UV–RADIATION TRENDS IN MOSCOW

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Variability of incoming UV–radiation ($\lambda \le 380$ nm) for a year as a whole and separately for warm (V–IX) and cold (XI–III) periods is considered based on data of ground measurements (1968–1993). The variability trends are estimated. Correlation between the incoming UV–radiation and total and low cloudiness is analyzed.

Natural ultraviolet (UV) radiation is an important factor of the environment affecting the biosphere. Owing to large quantum energy this radiation is of high photobiological and photochemical activities. The influence of UV–radiation on a living organism has many aspects. UV–radiation reaching the Earth influences beneficially in human tolerance dose. However, the UV–radiation excess leads to very serious diseases.[5,11,13,17] Large doses of UV–radiation is unfavorable for plants and water ecological systems and also result in the increase of smog repetition in urban areas and influences negatively the building materials and structures.[5,11,13,17] Therefore, the investigation of long–term variations in the incoming UV–radiation is of great interest. However, up to now, at the territory of Russia there are no networks for measuring UV–radiation.

Since 1967 at the meteorological observatory of the department of meteorology and climatology of Geographic faculty of Moscow State University continuous recording of total and diffuse radiation is being done in the entire UV spectral region ($\lambda \le 380$ nm) using equipment developed at the observatory.[14] The measurement error was about 10%.

Let us consider the long–term variations in the incoming UV–radiation for 1968–1993 period. Table I gives the mean values (M) and rms deviations (σ) for annual sums of total (Q_{UV}), diffuse (D_{UV}), and direct UV–radiation at a horizontal surface (S_{UV}) as well as for UV–radiation sums over the warm (May to September) and cold (November–March) periods. This table presents the data for a series of meteorological situations affecting the income at UV–radiation. The values of total (N_{tc}) and lower (N_{lc}) cloudiness were obtained on the basis of every hour observations during the daytime.

TABLE I.

Characteristic	Year		V–IX		XI–III	
	M	σ	M	σ	M	σ
Q_{UV}, MJ/m^2	152.4	9.8	108.1	7.3	23.0	2.9
D_{UV}, MJ/m^2	127.6	8.6	87.8	6.1	21.3	2.5
S_{UV}, MJ/m^2	24.8	2.8	20.3	2.7	1.7	0.5
N_{tc}, cover index	8.0	0.4	7.4	0.5	8.5	0.6
N_{lc}, cover index	6.1	0.5	5.2	0.7	6.8	0.7
U, %	37.6	2.9	48.8	4.8	20.7	4.2
$\tau_a(\lambda_0)$	0.24	0.05	0.25	0.05	0.18	0.07

The values of the aerosol optical thickness for a wavelength of $\lambda = 550$ nm were calculated by Abakumova and Yarkho[3] based on the data of direct integrated radiation using the technique described in the paper by Tarasova and Yarkho.[12] The calculations were carried out only for the cases when there was no cloudiness across the solar disk and in the space about the sun with the radius of 5°. Thus, data on the aerosol optical depth characterize the conditions of atmospheric turbidity only during fine days and days with low cloudiness.

Variations of the total ozone content do not practically affect the incoming radiation in the entire UV–region of solar spectrum since the contribution of the short–wave UV radiation with strong ozone influence is very small. Based on model calculations[15] with variation of the total ozone content from 0.20 up to 0.50 atm·cm the total UV–radiation at $\lambda \le 380$ nm, depending on the solar elevation angle, decreases by 6–7%.

As can be seen from Table I, the variability of annual sums of total UV–radiation is insignificant, the variation coefficient $V = M/\sigma \cdot 100\% = 6\%$, in the warm season $V = 7\%$, and in the cold season $V = 13\%$. The incoming direct UV–radiation is characterized by a greater variability: during the warm period $V = 13\%$ and during the cold period V is almost 30%.

Both for the overall and lower cloudiness the largest variability is observed during the warm period. In this case for lower cloudiness the variability is much higher ($V = 13\%$). In contrast to cloudiness the relative duration of solar radiance U varies strongly from year to year during the cold period (in XI–III $V = 20\%$ and in V–IX $V = 10\%$).

The aerosol optical depth variations are the largest from year to year. The variation coefficient for $\tau_a(\lambda_0)$ during warm period is 20% and during cold period increases up to 40%. Such a large variability of $\tau_a(\lambda_0)$ is substantially due to the influence of volcanic eruptions.[3,4]

Figure 1 shows the annual variations of parameters given in Table I. As follows from the figure, we do not observe a good fit of maximum and minimum sums of UV–radiation at minimum and maximum amounts of the total and lower cloudiness. This is due to the fact that the incoming UV–radiation is determined not only by the number of clouds but also by the combination of clouds of different levels, the degree of shading of solar disk and optical depth of the clouds. The atmospheric turbidity is also very important. For example, during warm period of 1972 we observed minimum values of the total and low cloudiness. However, the sums of direct UV–radiation turned out to be sufficiently low – 20.7 MJ/m^2 (maximum – 27.2 in 1975 and minimum – 15.4 MJ/m^2 in 1987). This is explained by a strong extinction of direct UV–radiation during smoke haze caused by forest and peat fires.[2] In this case the sums of scattered UV–radiation are somewhat reduced due to aerosol absorption.

Nevertheless, we observed a close linear connection between the incoming UV–radiation and the cloud amount

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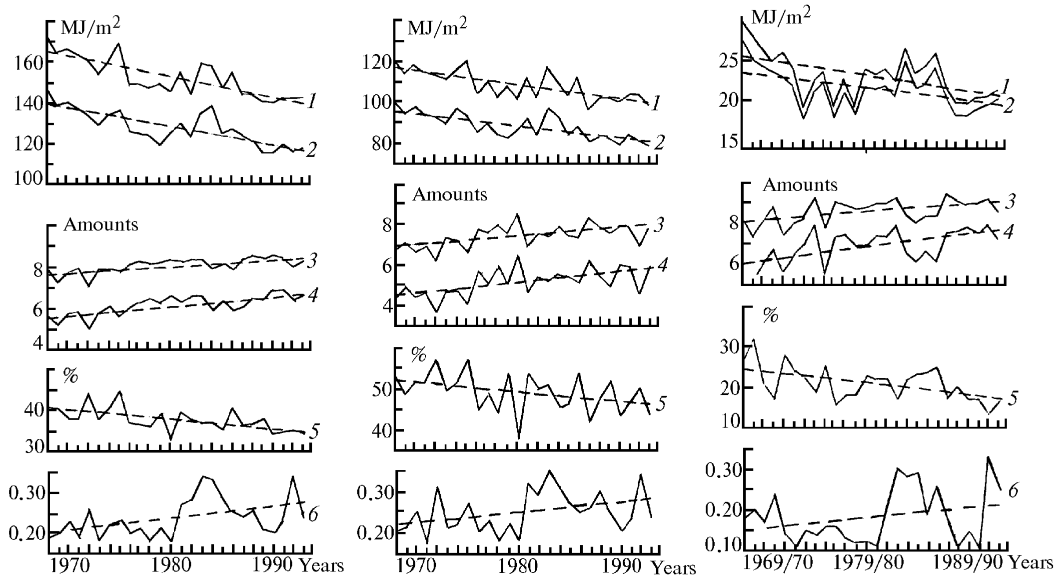
(total and especially lower cloudiness, Table II). Table II gives also the values of H:

$$H = |r| \sqrt{n - 1},$$

where n is the number of years of observations. Significance of the correlation coefficient r was checked by comparing the values of H obtained with their critical values for $n = 26$ at a given reliability of the derivation of P (Ref. 10, see Table II). The H values for the correlation coefficient between the incoming total UV–radiation and the amount of lower cloudiness far exceed the critical values of H even for $P = 0.999$.



a *b* *c*

FIG. 1. Variations in the sums of total (1), scattered (2) UV–radiation, mean amount of total (3) and lower (4) cloudiness during daytime, relative duration of Sun shine (5) and aerosol optical depth of the atmosphere at λ = 550 nm *(6) as a whole for one year – a, during warm period (V–IX) – b, and during cold period (XI–III) – c.*

TABLE II. Coefficients of correlation r between the incoming direct S'_{UV}, scattered D_{UV}, and total Q_{UV} UV–radiation for one year, during warm and cold periods and meteorological characteristics of the atmosphere (1968–1993).*

Period	Type of radiation	Characteristics					
		N_{tc}		N_{lc}		U	
		r	H	r	H	r	H
Year	Q_{UV}	– 0.72	3.60	– 0.77	3.85	0.74	3.70
	D_{UV}	– 0.67	3.35	– 0.72	3.60	0.61	3.05
	S'_{UV}	– 0.44	2.20	– 0.45	2.25	0.71	3.55
May–September	Q_{UV}	– 0.76	3.80	– 0.77	3.85	0.73	3.65
	D_{UV}	– 0.60	3.00	– 0.62	3.10	0.53	2.65
	S'_{UV}	– 0.66	3.30	– 0.67	3.35	0.76	3.80
November–March	Q_{UV}	– 0.59	2.95	– 0.75	3.75	0.71	3.55
	D_{UV}	– 0.54	2.70	– 0.73	3.65	0.64	3.20
	S'_{UV}	– 0.58	2.90	– 0.56	2.80	0.75	3.75

* In the case of October to March period the reading begins from the cold period of 1967–1968. For $n = 26$ at $P = 0.95$ $H = 1.941$; at $P = 0.99$ $H = 2.479$; at $P = 0.999$ $H = 3.037$.

In contrast to the integral flux[1] we observe sufficiently high negative correlation coefficients between the incoming scattered UV–radiation and the cloud amount. This is accounted for by the different influence of cloudiness on the value of scattered UV– and integrated radiation. Based on the data from Ref. 6 with the availability of cloudiness the daily sums of scattered integrated radiation increase on the average by 20–50% as compared to clear days and only at overcast we observe the 20–30% decrease of daily sums of scattered radiation. In the UV spectral range λ ≤ 380 nm the small growth in daily sums of scattered radiation is observed only in summer months at daily average cloudiness of 2–3 cloud amount and the losses at solid cloud cover of lower level are 50–60%.

TABLE III. Coefficients of correlation between the incoming total UV–radiation for each month and the meteorological characteristics of the atmosphere.

Months	N_{tc}		N_{lc}		U	
	r	H	r	H	r	H
January	– 0.70	3.50	– 0.74	3.70	0.54	2.70
February	– 0.75	3.75	– 0.85	4.25	0.84	4.20
March	– 0.67	3.35	– 0.80	4.00	0.67	3.35
April	– 0.78	3.90	– 0.81	4.05	0.82	4.10
May	– 0.75	3.75	– 0.80	4.00	0.80	4.00
June	– 0.78	3.90	– 0.84	4.20	0.88	4.40
July	– 0.80	4.00	– 0.74	3.70	0.77	3.85
August	– 0.70	3.50	– 0.64	3.20	0.81	4.05
September	– 0.86	4.30	– 0.91	4.55	0.88	4.40
October	– 0.67	3.35	– 0.87	4.35	0.91	4.55
November	– 0.52	2.60	– 0.62	3.10	0.61	3.05
December	– 0.33	1.65	– 0.37	1.85	0.50	2.50

For the direct UV–radiation, as it should be expected, the highest correlation is observed with the solar radiance time.

Based on the data from Table III, for most months one can see very high correlation between the monthly total UV–radiation and the cloud amount, except for their values in November and December. This is evidently explained by the fact that in these months the cloudiness reaches its peak and there are many days with the overcast. So the variations in the incoming UV–radiation are mainly determined by the cloud optical depth.

The lowest values of correlation between the incoming total UV–radiation and the duration of Sun shine are observed in November–January when the part of direct UV–radiation in the total one for a month is about 1–2%. As follows from our data, even in summer under cloudy conditions the total incoming UV–radiation is determined by scattered radiation (80%).

TABLE IV. Trends of radiation and meteorological characteristics of the atmosphere for one year, warm and cold periods, %.

Characteristics	Year		May–September		November–March	
	Δ	t^*	Δ	t^*	Δ	t^*
Q_{UV}	– 16	– 6.90	– 15	– 5.43	– 20	– 3.10
D_{UV}	– 16	– 6.44	– 16	– 5.90	– 18	– 2.88
N_{tc}	11	4.66	14	3.21	12	3.03
N_{lc}	21	5.37	27	3.30	27	3.67
U	– 14	– 3.74	–12	– 2.21	– 30	– 3.04
$\tau_a(\lambda_0)$	35	2.45	28	1.88	41	1.50

$^*t_{cr}$ = 2.06 at P = 0.95.

TABLE V. Trends of total UV–radiation and some meteorological characteristics of the atmosphere in different months, %.

Months	Q_{UV}	t	N_{tc}	t	N_{lc}	t	U	t
January	– 20	– 2.56	24	3.15	79	4.59	– 59	– 2.68
February	– 21	– 2.02	31	2.69	60	2.23	– 57	– 2.71
March	– 22	– 3.04	14	1.68	27	1.89	– 15	– 0.96
April	– 22	– 3.37	11	2.03	27	2.63	– 21	– 1.82
May	– 5	– 0.90	2	0.28	17	0.87	8	0.54
June	– 19	– 4.03	20	2.65	36	2.65	– 21	– 2.28
July	– 12	– 2.72	15	1.77	15	1.09	– 8	– 0.80
August	– 19	– 3.40	15	1.97	31	2.49	– 16	– 1.80
September	23	– 3.05	19	2.82	35	2.31	– 29	– 1.82
October	1	0.14	– 7	– 1.40	– 11	– 1.07	34	1.15
November	3	0.35	– 5	– 1.31	– 11	1.85	45	1.08
December	– 1	– 0.18	0	0.15	3	0.38	30	0.78

Over the period under study we observed a marked decrease of both the incoming total and scattered UV–radiation. Data on regression analysis show that a significant negative linear trend takes place in the incoming UV–radiation comprising 15–20% depending on season. Significance of trends is estimated using the Student distribution parameter t (Table IV).

In Moscow conditions we observe a significant growth (up to 27% during warm season) of lower cloudiness. The growth of total cloudiness (11–14%) during these years is somewhat less. In this case we observe a significant negative trend of relative duration of Sun shine varying from 12% in warm season and up to 28% in cold season.

As follows from Table V, the negative trend of UV–radiation in cold season is determined by the sharp radiation decrease in the second half of the season (I–III). In this case we can observe very large positive trends of lower cloudiness in January–February and sharp decrease of Sun shine duration in these months. In October–December trends of UV–radiation are lacking and in October and November the tendency of cloudiness decrease is observed although these variations are insignificant.

Based on the data presented we can conclude that the decrease of incoming UV–radiation is considerably due to the growth of cloudiness.

It should be noted that a significant increase of the mean annual values of lower cloudiness from 1964 to 1986, about 11%, was observed in Estonia.[16]

It seems likely that the cloudiness growth during the past 20–25 years was observed in the other regions of European part of CIS. The papers by Klimenko[8,9] have shown that during the past 25 years in the warm season in the southern half of European territory of the former Soviet Union the repetition of cyclonic processes increased sharply (147% of the mean over 100 years), that resulted in the cloudiness increase. In 1971–1990 during cold season we observe the increase of the number of cyclonic processes as well as sharp decrease of repetition of anticyclones (except those in Azores).

Close relation between the incoming UV–radiation and cloud amount or duration of Sun shine is observed when comparing with their integral–difference curves of distribution,[7] Fig. 2. This characteristics were obtained by summing deviations of the value under study for every year from its average. The dome–shaped curves indicate the existence of trends. It should be noted that from the middle of 1970's we observed the steady growth of cloudiness and the decrease in the incoming UV–radiation as compared to the average values during the observation period.

Based on the observation data, in Moscow a considerable growth of aerosol optical depth of the atmosphere is observed, however, due to strong variability of this value the above trend is recorded only over a two–year period. Nevertheless, the increase of atmospheric turbidity results also in the decrease of the incoming UV–radiation. Under urban conditions one of the reasons of the incoming decrease both of total and scattered UV–radiation may occur gradual increase of the number of absorbing aerosols.

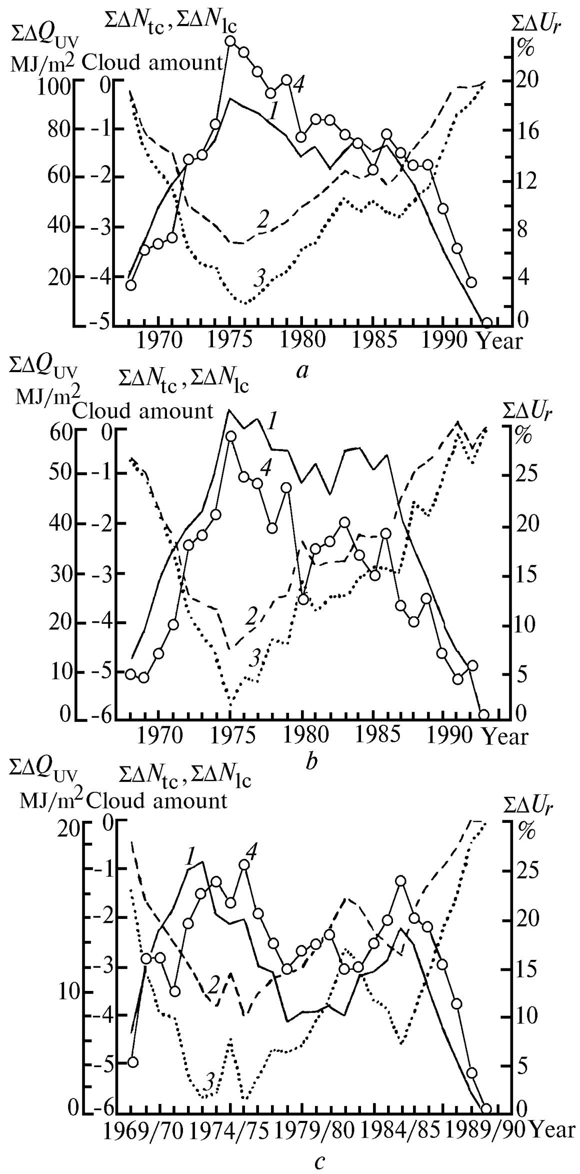


FIG. 2. Integral–difference distribution curves of total UV–radiation ($\Sigma\,\Delta\, Q_{UV}$), amount of total ($\Sigma\,\Delta\, N_{tc}$) and lower ($\Sigma\,\Delta\, N_{lc}$) cloudiness, and relative duration of Sun shine ($\Sigma\,\Delta$): a – year, b – May–September, and c – November–March.

From the above–mentioned it follows that when considering the variations of the incoming short–wave, the most active biologically, UV–radiation we need to take into account not only the effect on it from the increase of total ozone content in the atmosphere but also from the trends of cloudiness.

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