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Changes in Integral and Aerosol Atmospheric Turbidity in Trans-Baikal and Central Siberia

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Abstract—The analysis of time series of the Linke turbidity factors is performed for the atmosphere mass $m = 2$ (T_2) and atmospheric aerosol optical thickness for the wavelength $\lambda_0 = 0.55$ μm (AOT) from the data of 14 actinometrical stations of Central Siberia and Trans-Baikal territory. It is shown that over the period from 1976 to 2006, the increased atmospheric transparency is observed in the region. Quantitative estimates of changes in multiyear mean annual variations of T_2 and AOT at different periods of averaging and for different time periods are derived.

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INTRODUCTION

The global climate changes of the last ten-year period draw the interest to studying the dynamics of different climate factors in the regions. Solar radiation as an element of the climate system determines the energy of the Earth–atmosphere system and impacts the major parameters connected with the occurring climate changes.

Changes in the solar radiation are stipulated by different factors, including the instability of the atmospheric transparency, which in turn, is to a great extent determined by the aerosol component variations. Numerous studies demonstrate that the aerosol (both of a natural and anthropogenic origin) can significantly influence the radiation balance of the Earth–atmosphere system. In individual cases, the regional effect of the anthropogenic aerosol is comparable in the magnitude with greenhouse gas effect [9, 29–31].

In accordance with the results of observations carried out before 1971, Z.I. Pivovarova generalized the data on the atmospheric transparency in the USSR [21]. The peculiarities of the spatiotemporal changes in the atmospheric transparency in Russia, in 1976–2003, was analyzed in [14].

The atmospheric transparency in the individual Siberian regions as a whole and at individual stations was considered in many works [2–6, 13–15, 20, 24, 28]. In work [2], the data of eight stations, spaced by hundreds of kilometers, were used for the analysis of changes in the atmospheric transparency, direct and total solar radiation, and air temperature and clouds over a period up to 1986 over vast areas of Siberia and the Far East. At the same time, for a much smaller region of the Near-Baikal and Trans-Baikal territory and the adjoining Siberian territories within the zone of 50°–65° N with limited meridians of 90° and 120° E, the existed actinometrical network allows performing a more detail analysis of changes in the atmospheric turbidity.

The said region is characterized by significant variations in the air temperature [7, 10, 16, 17]. For example, according to the data in [7], the highest air temperature rise was observed in 1951–2000 in the Near-Baikal–Trans-Baikal territory (3.5°C per 100 years). According to [10], the temperature variation field in Siberia has a multi-center structure; the centers where the temperature has a tendency to change by more than 0.5°C per 10 years are localized in the Near-Baikal and Trans-Baikal territory. The transparency of the region considered is on the whole rather homogeneous. The differences revealed in several works are of an unordered character and depend on meso-peculiarities of the region and the specificity of the station location [3, 4, 11, 12, 19, 20, 23].

THE SUBJECT OF INVESTIGATIONS AND THE METHODOLOGY USED

The Linke turbidity factor for the atmosphere mass m = 2 (T_2) [18] and atmospheric aerosol optical thickness for the wavelength λ_0 = 0.55 μm (AOT) is used in this work as atmospheric transparency characteristics [26]. Atmospheric transparency characteristics were estimated from the results of direct solar radiation measurements carried out under conditions when the Sun's disk and the near-Sun zone in the radius of 5° from its center were cloud-free. When calculating the AOT for each station the total water content of the atmosphere was determined from the data on the partial pressure of the water vapor (e, hPa), incorporated into the meteorological information attended the actinometrical observations. The methodology suggested in [1] was used.

The series T_2 and AOT were analyzed for the 1976–2006 period at the Mangut, Chita, Ivolginsk, Borzya, Bogdarin (Trans-Baikal), Babushkin, Homutovo, Khuzhir, Baikal'skoe, Kazachinskoe (the area of Lake Baikal) as well as Tura, Erbogachen, Vanavara, Yeniseisk, Solyanka, Kuzedeevo stations over the Central Siberian Plateau south of 65° N for estimating the present-day regime of the atmospheric transparency in Central Siberia and Trans-Baikal territory. All listed stations, except the Babushkin and Baikal'skoe stations, which have been put out of operations since 2004 and 1997, respectively, perform actinometrical observations till now. Most of the actinometrical stations listed above are near rivers. The Kazachinskoe, Borzya, Yeniseisk, Erbogachen, Vanavara, Bogdarin, Chita, Mangut, Tura stations are located in the valleys of the Solyanka River, Kuzedeevo is on the hills and spurs with a height of 350–550 m, and also near rivers. A particular attention is paid to the stations located in the immediate vicinity of Lake Baikal: Baikal'skoe, separated from the lake with a high Baikal'sk ridge; Babushkin, at the southeastern coast of Lake Baikal over a vast not high cape jutting into the lake; Homutovo, at the southwestern coast of Lake Baikal, in the valley of the Kuda River; Khuzhir, on the Ol'khon Island; Ivolginsk separated from Lake Baikal with the Khamar-Daban and Ulan-Burgasy ridges.

Generally, the number of direct solar radiation measurements in the continental regions required for estimating the characteristics of transparency has an annual trend with the maximum in the summer months, which makes difficult and sometimes totally excludes the analysis of transparency in the winter months. For example, at the Tura, Erbogachen, and Yeniseisk stations, due to a peculiar character of the weather conditions, the number of observations used for getting the atmospheric transparency characteristics, over a period from November to February, does not exceed 10% of a total number of such cases per year. In this connection, at individual stations of the Near-Baikal and Central Siberian Plateau, in the winter months, it is impossible to get statistically provided multiyear means because of lack of data. For example, for the Kazachinskoe, Solyanka, Yeniseisk, Vanavara, Erbogachen, and Tura stations the multiyear mean T_2 and AOT values were calculated only for nine months (from February to October).

The Trans-Baikal territory as a whole is characterized by a high frequency of a cloudless sky, especially in the wintertime. Lower clouds used to be almost absent in that period. Over the period from 1976 to 2005, the total number the transparency characteristics obtained at the Trans-Baikal stations is 1.5–2 times longer than at the other stations. The maximum volume of the initial data was obtained at the Ivolginsk station, and the minimum, at the Kazachinskoe station.

For revealing different-scale time changes in the atmospheric turbidity for the regional stations the peculiarities of the annual AOT variations were considered in the following periods:

—1976–2005, a 30-year period (base), real conditions;

—1976–2005, a 30-year period excluding the periods with the pronounced consequences of the volcanic eruptions, "undisturbed" conditions;

—1994–2006, a period of relatively high transparency, "relatively transparent" conditions.

For each period multiyear mean monthly and annual T_2 and AOT values and respective coefficients of variations C_v were calculated; the differences of means for different periods of averaging and contribution of strong perturbations of the atmospheric transparency were estimated.

It is noteworthy that for getting regular information about the atmospheric aerosol properties the AERONET (Aerosol Robotic Network) was organized. The network consists of more than 100 stations; the results of their observations are given in the official site http://aeronet.gsfc.nasa.gov. Six such stations are in operation now in Asian Russia. These are the Irkutsk, Tomsk, Ussuriisk, Yakutsk, Krasnoyarsk, and Barnaul stations, whose information can be used for the analysis. Besides the other aerosol characteristics you can find in the open database the results of the atmospheric aerosol optical thickness τ_{a,λ_0} for the effective wavelength λ_0 = 500 nm at the Krasnoyarsk (2002–2003), Tomsk (2002–2007), Yakutsk and Irkutsk (2004–2007), and Ussuriisk (2005–2007) stations. The data for the Barnaul station are absent.

Table 1. Multiyear mean values of the T_2 turbidity factors of the atmospheric aerosol optical thickness (AOT) and their variation coefficients C_v (the period of averaging is 1976–1995)

Station	Latitude, grad N	Height above sea level, m	Year		April		July	
			T_2	C_v, %	T_2	C_v, %	T_2	C_v, %
Trans-Baikal								
Mangut	49.7	807	2.53	10	2.67	11	3.08	12
Borzya	50.4	675	2.48	13	2.61	17	2.80	14
Ivolginsk	51.8	562	3.03	10	2.99	17	3.43	9
Chita	52.1	671	2.84	13	2.83	17	3.23	13
Bogdarin	54.5	990	2.39	13	2.42	14	2.74	16
Lake Baikal region								
Babushkin	51.7	502	2.71	13	2.92	16	3.17	12
Khomutovo*	52.5	454	2.63	11	2.79	12	2.99	14
Khuzhir	53.2	487	2.49	15	2.60	20	2.82	15
Baikal'skoe**	55.3	478	2.73	14	2.98	15	3.13	15
Kazachinskoe	56.2	355	2.84	12	2.88	20	3.22	21
Central Siberian Plateau								
Kuzedeevo	53.3	203	3.06	12	3.17	18	3.41	12
Solyanka	56.2	359	2.61	15	2.63	18	2.90	13
Yeniseisk	58.4	77	2.77	14	2.70	20	3.03	18
Vanavara	60.3	252	2.82	13	2.71	14	3.00	15
Erbogachen	61.3	284	2.63	12	2.62	16	2.72	13
Tura	64.3	188	2.86	19	2.92	20	2.86	17

Note: * denotes the data for 1976–2002 (with missed data); ** denotes the data for 1976–1996.

A GENERAL CHARACTERISTIC OF THE CONDITIONS OF THE ATMOSPHERIC TURBIDITY IN NEAR-BAIKAL AND CENTRAL SIBERIA

Even the preliminary analysis of series of the turbidity factor T_2 and AOT from the data of the Near-Baikal and Central Siberia stations shows that the region considered is characterized by low atmospheric turbidity, especially compared to similar latitudes of European Russia. For example, if at the Trans-Baikal stations, annual mean T_2 and AOT values change within 2.5–2.9 and 0.11–0.16, then at the same latitudes of European Russia T_2 = 3.3, AOT = 0.20. Such differences are attributed to larger industrialization, differences in the character of the underlying surface (the feather-motly grass steppes, mainly plowed, are characteristic of the south of European Russia), and low water content of the atmosphere, characteristic of the Trans-Baikal regions. The scatter of the T_2 and AOT values observed at the stations considered has a non-ordered character and is attributed to meso- and micro-peculiarities of the region and peculiarities of the station location.

It was said more than once that in the lake basins, in general, and in the Near-Baikal region, in particular, the atmospheric transparency is higher [3, 4, 19, 20, 23]. It was noted as well that the atmospheric transparency is the highest in the Middle-Baikal region, and on the western coast of Baikal it is higher than on the eastern coast. This regularity, initially revealed based on a limited experimental material [3, 4], is also confirmed by the data for the period of 1976–2006. According to the data in Table 1, the highest transparency (both integral and aerosol) is observed at the Khuzhir station (the western coast of the central part of Baikal).

It is noteworthy that in Trans-Baikal the atmospheric transparency is also rather high. The Khamar-Daban, Ulan-Burgasy, and Ikatskii ridges spreading along the southern and southeastern coasts of Lake Baikal form orographic barriers, and the air masses, when overcoming these barriers, are significantly dehydrated. These ridges present a border, behind which the driest part of Eastern Siberia is located [12]. The climate continentality in the Trans-Baikal territory is more pronounced than at the same latitudes in the towns

Table 1. (Contd.)

October		Year		April		July		October	
T_2	C_v, %	AOT	C_v, %	AOT	C_v, %	AOT	C_v, %	AOT	C_v, %
Trans-Baikal									
2.31	14	0.13	30	0.22	35	0.15	39	0.09	52
2.21	13	0.11	42	0.16	53	0.10	47	0.07	60
2.59	15	0.18	26	0.20	40	0.20	23	0.11	48
2.49	15	0.16	35	0.19	41	0.17	34	0.11	49
2.08	15	0.11	44	0.18	49	0.12	52	0.06	73
Lake Baikal region									
2.46	15	0.14	35	0.20	37	0.16	34	0.08	67
2.31	14	0.11	30	0.17	42	0.12	51	0.07	51
2.24	18	0.11	50	0.16	54	0.11	58	0.06	90
2.53	14	0.14	29	0.21	27	0.15	33	0.08	75
2.46	17	0.17	28	0.21	44	0.17	57	0.10	57
Central Siberian Plateau									
2.65	13	0.18	31	0.21	41	0.19	32	0.10	46
2.32	21	0.12	50	0.15	51	0.12	46	0.08	94
2.52	21	0.15	39	0.16	54	0.15	52	0.10	79
2.36	17	0.17	30	0.19	37	0.14	46	0.09	63
2.33	17	0.13	35	0.17	40	0.10	45	0.09	59
2.46	23	0.17	46	0.21	44	0.12	56	0.14	100

of Western Siberia and the Far East. In winter severity and dryness as well as frost severity the region approaches the climate characteristic of Yakutia. At the Mangut, Borzya, and Bogdarin stations, annual mean T_2 and AOT values are close to T_2 and AOT values in the Middle-Baikal region. According to the Chita and Ivolginsk stations (the latter is 30 km southwest of Ulan-Ude), the atmospheric transparency is noticeably lower. Both these stations characterize the urban conditions; besides, the Ivolginsk station is under the effect of a local source, which causes stable atmospheric turbidity.

In the region considered, the tendency towards changes in the atmospheric turbidity from year to year are well pronounced; they are characteristic of the Russian territory as a whole: a monotonous decrease in the turbidity in 1976–2006 and a noticeable decrease in 1994–2006. Multiyear variations of T_2 and AOT values at the Chita (Trans-Baikal), Khuzhir (Near-Baikal), Solyanka (Eastern Siberia) stations are given as an example in Fig. 1. Changes in annual values of T_2 and AOT are quite synchronous; this indicates the leading role of aerosol in observed variations of atmosphere turbidity.

Thirty-year (1976–2005) mean T_2 and AOT values for year as a whole and for central months of the season (April, July, and October) are given in Table 1. As it follows from these data, the coefficients of variations of the mean T_2 and AOT values are rather high: for the monthly mean values they are larger than for the annual means and for the spring and especially for the fall months they are larger than for the summer values.

In order to reveal the influence of volcanic disturbances on the multiyear mean T_2 and AOT values for a 30-year period, multiyear meant T_2 and AOT values were calculated for a "undisturbed" time series (series 2). For that purpose, the periods of the pronounced consequences of large volcanic eruptions, when positive monthly anomalies T_2 and AOT were steadily above the standard deviation σ, were excluded.

The differences were calculated

$$\Delta_1 X = \frac{\overline{X}_1 - \overline{X}_2}{\overline{X}_2} \times 100\%,$$

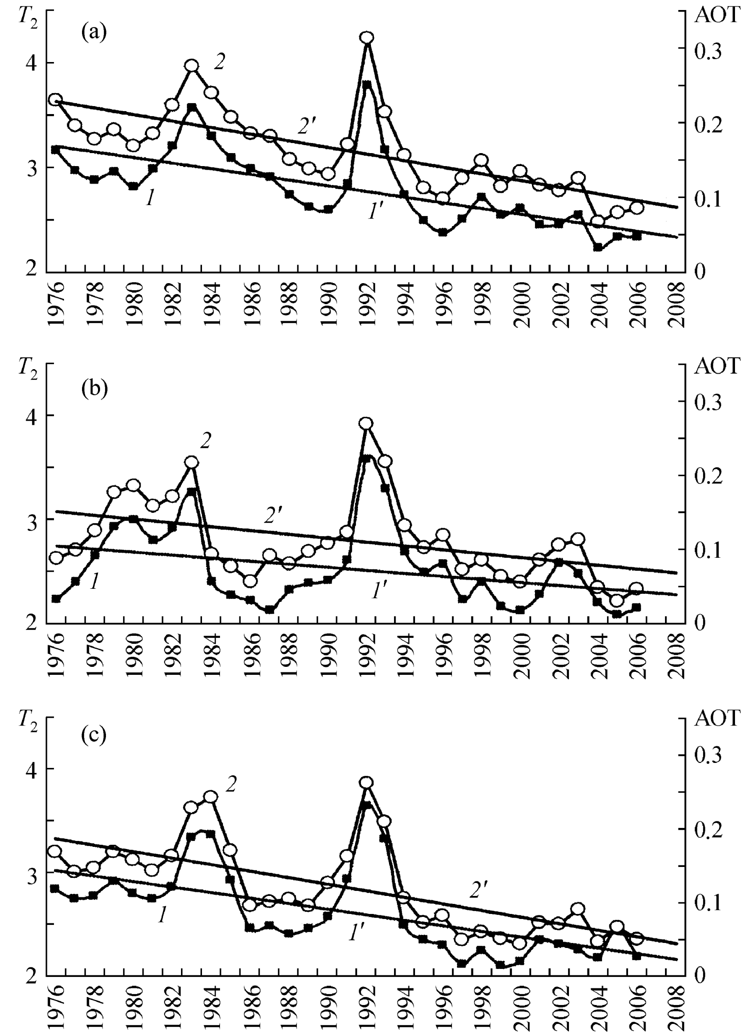

Fig. 1. Annual mean (*1*) T_2 and (*2*) AOT values at the (a) Chita, (b) Khuzhir, and (c) Solyanka stations in 1976–2006, and (*1*′, *2*′) their trends.

$$\Delta_2 X = \frac{\bar{X}_i - \bar{X}_2}{\bar{X}_2} \times 100\%,$$

where $\bar{X}_1$ are the mean T_2 and AOT values for base series 1 for the period of 1976–2005; $\bar{X}_2$ are the respective multiyear means for "undisturbed" series 2 for the same period; X_i are the T_2 and AOT values in the years of the maximally pronounced consequences of volcanic eruptions (1983 and 1992).

The results in Table 2 show that due to an abrupt increase in turbidity observed after the El Chichon and Pinatubo volcanic eruptions, the multiyear mean annual T_2 values over a period of 1976–2005 increased by 2–4%, and the similar AOT values increased by 6–15%.

As it follows from the data in Table 2, the anomalies of the annual T_2 ($\Delta_2 T_2$) values in the years of the maximally pronounced volcanic eruptions of El Chichon (1983) and Pinatubo (1992) vary from 15 to 30% in 1983 and from 20 to 40% in 1992, while the AOT (Δ_2AOT) anomalies amount to 50–85 and 80–150%, respectively.

The region under consideration is characterized as a region of the extreme fire danger; the hazard of fire exists from spring to the fall at the precipitation deficit and temperature rise, when the dry tropical air is transported from the desert Asian regions [8, 25]. In the Near-Baikal area the forest fire influence is mainly pronounced in the spring-summer months [4], in Central Siberia, in summer [8]. The forest fire smoke can lead to a significant increase in the atmospheric turbidity; in individual months, the monthly anomalies T_2 and AOT exceed the standard deviation σ. Such anomalies are seldom observed two months in a row and,

Table 2. Anomalies (%) of multiyear mean T_2 and AOT values in the periods when the El Chichon (1983) and Pinatubo (1992) eruption consequences are pronounced

Station	$\Delta_1 T_2$	$\Delta_2 T_2$		Δ_1AOT	Δ_2AOT	
		1983	1992		1983	1992
Trans-Baikal						
Mangut	3.0	18	33	10.6	78	97
Borzya	3.0	25	42	10.5	85	135
Chita	2.5	27	34	9.4	70	92
Ivolginsk	2.1	16	32	5.7	46	80
Bogdarin	3.5	28	37	11.8	84	127
Lake Baikal region						
Babushkin	4.2	23	45	12.4	68	115
Khuzhir	4.4	28	41	14.3	92	139
Kazachinskoe	3.0	33	21	6.7	76	42
Central Siberian Plateau						
Kuzedeevo	2.2	21	33	13.8	50	80
Solyanka	3.5	28	39	15.3	99	114
Yeniseisk	2.6	25	39	7.2	69	100
Vanavara	2.4	20	42	7.4	55	109
Erbogachen	1.5	17	28	5.8	50	76
Tura	1.6	24	33	5.7	55	149

as a rule, are not pronounced in the annual mean turbidity values. Over a period from 1996 to 2006, almost every day, from May to September, short-term increases in turbidity are recorded from the data on individual stations.

The peculiarities of annual variations of T_2 and AOT, when the data are averaged over 30 years (1976–2005), and in the "undisturbed" (1976–2005) and "relatively transparent" (1994–2006, series 3) conditions, are presented in Fig. 2 with a reference to the Chita and Solyanka stations; this example confirms the earlier presented peculiarity that the shape of the annual AOT or T_2 variations is sufficiently stable and noticeably changes only under "disturbed" conditions [6]. In the rest of periods, the AOT and T_2 values in the "real," "undisturbed," and "relatively transparent" conditions differ in magnitude; these differences change somewhat from station to station and from region to region. For example, at the Solyanka, Chita, and Khuzhir stations, the differences in the annual variations in means for different periods are well pronounced. At the Vanavara, Mangut, and Ivolginsk stations they are not well pronounced and mainly in a cold season. The revealed differences in the annual variations of T_2 and AOT for "real," "undisturbed," and "relatively transparent" conditions are statistically insignificant (Fig. 2), as they do not exceed in the magnitude the standard deviation of the monthly mean T_2 and AOT values for a base 30-year period.

In the period of "relatively high" transparency (1994–2006), the direct solar radiation, which reaches the earth surface, increased, on average, by 0.04–0.05 kW/m^2 at the solar angle of 30°, which caused a decrease in the annual T_2 values by 4–16%, and in the AOT values, by 16–40%. Detail data on changes in a mean transparency level in 1994–2005 relative to the atmospheric transparency in 1976–1995 are given in Table 3.

If multiyear variations in the annual T_2 and AOT values for the stations considered are identical (Fig. 1), then the annual variations of each of these parameters, as it follows from Fig. 2, have their specific characteristic features. Typical examples of the annual variations of T_2 and AOT are given in Fig. 3.

The T_2 annual variations with the maximum in the summer months (in June–July) are well pronounced at the Trans-Baikal stations. The AOT annual variations have fundamental differences. At all stations, the maximum AOT values are observed in April. From April to October, the AOT values decrease with the slight secondary maximum in July observed in some cases.

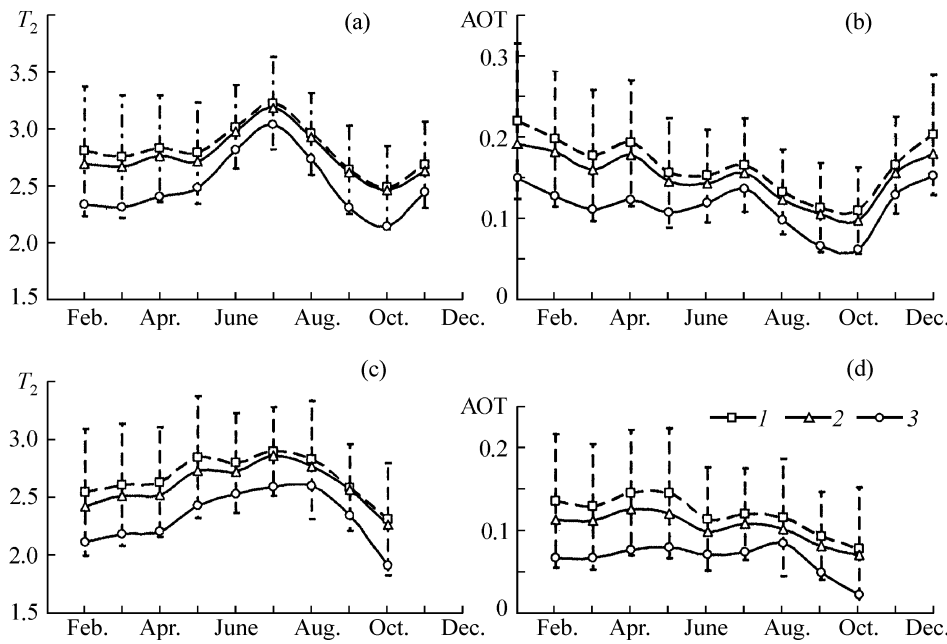

Fig. 2. Annual (a, c) T_2 and (b, d) AOT variations for the (a, b) Chita and (c, d) Solyanka stations under different periods of averaging. (*1*) 1976–2005 (real conditions); (*2*) (1976–2005) ("undisturbed" conditions); (*3*) 1994–2006 ("relatively transparent" conditions). Vertical segments denote standard deviations of monthly mean T_2 and AOT values for a base period.

Table 3. Differences Δ_3 (%) between multiyear mean T_2 and AOT values in different periods

Station	T_2			AOT		
	Year	Summer	Winter	Year	Summer	Winter
Trans-Baikal						
Mangut	4.4	–0.8	10.8	16.2	4.8	30.8
Borzya	14.2	13.9	14.5	39.5	38.5	40.5
Chita	16.1	13.0	19.3	37.8	36.0	39.6
Bogdarin	9.4	7.7	11.4	28.5	28.6	30.5
Lake Baikal region						
Babushkin	10.0	7.7	12.5	28.5	22.7	35.4
Ivolginsk	11.4	7.8	15.5	27.3	21.3	33.5
Khuzhir	12.4	10.5	–	39.6	35.5	–
Kazachinskoe	11.0	10.5	–	30.1	28.7	–
Central Siberian Plateau						
Kuzedeevo	14.3	12.6	16.2	34.0	31.8	36.2
Yeniseisk	15.8	19.1	–	40.1	50.1	–
Vanavara	8.8	4.0	14.4	24.1	15.6	31.6
Erbogachen	14.7	12.9	–	38.5	36.2	–
Tura	4.4	6.1	–	17.4	19.1	–

Note: $\Delta_3 = [\overline{X}(1976–1995) – \overline{X}(1994–2005)] / [\overline{X}(1976–1995)] \times 100\%$, where $\overline{X}$ is the multiyear mean T_2 and AOT values for the period given in the brackets.

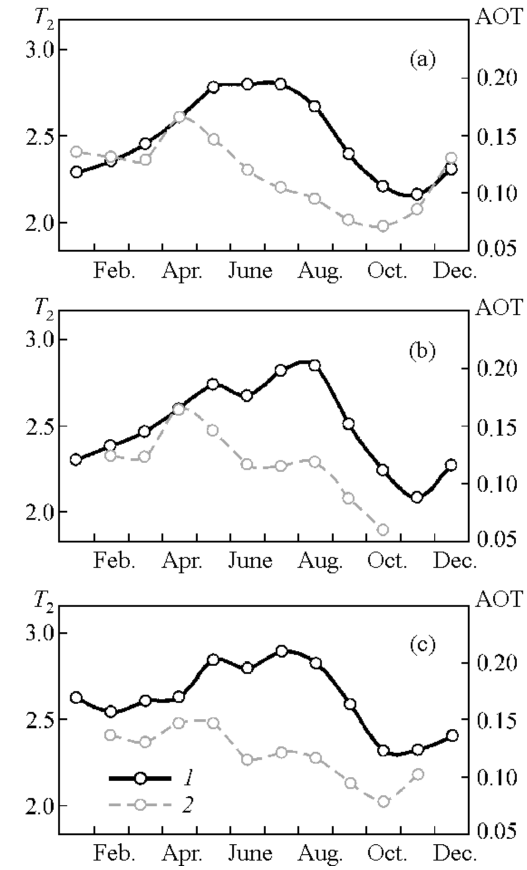

Fig. 3. The annual (*1*) T_2 and (*2*) AOT variations (the period of averaging is 1976–2005) for the (a) Borzya (Trans-Baikal), (b) Khuzhir (Near-Baikal), and (c) Solyanka (Eastern Siberia) stations.

The T_2 annual variations with the maximum in July–August are observed at the Near-Baikal stations (Babushkin, Kazachinskoe, and Khuzhir). The AOT annual variations are characterized with the maximum (well-pronounced or smoothed) in April and a weak secondary maximum in August. The AOT decreases from April to October.

Significant differences in the T_2 and AOT annual variations are also found at the Central-Siberian Plateau stations. The amplitude of the T_2 annual variations is generally smaller than that in the Near-Baikal and Trans-Baikal territory; the T_2 maximum values are observed from May to August. The maximum AOT values are observed in April–May, then AOT monotonously decreases reaching the minimum in October; the second summer maximum of the AOT is slightly pronounced.

The observed AOT spring maximum is, from the one hand, connected with the increased spring soil weathering, active after snow cover melting. On the other hand, in spring, when the temperature rises and under the influence of the earth surface heating, the effect of the Asian anticyclone weakens. The air mass transport with cyclones from southwest and west strengthens; the cyclones bring the warm dusty air from Central Asia and Kazakhstan as well as from the Asian deserts. Similar AOT variations are observed also in other regions and are confirmed by the data of observations within the AERONET [27].

In order to reveal the causes of discrepancies in the T_2 and AOT annual variations , the components of the attenuation of the solar radiation due to the effect of water vapor ΔS_w and aerosol ΔS_a [21] were calculated at the atmosphere mass 2 (for the solar angle of 30°). The generalized results of this calculation for the Near-Baikal and Trans-Baikal regions are given in Fig. 4; the urban stations of the Trans-Baikal territory are singled out into a separate category. The estimates derived demonstrated that the ΔS_w values for different Near-Baikal and Trans-Baikal stations differ little. The annual variations of ΔS_w repeat the annual variations of the atmospheric water content with maximum in summer (in Near-Baikal it is observed in June–July, in Trans-Baikal, in July–August), and minimum is observed in the winter months. In the spring months, the radiation attenuation due to the water vapor effect is somewhat less than in the fall months. No difference is observed in the ΔS_w variations over the periods of 1976–1995 and 1995–2006.

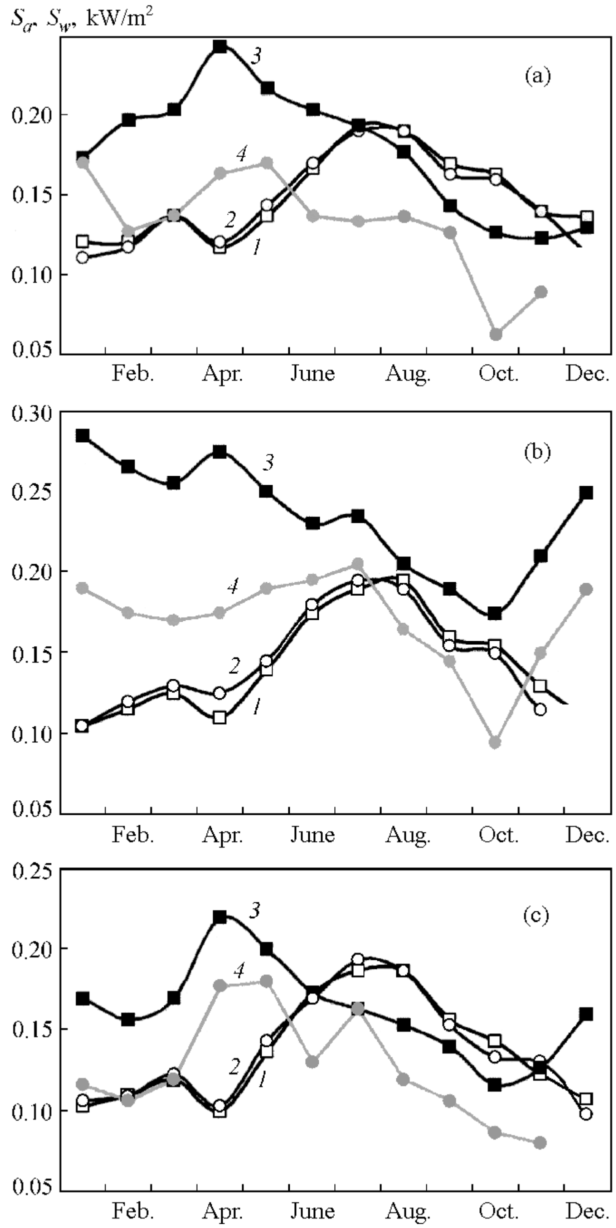

Fig. 4. Annual mean variations of the direct solar radiation attenuation (*1*, *2*) due to water vapor ΔS_w and (*3*, *4*) aerosol ΔS_a for (*1*, *3*) 1976–1995 and (*2*, *4*) 1994–2006. (a) The Near-Baikal stations; (b, c) Trans-Baikal stations; (b) urban and (c) rural conditions.

The annual variations of the radiation attenuation due to the aerosol ΔS_a are asymmetric: in the fall the attenuation is noticeably lower than in spring. The ΔS_a changes are to a significant extent determined by the atmosphere stratification and the influence of local air pollution centers. In the cold period of the year, at the inversion stratification, the aerosol particles cluster under the inversion layer, which leads to the increased ΔS_a. In the annual variations the ΔS_a, maximum is observed in the spring months, when a large amount of dust enters the atmosphere. Large ΔS_a values, recorded in May both in the region of Lake Baikal and in the Trans-Baikal territory, are associated with the increased number of forest fires of that time. The spring ΔS_a maximum and the summer ΔS_w maximum determine the annual variations of the integral atmospheric turbidity T_2 with the maximum (generally one) in the summer months (Fig. 2).

The peculiarities of the atmosphere state in different regions as well as changes in the attenuation of the direct solar radiation due to the aerosol over the last 13 years are distinctly traced from the data in Fig. 4. The aerosol attenuation of the radiation prevailed in 1976–1995 in the winter-spring period; at the urban

Table 4. Tendencies of temporal changes in T_2 and AOT annual values for "undisturbed" conditions

Station	1976–2006				1976–1995			
	ΔT_2/year	R^2	ΔAOT/year	R^2	ΔT_2/year	R^2	ΔAOT/year	R^2
Trans-Baikal								
Mangut	–0.001	0.00	–0.001	0.05	0.018	0.31	0.002	0.21
Borzya	–0.014	0.35	–0.002	0.39	–0.010	0.12	–0.003	0.33
Chita	–0.026	0.68	–0.004	0.74	–0.015	0.15	–0.003	0.28
Ivolginsk	–0.016	0.42	–0.003	0.51	–0.004	0.02	0.0	
Bogdarin	–0.015	0.39	–0.002	0.46	–0.015	0.16	–0.002	0.22
Lake Baikal region								
Babushkin	–0.005	0.05	–0.001	0.09	–0.013	0.17	–0.003	0.37
Khuzhir	–0.013	0.20	–0.002	0.32	–0.012	0.05	–0.002	0.10
Kazachinskoe	–0.008	0.06	–0.002	0.17	–0.007	0.01	0.0	
Central Siberian Plateau								
Kuzedeevo	–0.019	0.34	–0.003	0.43	–0.009	0.04	0.0	
Solyanka	–0.026	0.60	–0.004	0.74	–0.017	0.14	0.003	0.27
Yeniseisk	–0.017	0.29	–0.003	0.29	–0.002	0.00	0.0	
Vanavara	–0.006	0.06	–0.001	0.17	–0.002	0.00	–0.001	0.11
Erbogachen	–0.018	0.32	–0.003	0.36	–0.004	0.01	0.0	
Tura	–0.010	0.03	–0.001	0.02	–0.007	0.02	–0.001	0.05

Note: ΔT_2/year and ΔAOT/year correspond to the coefficient a in the regression equation $y = ax + b$; R^2 is the coefficient of determinateness.

stations this effect was observed throughout the year. In 1995–2006, on average, the total level of the aerosol pollution not only decreased but it became much lower in the annual variations. In the summer-fall period (June–November), the radiation attenuation due to the water vapor ΔS_w exceeded the ΔS_a even at the urban stations.

In considering the temporal variability of T_2 and AOT one cannot ignore long-term tendencies of changes in the parameters said. There is a number of works where it is said that in the second half of the 20th century a tendency towards the increased atmospheric turbidity was observed in most Russian regions. In [14] it was shown that the decreased atmospheric turbidity that occurred after 1994 turned out to be so significant that on the whole for the last quarter of the 20th century, in Russia, one should state the increased atmospheric transparency. The AOT variations for 1976–1994 and 1976–2003 were presented in [15] for individual stations of different climatic zones. The increased AOT, although statistically insignificant, was ascertained for the first period. This conclusion, which is formally correct, was principally derived only as a result of the fact that the years with the pronounced volcanic eruption implications, when the stationary process of the T_2 and AOT changes in time is disturbed, were not excluded from consideration. The characteristics of the linear trends of T_2 and AOT, derived for "undisturbed" conditions in the 1976–2006 and 1976–1995 periods, are presented in Table 4 for the stations of the region considered.

A tendency towards decreased turbidity (both integral and aerosol) is observed with different statistical significance in 1976–2006 at all stations of the region. A slight tendency to a decrease in T_2 with steady state or an insignificant decrease in AOT is observed at most stations in 1976–1995. There are stations, where an increase in T_2 and AOT is observed (generally slight).

The intercomparison of the results obtained and the AERONET data can be performed only for the monthly AOT values. On the whole, the data series at the AERONET stations located in Siberia are fragmentary and are in need of a special analysis. Especially it refers to the Ussuriisk station data, where very large values of $\tau_{a,\,0.5}$ are recorded: in some cases they exceed 0.7. Figure 5 gives a pictorial presentation

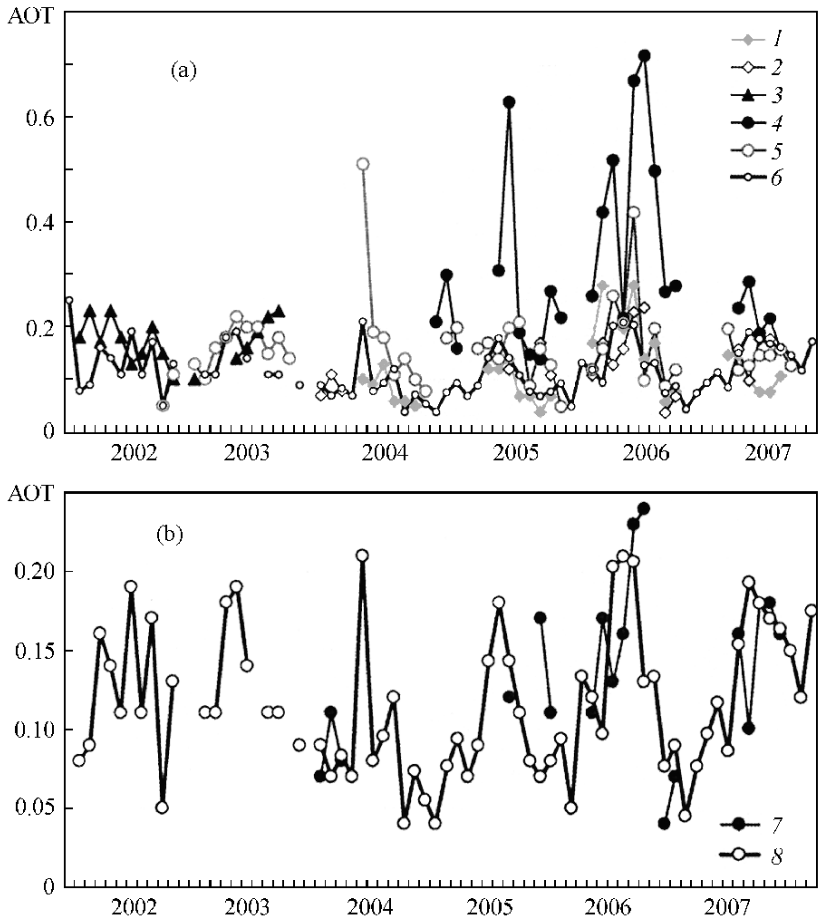

Fig. 5. Monthly changes of $\tau_{a,0.5}$ and AOT in 2002–2007. (a) At the AERONET and Roshydromet stations (Near-Baikal area); (*1*) Yakutsk; (*2*) Irkutsk; (*3*) Krasnoyarsk; (*4*) Ussuriisk; (*5*) Tomsk; (*6*) Near-Baikal stations; (b) at the Irkutsk station (AERONET) (*7*) and at the Khomutovo station (*8*) using the methodology [26].

about the results of the $\tau_{a,0.5}$ measurement at the AERONET. The $\tau_{a,0.5}$ data at the Irkutsk station (AERONET) and the AOT data of the Khomutovo station (the methodological estimation [26]) give qualitatively commensurable results (Fig. 5b). The AOT data averaged for the Baikal region agree with the $\tau_{a,0.5}$ variations from the AERONET data, if to exclude the Ussuriisk station data and individual emissions recorded at the Yakutsk and Tomsk stations from consideration (Fig. 5a). The relatively large $\tau_{a,0.5}$ values noted in 2006 at the Yakutsk station are not confirmed by the integral T_2 and aerosol atmospheric turbidity AOT data derived from the network actinometrical observational data.

CONCLUSIONS

The Near-Baikal, Trans-Baikal and Central Siberia regions present a sufficiently homogeneous region in the atmospheric turbidity. Significant spatial changes in turbidity are generally pronounced at the urban stations.

The differences in multiyear mean values, revealed in the T_2 and AOT annual variations, for “real,” “undisturbed,” and “relatively transparent” conditions are within a standard deviation of the monthly mean T_2 and AOT values for a base 30-year period.

T_2 and AOT changes in time are stipulated by the atmospheric aerosol scavenging of the recent years. The estimates derived show that in the period of “high” transparency (1994–2006) the T_2 values decreased by 4–15% and AOT, by 16–40% relative to respective multiyear means for 1976–1995.

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