VARIABILITY OF TOTAL AND SPECTRAL DIRECT SOLAR RADIATION FLUXES IN THE VICINITY OF TOMSK IN SPRING OF 1993

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Some results of the investigation of the atmospheric radiation regime in spring of 1993 are presented. The behavior of variability of hourly, diurnal, and monthly sums of total radiation is analyzed as compared with the long–term data of actinometric network. Peculiarities of variations of spectral direct radiation are considered for a number of wavelengths in the visible and IR spectral ranges. The estimates are presented of interconnections between the incoming radiation fluxes and the atmospheric moisture content and transmission.

The character of variability of actinometric parameters (total, direct, scattered radiation) is determined, to our knowledge,[1,2] by astronomical and geographic factors and by the state of the atmosphere, namely, cloudiness, aerosol turbidity, and moisture content. According to the data from actinometric network, the average values of radiation fluxes and the range of variations are mainly latitude–dependent. At the same time, natural and anthropogenic characteristics of specific regions and, especially, of atmospheric circulation may have a pronounced effect on the character of radiation regime and may result in deviations from the average data.

The magnitude of spatial variability of the radiation fluxes can be determined from the estimates of the correlation coefficient r, for different distances, between the actinometric stations.[1] Thus, under the plain land conditions at distances up to 300 km the value of r for daily sums of total radiation exceeds 0.5, at distances of 30 to 50 km the value of r is already above 0.8–0.9, while at the distances about 1000 km the value of r equals zero. Similar values are obtained also for monthly sums of radiation despite the fact that much lower variability is typical for them.

From the point of view of reasonable distances between the points of actinometric network, being about 300 km for the plain,[1] the region of Western Siberia is characterized by insufficient number of stations. For the Tomsk region many stations are at distances more than 470 km [Novosibirsk (Ogurtsovo) – 200 km; Eniseisk – 470 km, Khakasskaya – 490 km; Blagoveshchenka – 520 km, Aleksandrovskoe – 600 km, Omsk – 740 km], therefore the interpolation of actinometric data can result in large errors when describing the radiation over the territory under study.

Taking into account this fact, in the framework of the Program "Climatic–Ecological Monitoring of the Siberia",[3] the Institute of Atmospheric Optics has started the investigations of regional and local peculiarities of the variability of solar radiation components in the vicinity of Tomsk. The first cycle of measurements was conducted in the spring–summer period of 1993 (from April 3 to June 15).

An M–80 M pyranometer was used to measure the instantaneous values of the total radiation Q as well as the hour $\Sigma Q_{\rm h}$, daytime $\Sigma Q_{\rm d}$, and monthly $\Sigma Q_{\rm m}$ sums were calculated.

The radiation fluxes Q were continuously recorded using a LKS4–003 X–Y recorder.

The spectral direct solar radiation (incident on the perpendicular surface) $S_{\rm k}$ was measured with a multiwave solar photometer AMSF[4] in the spectral range from 0.447 to 12.1 μm (14 spectral intervals) with the average resolution of 10^{-2}. The absolute values of $S_{\rm k}$ were calculated on the basis of the long Bouguer method[4] using extraatmospheric values of the spectral solar constant.[5]

The measuring platform was mounted on the roof of the building to avoid shading from buildings and trees. The coordinates of the observation point were 56.47°N and 85.03°E.

During the measurement period we have obtained more than 60 daytime realizations of the total radiation Q and more than 900 spectra of direct solar radiation $S_{\rm k}$ for 40 days.

TOTAL RADIATION

General character of variations in the daytime sums of radiation is given in Fig. 1. The effect of the astronomic factor over the period under study (increase in the sun elevation angle and the sun shine duration) must be manifested as a monotonic growth of the daytime total radiation. In fact, starting from the last decade of April, the decrease of radiation level with its subsequent sharp increase was observed. Analysis of the atmospheric conditions has made it possible to reveal the following factors, whose total effect resulted in the delay of radiation influx and in characteristic transition period from spring to summer in the middle of May:

a) more dense cloudiness and precipitations from the end of April to the middle of May due to the action of unstable air masses (including the influence of local cooling during the ice motion of rivers of the Ob' basin);

b) enhanced atmospheric turbidity because of aerosol convection when snow cover is being gone off the soil as well as under the effect of change of a phenological phase (formation of the plant pollen).

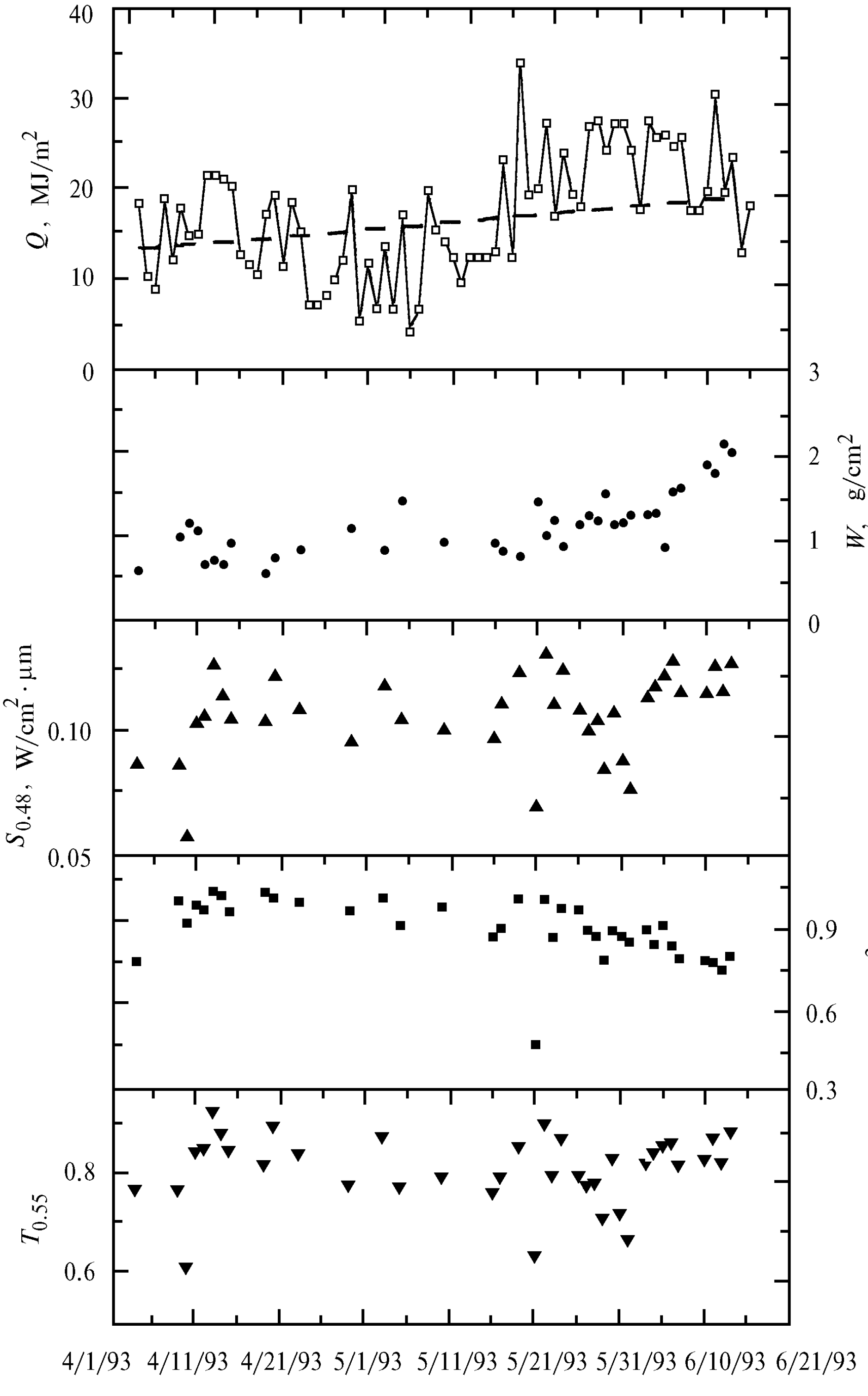

FIG. 1. Variability of ΣQ_d *and the average (from* 9 h *to* 15 h*) values of radiation fluxes* $S_{0.48}$ *and* $S_{3.8}$*, the moisture content W and the atmospheric transmission* $T_{0.55}$ *in Tomsk over the period of studies (seasonal trend of long–term data for Novosibirsk region*^{6} *is shown by dashed line).*

In the histograms of repetition rates of the values of ΣQ_d (Fig. 2) there are two modes corresponding to the spring periods (to be more precise, its end) and the summer that has made it possible to distinguish between two subarrays and analyze them separately.

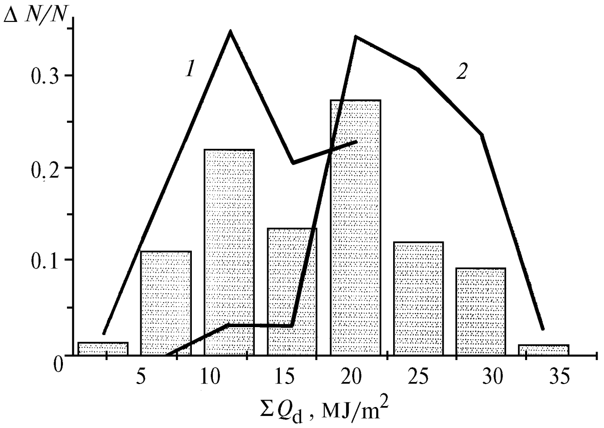

FIG. 2. Histograms of repetition rates of the values of ΣQ_d *(columns are given for the total data array while the date for spring (1) and for summer (2) are shown, in the figure, by solid lines).*

Qualitative characteristics of variations of the values of ΣQ_d are presented in Table I. When going from spring to summer (the periods I and II in Table I) an increase of the average radiation level amounted more than 70 per cent. At the same time, diurnal variations in radiation influx stabilized, and the value of the variation coefficient ($\sigma/\Sigma Q$) decreased by a factor of 1.64.

TABLE I. Statistical characteristics of the daytime total radiation ΣQ_d (MJ/m^2) *for different observation periods.*

Observation period	$\overline{\Sigma Q_d}$	σ	$\sigma/\overline{SQ_d}$	Min	Max	N
I 4.04–16.05.93	13.48	4.82	0.36	4.31	21.61	43
II 17.05–15.06.93	23.07	5.08	0.22	12.73	34.09	30
April, 1993, Tomsk,	14.35	4.75	0.33	5.34	21.61	30
Ogurtsovo[6]	14.86	–	–	–	–	
May, 1993, Tomsk,	17.59	7.56	0.43	4.32	34.09	31
Ogurtsovo[6]	19.51	–	–	–	–	
June, 1993, Tomsk ,	22.59	4.83	0.21	13.42	31.01	15
Ogurtsov[6]	20.85	–	–	–	–	

Below in Table II the values of ΣQ_d are presented for different months. In this table, for a comparison, the averaged data from Ogurtsovo station are given (hereinafter the data from Ref. 6 are recalculated from [cal/cm^2] to [MJ/m^2]. From a comparison with the long–term data one can see a deficit in radiation influx during the first two months and an excess above the average level in June. As to the day–to–day variation (σ and $\sigma/\Sigma Q_d$), it should be noted that the instability of radiation regime in May decreases by a factor of 1.5–2 compared to variations in April and June.

In the monthly sums of total radiation ΣQ_m (Table II) no sharp changes were observed since the above–mentioned sudden change of the radiation level occurred in the middle of month. For a comparison with the results, obtained in Tomsk, Table II gives the long–term data from three nearest actinometric stations.[2,6] When comparing the results, we can conclude that for April the value of ΣQ_m was somewhat lower than the average long–term values for all the stations in the region. In May the monthly sum of total radiation was at the level of the average values, and in the first half of June the half month sum of total radiation reached the maximum ever recorded in the region.

TABLE II. Monthly sum of total radiation ΣQ_m (MJ/m^2).

Region	Average (min–max)		
	April	May	1/2 June
Tomsk, 1993	430.5	545.4	338.9
Aleksandrovskoe, Ref. 6	443.8 (393.6–506.6)	556.8 (515.0–615.5)	309.8* (263.7–349.6)
Kolpashevo, Ref. 6	477.3 (431.2–573.6)	523.3 (456.4–623.8)	288.9* (286.8–334.9)
Novosibirsk, Ref. 6	448.0 (376.8–519.2)	577.8 (468.9–661.5)	320.3* (301.4–355.9)

* For the half–month radiation sums the values 0.5 $\overline{SQ_m}$ were used.

Analysis of the diagrams of the time variability of hourly sums, ΣQ_h, shows that on the average we observed practically symmetric diurnal variation relative to the noon time. As an example, Table III gives the statistics of ΣQ_h for three periods of observation (9, 12, and 15 h) over the entire period of observations.

TABLE III. Hourly sums of total radiation, ΣQ_h *, for the entire observation period.*

Observation period, h	$\overline{\Sigma Q_h}$	σ	$\sigma/\overline{Q}$	min	max	N
9	1.71	0.62	0.36	0.59	2.69	52
12	2.21	0.78	0.35	0.23	3.69	53
15	1.63	0.63	0.39	0.24	2.65	52

SPECTRAL DIRECT RADIATION

In contrast to a more complicated relation of the total radiation to the atmospheric conditions, the direct radiation is determined by the atmospheric transmission and varies with the change of moisture content and aerosol composition (see Fig. 1). The main influx of direct radiation occurs, as is known, in the spectral range of 0.3–4 μm. The value of contribution of different S_{k_i} can be estimated according to statistical data given in Table IV and in Fig. 3.

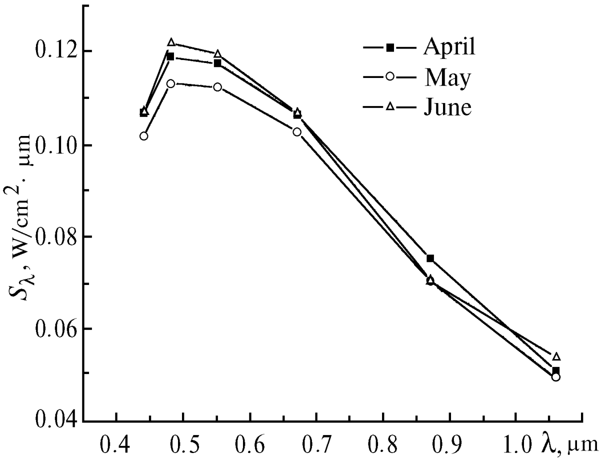

FIG. 3. Mean spectral dependence of the noon values of short–wave radation, S_k *, for three months of observations.*

TABLE IV. Mean values and coefficients of radiation variations of S_k *(*0.447–1.06 µm *in* mW/cm^2·µm, 3.8–12.1 *in* µW/cm^2·µm*) observed at noon for three months of observations.*

λ, µm	April		$\Delta/\overline{S}$, %	May		June	
	$\overline{S}_k$	V_s, %		$\overline{S}_k$	V_s, %	$\overline{S}_k$	V_s, %
0.447	106.7	11.5	–4.4	102.0	12.7	107.2	12.1
0.484	118.9	10.2	–5.0	113.0	13.1	121.9	11.6
0.552	117.7	9.4	–4.4	112.5	9.4	119.7	8.1
0.674	106.8	8.9	–3.4	103.2	8.1	107.2	5.7
0.869	76.1	5.9	–6.4	71.2	7.1	71.3	3.5
0.941	60.9	11.3	–13.0	53.0	13.9	50.8	11.3
1.061	51.7	5.4	–2.7	50.3	7.9	54.8	3.9
3.8	1011	2.4	–9.0	919.5	7.3	847.3	7.0
4.7	368.1	5.8	–11.1	327.3	14.2	281.9	13.5
8.1	49.4	5.7	–12.8	43.1	12.7	38.7	10.8
9.1	31.8	4.2	–9.7	28.7	9.1	26.3	11.2
9.47	25.0	8.0	–11.2	22.2	13.0	20.0	10.8
10.55	18.6	4.6	–11.3	16.5	12.4	14.1	14.2
12.1	10.8	3.4	–12.0	9.5	11.6	8.2	12.4

The results obtained show that the largest absolute variations of S_k occur in the visible spectral range. Both absolute and relative ($\sigma/\overline{S}_k$) characteristics of S_k variations are reduced with the wavelength increase into the infrared range and as the influence of aerosol extinction decreases.

The effect of atmospheric factor in May turned out to be stronger than the expected increase of direct radiation due to higher sun (the S_k values in May are lower than those in April).

The influence of absorption by atmospheric gases (mostly by H_2O) can be revealed from the S_k value decrease in the IR range from April to June and from a twofold increase of the variation coefficient $V_s = \sigma/\overline{S}_k$ with the transition from the transmission window to an H_2O absorption band (see the data for $\lambda_{H_2O} = 0.941$ µm).

Table IV, in a separate column, gives the value of a relative change in the direct radiation in April compared to that in May ($\Delta/\overline{S}_k$). The estimates of $\Delta/\overline{S}_k$ presented show that in the short–wave spectral range (up to $\lambda = 1.06$ µm) the radiation decrease was on the average about 4.5 per cent, while in the long–wave spectral range it was 11 per cent. From the character of variations of the total moisture content (see W in Fig. 1) the conclusion can be drawn that the decrease of S_k in the IR spectral range occured because of seasonal increase in the atmospheric moisture content.

Diurnal behavior of S_k value shown in Fig. 4 reveals, along with the regular astronomic factor (increase of solar radiation flux by noon), certain peculiarities in the diurnal behavior of the atmospheric transmission. Thus, in the diurnal behavior of S_k in May we can observe asymmetry and decreased radiation values, except for morning hours. Such a behavior of S_k is connected, as was noted, with the snow melting in the morning as well as with the increase of convection and atmospheric turbidity because of aerosol and water vapor.

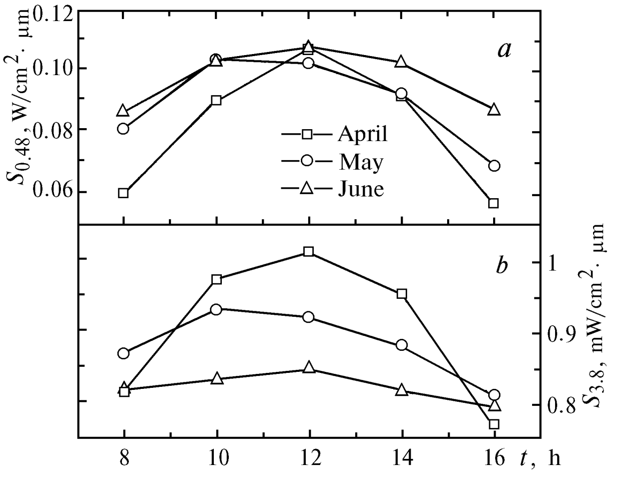

FIG. 4. The mean behavior of radiation $S_{0.48}$ *(a) and* $S_{3.8}$ *(b).*

Qualitative data on the character of diurnal variation of S_k are given in Table V. From the results obtained it follows that for April and May the variance of the radiation variation, S_k, increases from morning to evening and in June, in the afternoon, its decrease is observed. The coefficients of variation for the first two months before noon are practically constant and then their increase is observed. In June all the statistical parameters have a symmetric daytime behavior; in this case, the values of σ and V decrease by a factor of two as compared with the spring values. This is indicative of a stabilization of the atmospheric conditions.

TABLE V. Statistics of $S_{0.55}$ (mW/cm^2·μm) for different observation periods.

Observation periods, h		$\overline{S}$	σ_s	$\sigma_s/\overline{S}$	$S_{\min}$	$S_{\max}$	N
April	10	10.4	0.96	0.093	9.07	12.49	9
	12	11.8	1.10	0.094	9.33	12.73	8
	14	10.7	1.11	0.104	8.78	12.04	7
May	10	11.4	1.07	0.094	9.80	13.37	9
	12	11.3	1.06	0.094	9.44	12.93	11
	14	10.5	1.14	0.108	8.93	12.05	8
June	10	12.0	0.57	0.048	7.70	12.75	9
	12	12.0	0.96	0.081	9.93	12.73	7
	14	11.6	0.82	0.071	9.93	12.54	7

Taking into account a strong effect on the radiation components, (along with the cloudiness) of moisture content and atmospheric aerosol transmission, it is interesting to consider the degree of correlation between the above values (see Fig. 1). For this purpose we calculated the coefficients of cross–correlation for the mean values of the radiation fluxes Q, $S_{0.48}$, $S_{3.8}$, the total moisture content W (spectroscopic method), and atmospheric transmission $T_{0.5}$ for the middle of the day, from 9 a.m. to 3 p.m. of the local solar time (Table VI).

TABLE VI. Coefficients of correlation between the radiation components, moisture content, and atmospheric transmission.

	Q	W	$S_{0.48}$	$S_{3.8}$	$T_{0.55}$
Q	–	0.21*	0.32*	–0.23*	0.21*
W	–	–	0.10**	–0.63**	0.10**
$S_{0.48}$	–	–	–	0.31**	0.94**
$S_{3.8}$	–	–	–	–	0.46**
$T_{0.55}$	–	–	–	–	–

Critical value of the correlation coefficients r (at 0.95 level of significance) are * $r = 0.34$ and ** $r = 0.32$.

As could be expected, the maximum values of correlation are observed between the direct radiation $S_{0.48}$ and aerosol transmission component $T_{0.55}$ as well as between $S_{3.8}$ and the moisture content W and $T_{0.55}$. In this case negative correlation $r(S_{3.8}/W)$ is also evident because of the inverse proportionality of the atmospheric transmission (and, hence, incoming radiation) to the moisture content. The interrelation between the fluxes $S_{0.48}$ and Q and $S_{3.8}$ turned out to be at the level of significance threshold, that in each case is due to the counter actions (on Q and $S_{3.8}$) of different factors. On the one hand, a decrease in aerosol turbidity results in an evident increase of $S_{0.48}$ and the fluxes Q and $S_{3.8}$. On the other hand, the water vapor content makes a greater impact on the $S_{3.8}$ radiation, while Q is more strongly affected by cloudiness. These parameters are not connected directly with the aerosol atmospheric transmission.

Thus obtained data on the variability of the fluxes P and S_k characterize the peculiarities of radiation regime which are connected both with the total seasonal transition and with the specific properties of circulation processes in the atmosphere over Tomsk region in the spring period of 1993.

In conclusion, it should be noted that the above results and conclusions are tentative since they rely only on data of one measurement season.

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