorter than 310 nm.

Radiation at the wavelengths of 315 nm is weaker absorbed by the ozonosphere, and the statistical correlation between series of TOC and dose values considerably reduces. Radiation dose variability at this wavelength is connected with the seasonal behavior and depends on the geographical location of the region and its latitude, as well as on the aerosol–cloud state of the atmosphere and the surface albedo.

Application of smoothing procedure and averaging over a synoptic period about 10 days considerably amplifies connection of the oscillations of the ozonosphere with the change in the UV-B radiation that is of great importance for the regions with low TOC.

For the series of annual mean and normalized monthly mean TOC values and UV-B radiation dose, the statistically high negative correlation (at least, for the confidence level $\beta = 0.95$) remains the same for the wavelengths shorter than 315 nm in the regions of temperate zone with high total ozone and at the wavelengths shorter than 310 nm in regions with relatively low TOC.

Thus, in studying the effect of UV-B radiation with the wavelengths shorter than 315 nm on biological objects in the regions of middle and high latitudes with high total ozone level, time series of TOC values can certainly be used as an adequate substitute, when no reliable long series of radiation observations are available.

Acknowledgments

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