Measurements of the total solar radiation near Tomsk

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In this paper we present some results of monitoring the total solar radiation, which is being performed at the TOR station of IAO SB RAS since April 1995. Some results of evaluation of the radiation regime nearby Tomsk have been verified by the comparison with the actinometric data of Ogurtsovo station. We have revealed that during the period of the study quite steady radiation regime with maximum of incoming solar radiation in July was observed. The amount and variation range of the monthly mean solar radiation varied depending on the season. During wintertime the coefficient of variation of the monthly mean radiation varied within 5 to 9% and from 2 to 24% during transition periods. The amount of solar radiation income depending on air mass type and synoptic condition has been investigated. The complex dependence is observed of the income of solar radiation during a year on the type of air mass that reflects the peculiarities of the general circulation of the atmosphere over the region. During other periods diurnal solar radiation sums are 1.8 times larger at the presence of anticyclones.

Investigation of the radiative budget of the atmosphere, the part of which is the total solar radiation, is important for understanding physical processes occurring in the atmosphere. These processes determining the energy characteristics of the "Earth – atmosphere" system are the primary source of life on the Earth. In its turn, the atmosphere affects the propagation of solar radiation. So the study of transformation of solar radiation in the atmosphere requires quantitative estimation for getting an idea about the radiation budget as whole.

A number of papers have been published in recent years devoted to analysis of the long-term variability of the income of solar radiation to the Earth surface over Russia, and in particular, over Western Siberia. Yu.V. Zhitorchuk et al.[1] and I.M. Baikova[2] have noted based on the data of actinometric network of the USSR till 1990 that, in general, the decrease of annual sums of the total and direct radiation and the increase of the scattered radiation are observed over the Western Siberia. At the same time, some peculiarities are observed in some areas of the region.

There were no regular or network measurements of the solar radiation characteristics in Tomsk. So systematic measurements of the radiation characteristics: total solar radiation Q and radiative budget B, have been started in April 1995 on the automated post (TOR station) created at the IAO SB RAS in 1992 and intended for monitoring the aerosol and gas composition of air, meteorological parameters and other geophysical values.[3] The standard devices that are being used for this purpose are an M–115M pyranometer and an M–10M balancemeter connected with a computer via special transducers. Measurements are performed every hour round-the-clock. The duration of one measurement cycle is 10 min, during which the above parameters are readout at the frequency of 1 Hz. The value recorded by the computer is the result of averaging over 600 readouts and calculation of the rms error of each of the measured parameter. The data on the intensity of total solar radiation and the radiative budget are recorded on a hard disk.

This paper is aimed at estimating of the income of solar radiation and its variability in Tomsk region.

To obtain the data on the change of total solar radiation during the period of measurements, the daily sums were calculated, as well as the monthly and annual income of the total solar radiation. Defective data were first rejected from the initial bulk of data, and the missing values were reconstructed by extrapolating between two neighbor ones. The mean annual behavior of the total solar radiation in 1995–1999 near Tomsk (Fig. 1) was obtained from analysis of the data.

It is seen in the figure that the lowest, in the annual behavior, level of radiation is observed in December. It sharply increases beginning from March and reaches its maximum value in July. One should note that, though being quite classical, the annual behavior of Q exhibits a deviation in that the mean incoming total radiation in June is lower than in May. As we have only short series of measurement data, it is necessary to determine the error in the annual mean incoming total radiation and to estimate significance of this deviation. The annual mean incoming total solar radiation estimated from the data obtained is 4134.68 MJ/m^2, and the rms error is equal to 87.43 MJ/m^2. The error in the annual mean Q equals to 50.477 MJ/m^2. If one takes this error to be 30 MJ/m^2 (the error of the long-term mean income

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of the radiation), the period of 9–10 years is necessary for obtaining the annual mean Q within that accuracy assuming also that the rms error is the same. So the results presented characterize only the period under consideration, but not the long-term features.

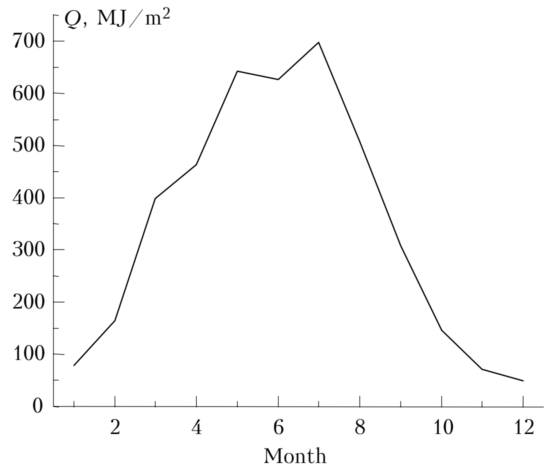

Fig. 1.

As there were no earlier measurements of the total solar radiation in Tomsk, it is interesting to compare the data obtained with the data of long-term observations at the nearby stations. The monthly mean sums of the total solar radiation observed in Tomsk and the monthly mean Q recorded at the stations Ogurtsovo (150 km to the south-west of Tomsk) and Aleksandrovskoe (600 km to the north) since 1959 till 1994 are shown in Table 1. These stations were selected not only because of their nearness, but also because of the fact that, as was noted in Ref. 4, there is no significant trend of the total solar radiation at the stations Ogurtsovo and Aleksadnrovskoe during the recent 36 years. It is seen from Table 1 that the monthly mean sums of the total radiation near Tomsk are comparable with the long-term observations at the station Ogurtsovo. At the same time, the displacement of the maximum of the monthly sum from June to July is observed in Tomsk, that is an evidence of the peculiarities of the circulation of air in this region.

It is seen[5] that the monthly income of the total radiation varies stronger, from year to year, than the annual one. So it is interesting to consider in detail the inter-annual variations. It is seen from Fig. 2 that the value and the range of variation of the monthly sums of radiation depend on season. The variation coefficient V of the monthly sums in winter (November till February) varies within 5–9%, and the minimum variations are observed in December and January. In summer (July–August) V = 9–13%. The minimum monthly sum Q was recorded in June 1995, and the maximum one in July 1998. The range of variations of the monthly sums in transition seasons (spring and fall) is more wide V = 2–24%. The smallest variations of the monthly sum are observed in May (V = 2%) and the greatest ones in September (V = 23.9%). Such months as April and June attract our attention by the instability of monthly sums. It is a little bit greater than that from the data obtained by Z.I. Pivovarova and V.V. Stadnik[5] who showed that the variation coefficient in spring and summer in Western Siberia equals 10% and increases in the fall up to 15%, on average. Perhaps, here we observe the effect of differences in the series length.

Table 1. Monthly mean sums of the total radiation Q (MJ/m^2) at the stations Aleksandrovskoe and Ogurtsovo (1959–1994) and near Tomsk (1995–1998)

Month	Aleksandrovskoe	Ogurtsovo	Tomsk
I	36.43	81.03	78.96
II	112.05	169.28	165.10
III	299.92	350.83	401.10
IV	452.27	460.66	473.10
V	545.36	570.64	626.80
VI	598.80	646.97	634.00
VII	609.38	641.04	685.5
VIII	423.34	496.08	504.6
IX	235.28	313.92	298.50
X	110.69	165.28	146.20
XI	48.31	88.00	71.33
XII	19.56	57.35	49.38
Year	3491.39	4041.08	4128.98

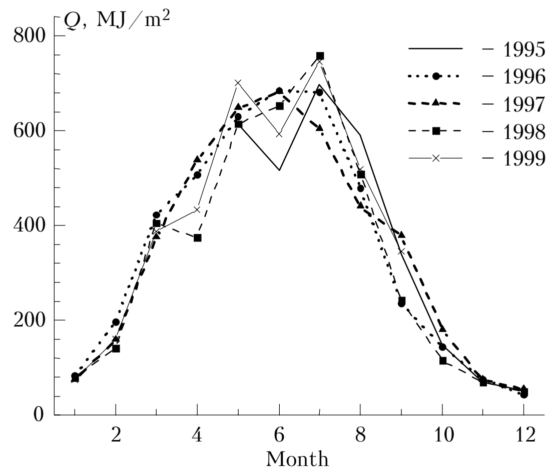

Fig. 2. Annual behavior of the total solar radiation in Tomsk region.

It is known that the income of the solar radiation to the Earth's surface depends on many factors, including the atmospheric transmission, cloud fraction and shape, the formation of which is determined by synoptic conditions. The conditions least favoring the income of solar radiation can be formed at certain combination of the factors, and then the decrease of solar radiation is observed. A large number of cyclones (32%) with continuous cloudiness (cloud fraction of

0.8–1) in April 1998 resulted in the anomalously low monthly sum of 374.39 MJ/m^2, which are not characteristic of this season.

It should be noted that, as a rule, June in Tomsk is characterized by unstable synoptic situation that results in a decrease of the monthly sum of the total radiation as compared with that in the neighboring regions. Thus, in June 1995 there were observed 16.9% of cases with cyclones and continuous cloudiness of low layer, and 16.8% of anticyclones. The greatest part of anticyclones also were accompanied by the high occurrence of the low layer cloudiness and precipitation, that led to the decrease of the monthly sum Q by 17.5% of the mean value. At the same time, prevalence of anticyclones with high transparency of the atmosphere in July 1998 and 1999 favored maximum income of radiation.

On the whole, quite stable radiative regime was observed in Tomsk in the period under consideration. It is seen from Table 2 that the annual sum Q practically does not change from year to year, and the variation coefficient of the annual sums of the total radiation is 2%, while in the south of Western Siberia[5] the characteristic value V = 4–5%. Variations of the annual sums at Ogurtsovo station since 1959 until 1994 were 5.3%, and at the Aleksandrovskoe station 4.5%. Perhaps, the low value V in Tomsk is caused by the short series of observations and by the fact that the period of measurements coincided with the phase of low values of the Wolf number (Fig. 3).

Table 2. Annual income of the total solar radiation in the Tomsk region

Year	1995	1996	1997	1998	Mean
Q, MJ/m^2	4143.14	4184.80	4201.91	4008.87	4134.68

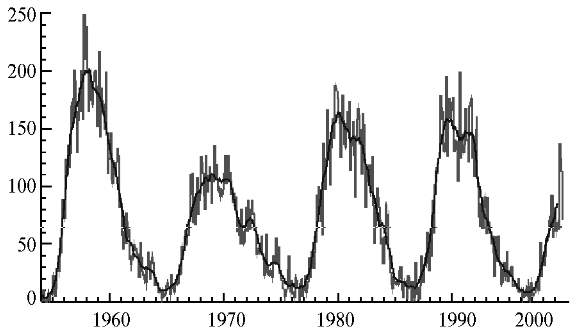

Fig. 3. Wolf numbers for the northern hemisphere.

The inter-annual variability is not principal and makes up only 10–20% of the total variability of the radiation due to variation of the daily sums.[5] Variability of the daily sums includes the variations of the radiation within each month caused by the change of synoptic processes and year-to-year variations related to the change of the prevalent forms of the general circulation during an individual year. The mean daily sums of the total radiation (Q_d) and their minimum and maximum values recorded at the TOR station are shown in Table 3. As for the inter-day variability, one should note quite a stable radiative regime in March and July, and 2.5–3 times greater variations in October and November. At the same time, no sharp changes of the daily mean sums of Q were observed. The range of variations of the daily sums within a month changes depending on season.

Figure 4 shows the repeatability of the daily sums of the total radiation during the central months of seasons in Tomsk. The histogram of repeatability of the daily sums in March is symmetric and 50% of Q_d is in the range 10–15 MJ/m^2. However, in other months the curves of the distribution are asymmetric: negative asymmetry in spring and summer and positive one in the fall and winter. The mean inter-day variability in winter is 0.8 MJ/m^2, the maximum one is observed in June, 7.28 MJ/m^2, and in the transition seasons it changes from 2 to 5 MJ/m^2.

The authors of Refs. 6 and 7, in analyzing the data of the long-term observations (1964–1994) of the total solar radiation at the world network, have determined the maximum and minimum possible daily sums of the total solar radiation in each month at different latitudes. Comparison of the maximum and minimum daily sums of the total radiation recorded at the TOR station with the possible sums at the latitude of 56° published by I.V. Morozova and G.N. Myasnikov has shown that all recorded daily sums are in this range, and there were no extreme situations during the period under consideration.

The results of a comparison of the monthly mean sums Q obtained by us with those from the handbook[8] and the data obtained later at the Ogurtsovo station are shown in Table 4. The increase of the daily income of the solar radiation in spring and summer from the data of the station Ogurtsovo in recent years is seen, that explains the greater income of the total solar radiation in spring and summer in Tomsk in comparison with the long-term data of the station Ogurtsovo (see Table 1). The mean daily sums in Tomsk in winter are a few less than the long-term mean data at the station Ogurtsovo that is most likely explained by the more southern position of the last.

The dependence of the variability of the daily sums of the total radiation on the type of pressure field and type of air mass is of a certain interest. The days with the prevalence of a certain type of pressure field (cyclone Zn or anticyclone Azn) or air mass (Arctic, mid-latitude, subtropical) were chosen. This choice allowed us to construct the annual behavior of the daily sums of the total radiation for cyclone and anticyclone.

Table 3. Daily mean sums of the total radiation (MJ/m²) recorded at the TOR station

Month	Year								
	1995	1996	1997	1998	1999	Mean	Min	Max	*V*
I	–	2.69	2.28	2.56	2.38	**2.49**	0.49	5.01	0.413
II	–	6.78	5.59	4.97	5.82	**5.80**	1.80	11.54	0.429
III	–	13.64	11.88	13.00	11.93	**12.65**	3.25	21.10	0.246
IV	–	16.65	18.08	12.55	15.16	**15.29**	3.62	24.76	0.413
V	20.06	20.53	21.73	19.81	22.31	**20.81**	3.93	31.90	0.319
VI	17.04	22.73	22.60	21.63	19.45	**20.54**	5.02	33.09	0.360
VII	22.50	21.87	19.62	24.32	24.06	**22.50**	3.97	32.23	0.292
VIII	19.21	15.38	14.61	16.16	16.68	**16.50**	3.03	26.19	0.372
IX	11.28	8.99	12.54	7.91	11.55	**10.52**	2.09	20.19	0.456
X	4.75	4.71	5.85	3.56	–	**4.70**	0.49	12.58	0.665
XI	2.26	2.52	2.52	2.23	–	**2.38**	0.34	6.61	0.596
XII	1.63	1.40	1.81	0.88	–	**1.43**	0.32	3.68	0.517

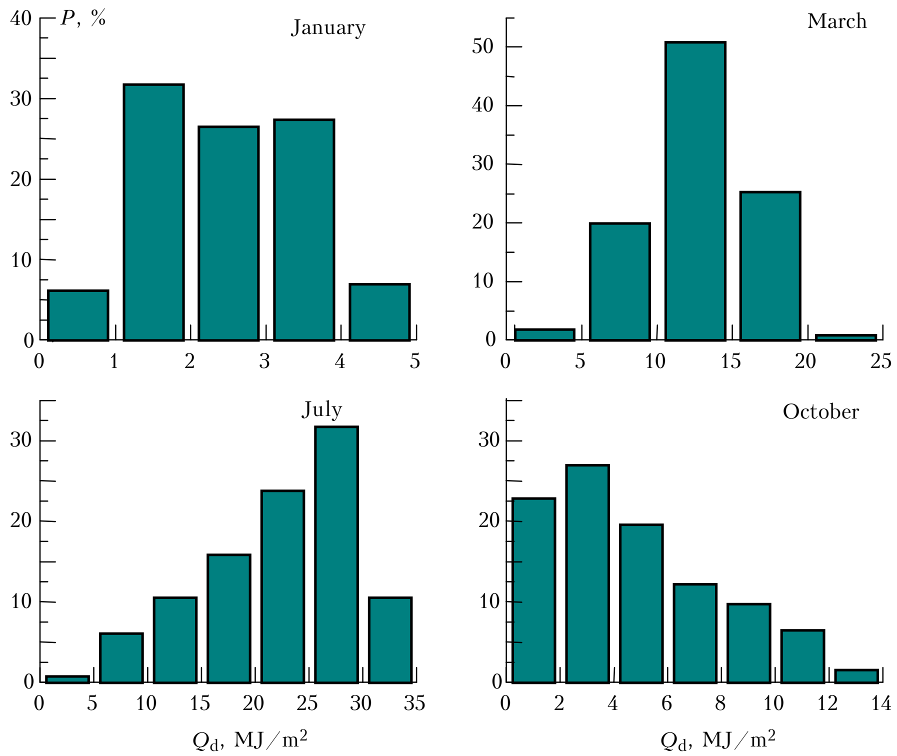

Fig. 4.

Table 4. Daily mean sums of the total radiation (MJ/m²) at the TOR station and Ogurtsovo station

Month	Tomsk	Ogurtsovo	
	(1995–1999)	(before 1968)	(1993–1994)
I	2.49	2.97	–
II	5.80	6.03	–
III	12.65	11.27	–
IV	15.29	14.87	15.92
V	20.81	19.52	18.00
VI	20.54	20.86	23.84
VII	22.50	19.56	21.56
VIII	16.50	15.71	16.62
IX	10.52	11.10	–
X	4.70	5.15	–
XI	2.38	3.02	–
XII	1.43	2.01	–

It is seen from Fig. 5*a* that the daily income of the total radiation in an anticyclone is greater during a year. The absolute difference between the mean daily sums *Q* in anticyclone and cyclone increases from winter to summer. Obviously, the absolute value of the difference is caused by the increase of the sunshine duration in summer. Really, the difference in the income of the total radiation in anticyclone and cyclone remains during the whole year. This is clearly seen from Fig. 5*b* where the ratio of the sums in anticyclone and cyclone is shown. On the average, this ratio is equal to 1.8 and varies from 1.6 to 2.2 except for December, for which no data are shown. The point is that the value of the total radiation in this month is very small, so any anomalies in the income of the radiation significantly change the ratio. If generalizing the data presented in Figs. 5*a* and 5*b*, one can conclude that the income of the total solar radiation in anticyclone and cyclone in Tomsk depends on the type of pressure field, and, in an anticyclone it is, on the average, 1.8 times greater than in a cyclone.

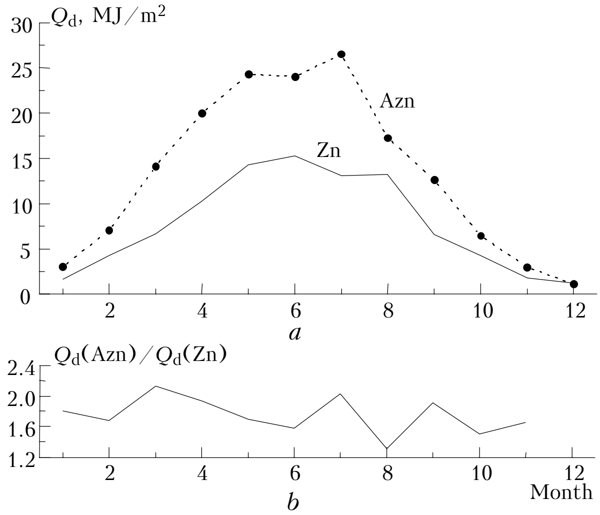

Fig. 5. Dependence of the daily sums of the total radiation on the type of pressure field: cyclone Zn, anticyclone Azn.

Obviously, the change of air mass affects the variations of the radiative characteristics. The prevalence of Arctic and mid-latitude air masses is characteristic of the Tomsk region. There were 470 days with Arctic air mass (CA), 374 days with the mid-latitude one (CM), 59 days with subtropical one (CS) and only 3 days with the tropic air mass. It should be noted that the curve of variation of the daily sums in CS is rather qualitative, because of its poor statistics and longer series of observation is needed for reliable conclusions to be drawn. So let us compare two types of air mass – the Arctic and mid-latitude. Let us emphasize that the days when the change of air mass occurred during the day were excluded from the data sample.

As seen from Fig. 6 the relationship of incomes of the total radiation in arctic and mid-latitude air masses changed during a year. Thus the values of the daily sums of radiation in both air masses are close to each other since November until March, while in other periods the relationship of incomes of the total radiation in these air masses can be higher or lower. There is some contradiction with the preconceived conceptions. Obviously, the effect of the peculiarities in the air circulation over the region in a warm season takes place here. The maximum of the aerosol optical thickness in April is characteristic of the Western Siberia. It is formed by the middle-layer transport of aerosol particles produced after snow thawing in the southern regions.[9] The snow cover line in May approaches the Western Siberia, and the relationship of attenuating and scattering factors in the region equalizes. The attenuating effect of the total and low cloudiness works in summer in Arctic air mass, which is cleaner, on the average. It is seen from Table 5 that the days with cloud fraction of 0.8–1 and low cloud fraction > 0.5 were prevalent in summer in Arctic air mass as compared with the mid-latitude one. This led to a decrease in the daily sums by almost 20% compared with the mid-latitude air mass.

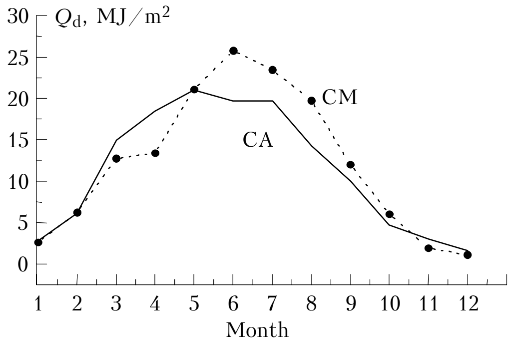

Fig. 6. Dependence of the daily sums of the total radiation on the type of air mass: arctic CA and mid-latitude CM.

Table 5. Number of days with Arctic and mid-latitude air mass (1) including days with total cloudiness cloud fraction of 0.8–1 (2); total cloudiness cloud fraction of 0.8–1 with the low clouds of the cloud fraction > 0.5 (3)

Month	Arctic			Mid-latitude		
	1	2	3	1	2	3
I	33	15	–	30	21	5
II	28	15	2	25	17	6
III	28	11	4	30	16	7
IV	30	16	5	24	13	8
V	37	26	17	26	15	7
VI	40	30	20	26	9	3
VII	25	11	8	62	27	7
VIII	50	43	32	27	11	6
IX	69	52	37	22	14	6
X	42	34	25	35	25	13
XI	50	34	14	30	26	19
XII	38	30	11	37	34	24

Based on analysis performed, one can conclude the following:

– as a whole, quite a stable radiative regime with a minimal variations of both monthly and daily mean sums of the total radiation was observed in March during the period of measurements near Tomsk;

– the data on the total solar radiation obtained at the TOR station well correlate with the measurement data from the nearby stations both in magnitude and annual behavior;

– the peculiarity of the radiative regime in Tomsk is the displacement of the maximum of radiation toward July;

– the complex dependence is observed of the income of solar radiation during a year on the type of air mass that reflects the peculiarities of the general circulation of the atmosphere over the region;

– the value of the daily sum of the total radiation in an anticyclone is, on the average, 1.8 times higher than that in a cyclone during the whole year.

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