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Transmissivity of the atmosphere above the Russian territory: observed climatic changes

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Abstract. We report the systematic investigation of spatial-temporal changes of integral and aerosol atmosphere turbidity above the territory of Russia in the period 1976-2016. The data referring both to the whole territory of Russia and some certain regions are discussed.

1. Introduction

Ambient monitoring is a complex observing system; it includes environmental conditions observation, estimations and predictions of changes of ambient conditions affected by natural and anthropogenous factors. Solar irradiation is one of the basic climate forcing factors. Solar irradiation measurements have been in the focus of researchers' interests during last decades [1–8]. Transmissivity of the atmosphere, solar angle and cloudiness determine solar irradiation income at a ground surface, therefore being essential characteristics of irradiation regime. The most prominent and long-term changes in the transmissivity of the atmosphere occur under influence of volcanic eruptions and anthropogenous activity; relatively short-range changes are the result of smoke haze caused by peat-bog and forest fires.

In the mid- 20th century the researchers' attention was centered on the investigation of integral transmissivity of the atmosphere. Last decades the issue of systematic and regular investigation of long-term changes of aerosol turbidity of the atmosphere (aerosol optical thickness, AOT) has come to the fore. In the 60's 33 stations (11 stations at European part of USSR, ETC, and 22 – at Asian, ATC) have been chosen for determination of atmosphere transmissivity. Further data from 228 stations were used for investigation of the dependencies of coefficient transmissivity change.

Nowadays data from different observing systems underlie the atmosphere transmissivity monitoring. The system includes land-based actinometrical network of RosGidroMet (116 stations that register direct solar irradiation), international network AERONET (Aerosol Robotic Network – 9 stations in Russian Federation) and satellite monitoring system, implemented by satellites Terra and Aqua.

Data, obtained from Roshydromet actinometrical network, provide information about integral and aerosol transmissivity of the atmosphere (from the mid- 20th century). AERONET data and satellite measurements have provided information about AOT of the atmosphere only since 2000 year. Nevertheless, these data are used when analyzing the tendency of AOT change in different regions [9–13]. AERONET data alongside with satellite information allow characterization of the atmosphere transmissivity at vast areas.

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The aim of the work is to systematize and generalize data on spatial-temporal changes of integral and aerosol transmissivity of the atmosphere both at the Russian territory as a whole and at certain regions for the period from 1976 to 2016.

2. Material and methods

Used data base

The objects of investigation were series of monthly and annual values of turbidity factors T2 and AOT over the period of 40 years (1976–2016) for the basic regions of Russia. Three regions in European Russia were considered: North, South and Center. Six regions from Asian Russia were chosen: Ural, West Siberia, North-East, Central Siberia, Baikal region, Transbaikal, Far East. Calculation methodology used for integral turbidity characterization and general characteristics of the considered regions are given in [14, 15]. The series of transmissivity characteristics for a number of stations were formed in the period from 1957 to 1960. The said series are regularly amplified with the current data.

A tricenarian period (1976–2005) was chosen as a base period for determination of normal values of T_2 and AOT.

The changes of monthly and annual values of T_2 and AOT were analyzed for two periods: 1976–2016 and 1994–2016. The second mentioned period is featured by the absence of powerful volcanic eruptions and, therefore, the increase of income solar irradiation and growth of the atmosphere transmissivity. Sometimes it is called «brightening» — the period of aerosol translucence of the atmosphere [3].

The series of monthly and annual values of T_2 and AOT are described by linear equations. The velocity of change of T_2 and AOT is estimated by a coefficient in a regression equation ($a \times 10$), for 10 years.

The results of the analysis are represented for three regions: Ural, the South of European part and the North-East of Asian Russia. This choice provides a glimpse of observable changes in regions with different aerosol load.

3. Results and discussion

The atmosphere turbidity over the territory of Russia increases in the direction from North-East to South-West. The highest transmissivity of the atmosphere is observed in the north-west of Asia. The South of European part of Russia is characterized by high turbidity [9–13]. The European Russia is featured by a growth of turbidity in the direction from north to south; the same tendency is valid for Asian part, though it is less prominent.

The time dependencies of T_2 and AOT that have been registered within 55 years can be divided into three periods: 1) 1960-1981 years – stable growth of atmosphere turbidity; 2) 1983–1992 years – slight decrease of atmosphere turbidity; 3) from 1994 till present – significant decrease of atmosphere turbidity. Noticeable growth of average annual values of T_2 and AOT is caused by powerful eruptions of volcano El Chichón and volcano Pinatubo.

Figure 2 shows the alteration of the annual courses of T_2 and AOT in regions with different aerosol load. The turbidity turndown along the Russian territory is determined by the curves for the North-East of Asian Russia and the South of European Russia.

The World Meteorological Organization (WMO) recommended to choose the period 1961-1990 as the basic period for monitoring and estimating current climate changes. Taking into consideration the duration of available series of normal values of T_2 and AOT, we have chosen a tricenarian period 1981–2010, which should be applied (according to WMO recommendation) when performing climatic service works. The comparison of average values within different periods was completed using data from several stations. The averages within the period 1961-1990 are just over than the averages within other periods 1981–2010 and 1976–2005; averages within the period 1976-2005 are the closest to the base averages WMO.

The analogous dissimilarities for the long-term annual averages for individual months fluctuate in a wider range: in winter-time these differences are more noticeable than in summer.

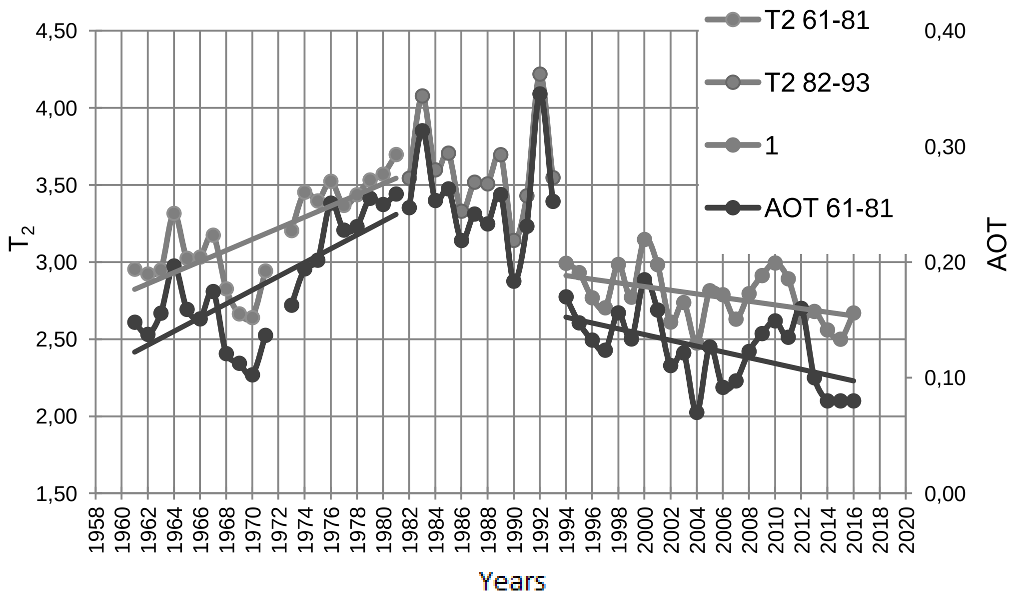

Figure 1. T_2 (1) and AOT (2) courses at the station "Tsimlyansk", period 1961-2016.

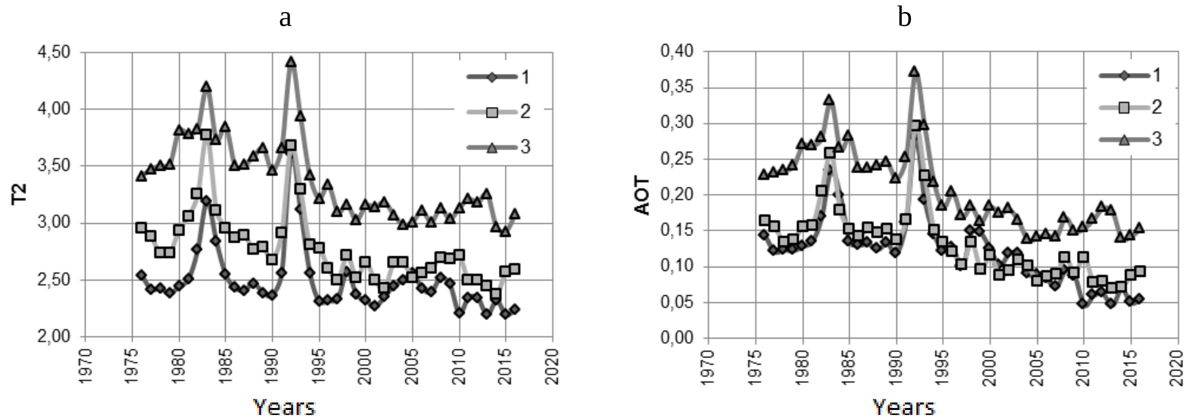

Figure 2. T_2 (a) and AOT (b) courses in the period 1976-2016. 1 – North-East of Asian Russia, 2 – Ural, 3 – South of European Russia.

Table 1. Comparison of average annual T_2 values.

Station	T_2 av	Δ T_2 av			
	1961-1990	1981-2010	1976-2005	1955-2016	1994-2016
Umba	2.74	–0.08	–0.05	–0.08	–0.27
Valday	2.90	–0.15	–0.09	–0.13	–0.39
Kamennaya Ctep	3.25	–0.15	–0.03	–0.25	–0.46
Tsimlyansk	3.30	–0.13	–0.02	–0.19	–0.50
Verhnee Dubrovo	2.76	–0.03	–0.05	–0.02	–0.11
Khabarovsk	2.91	–0.06	–0.04	–0.10	–0.31

The average values of T_2 and AOT for the regions are represented in figure 3. It clearly demonstrates the diversity of atmosphere aerosol load. The highest transmissivity is typical for the North-East of Asian Russia; the region with the highest turbidity is the South of European Russia. The atmosphere transmissivity remains stably high over recent years.

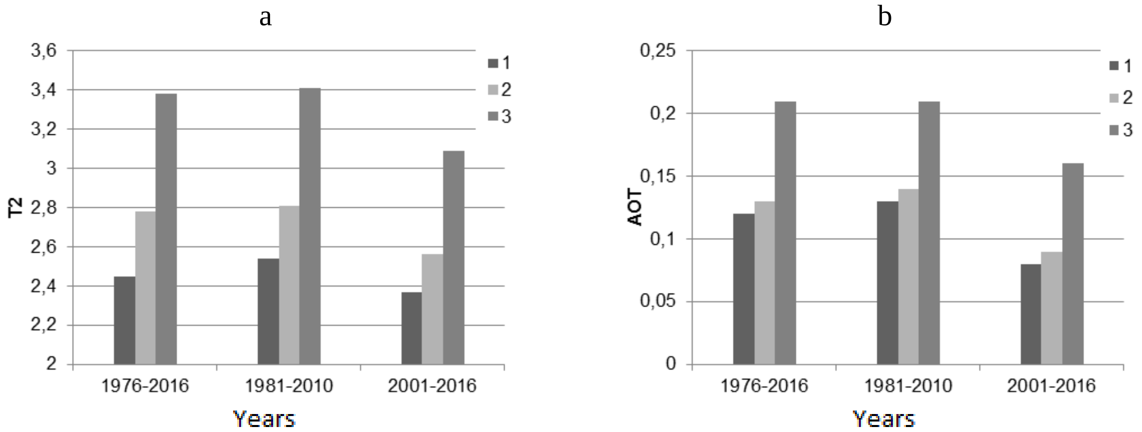

Figure 3. Average long-term T_2 (a) andAOT (b) in different periods.
1 – North-East of Asian Russia, 2 – Ural, 3 – South of European Russia

The evaluation of the annual course of T_2 and AOT shows the decrease of the average monthly values for all the regions; the most drastic reduction is observed in the first part of the year. However, the annual course trends of T_2 remain intact – the extremes refer to the same months. The diminishing of the average monthly values at Asian territory resulted in decrease (in some cases even in vanishing) of spring maximum of AOT (in April) [16].

The linear approximation of series of monthly values of T_2 and AOT allowed to estimate changes of the said characteristics (figure 4).

The period from 1994 till present is characterized by the absence of powerful volcanic eruptions. Only short-term (not more than 2 months) and local atmospheric disturbances have been registered during this period. A noticeable decrease of average long-term annual and monthly values of integral (T_2) and aerosol (AOT) atmosphere turbidity arised in period the of “aerosol transmissivity” (see table 2).

We have analyzed the structure of deviations of monthly turbidity characteristics from its average long-term values. Fractional histograms of T_2 and AOT anomalies frequency (%) have been constructed and analyzed; the step being 0.5 σ. The anomalies for the periods 1976-1993 and 1994-2015 have been considered. The results of the analysis for the two regions are represented in figure 5.

The anomalies of AOT and T_2 that have been registered during the period 1976-1993 stay within the + σ with a probability of 65-80 %. No reversed-polarized anomalies exceeding –2σ have been observed within the period under review. Normal-polarized anomalies exceeding 2 σ and, sometimes, 3 σ are dedicated by perturbations caused by volcanic eruptions. The possibility of occurrence of such high anomalies does not exceed 8%. Maximal frequency of AOT and T_2 usually lies in the range 0.0 ÷ −0.49 σ. West Siberia and South of European Russia are exceptions, because maximal frequency for the said regions lies in the range 0.01−0.50 σ.

The anomalies of monthly AOT and T_2 values within the “aerosol transmissivity” period fit into the range +σ (in most cases), but the structure of the anomalies’ values distribution is different – histogram shifts towards negative values. The sift is the more significant, the more pronounced is the difference between the average values of the considered periods. There are practically no normal-polarized anomalies exceeding 2σ within the period 1997-2015 while there is a noticeable increase of

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AOT negative deviation frequency in the range $-2\sigma \div -\sigma$. The AOT maximal frequency is –0.99 до –0σ and T_2 - –0.99 ÷ –0.50 σ.

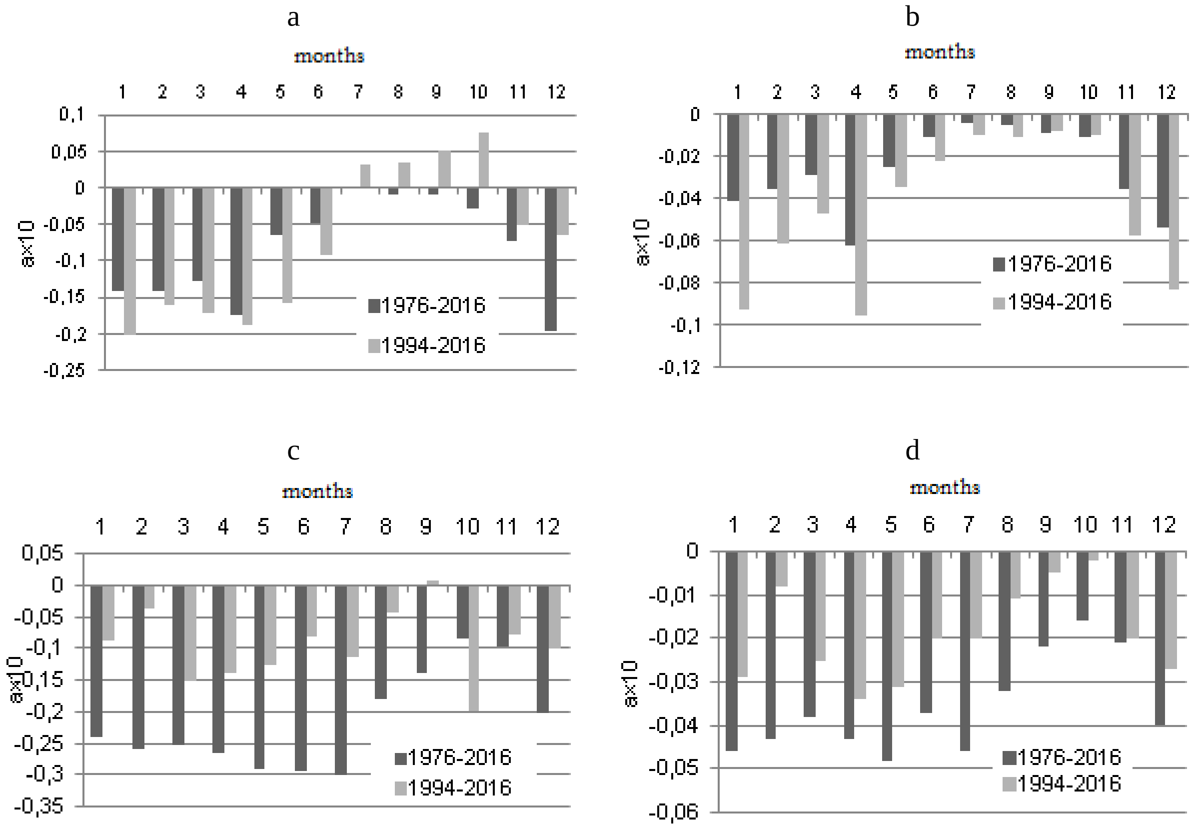

Figure 4. Annual course of coefficient of a linear trend of T_2 (a, c) and AOT (b, d) in 10 years: a, b – North-East of Asian Russia, c, d – South of European Russia.

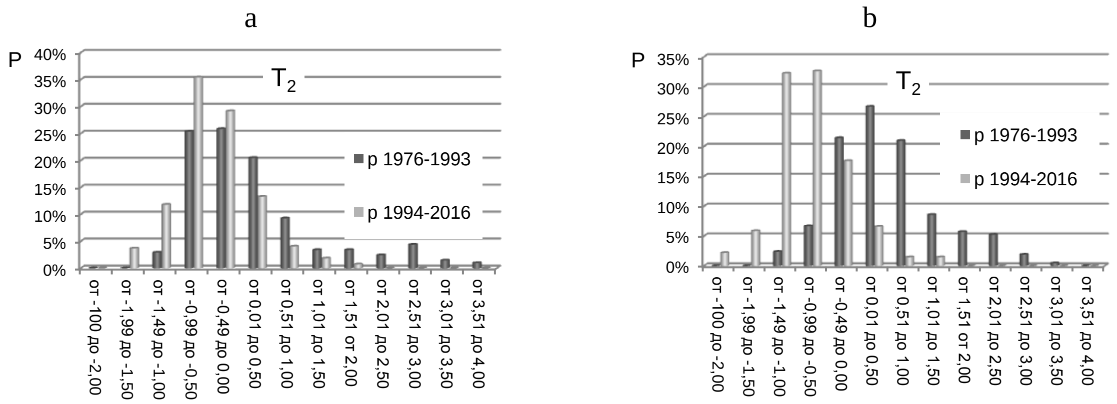

Figure 5. Histograms of T_2 anomalies frequencies (P) for the regions: North-East of Asian Russia (a) and South of European Russia (b).

The annual and monthly values of AOT and T_2 within the territory of West Siberia and the North-East of Asian Russia have less changed than in other regions within the “aerosol transmissivity” period. The histograms of the T_2 anomaly frequency for both considered periods coincide with each other. Histograms for AOT are also similar, though there is a slight shift of the anomalies towards negative values.

The histograms of T_2 and AOT anomalies for the South of European Russia differ qualitatively. The most prominent transmissivity changes (for the period 1976–2015) have happened in this region. Anomalies have maximal frequency in the range –0.99 ÷ –0.50 σ. AOT and T_2 anomalies have probability of 82−85 % and stay within the limit 0 ÷ −1.49σ.

Table 2. Divergence of average annual values of T_2 and AOT.

Region	**T_2**		**ΔT_2**	**AOT**		**ΔAOT**
	1976–1993	**1994–2015**		**1976–1993**	**1994–2015**	
North of European Russia	2.84	2.56	−10.3	0.17	0.10	−47
Center of European Russia	3.33	2.77	−17.8	–0.21	0.12	−50
South of European Russia	3.71	3.13	−16.6	0.26	0.17	−39
Ural	3.02	2.59	−15.1	0.17	0.10	−47
West Siberia	2.91	2.62	−10.3	0.17	0.11	−40
North-East of Asian Russia	2.63	2.38	−9.8	0.15	0.10	−36
Central Siberia	2.84	2.53	−11.5	0.18	0.11	−47
South of Asian Russia	2.88	2.57	−11.3	0.19	0.12	−41
Far East	3.01	2.68	−11.4	0.19	0.13	−35

Comments: $\Delta T_2 = (T_{2\,1976-1993} - T_{2\,1994-2015}) / T_{2cp.}$; $\Delta AOT = (AOT_{1976-1993} - AOT_{1994-2015}) / AOT_{cp}$. $\mathbf{T_2}$, AOTav**.** – mean for the period 1976−2005 .

4. Conclusion

Monitoring of atmosphere transmissivity is based on the data, available by different observing systems: land-based actinometrical network, AERONET and satellite monitoring system. Data available by the above-mentioned systems located in different parts of the Earth are coinciding.

The decreasing tendency of the integral and aerosol turbidity of the atmosphere has been observed within the territory of Russia during last decades; substantial interannual variability of monthly and annual T_2 and AOT values is in evidence. Northern regions of Russia (both Asian and European) are defined by the highest transmissivity of the atmosphere.

Aerosol cleaning of the atmosphere above Russia in the period 1994–2017 is characterized by a stable decrease of atmosphere turbidity. There are some peculiarities in the course of T_2 and AOT anomalies in several regions. Practically no normal-polarized anomalies of T_2 have been registered during the period 1994-2010 in the South of European Russia though recently they have been noticed in the South of Asian Russia. Periods with normal-polarized anomalies are typical for the Far East.

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