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Spatial Variations in the Air Turbidity Factor above the European Part of Russia under Conditions of Abnormal Summer of 2010

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Abstract—We analyze spatial variations in the air turbidity factor T obtained from the interpolation of ground-based solar radiometry data within the territory (40°–70° N, 30°–60° E) in summer 2010. The abnormal heat and connected fires of summer 2010 changed the mean values of air turbidity and the character of its spatial variations. As a result, a "tongue" of increased values of the turbidity factor was observed in the south-to-north direction in July, and a closed region of anomalous high T was formed over the territory (48°–55° N, 37°–42° E) to the south of Moscow and partly covered the Moscow region in August. Such a pattern resulted from blockage preventing from ingress of air masses from the west and producing closed air circulation over the European Part of Russia (EPR).

Keywords: turbidity factor, air transparency, spatial variations, fires, blocking anticyclone.

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The work presents the spatial variations in the air turbidity factor (T) according to ground-based measurement data from 18 solar radiometry stations within the territory (40°–70° N, 30°–60° E) in summer 2010. We have shown earlier [1–3] that the spatial distribution of the aerosol optical depth (AED) over the territory of Russia averaged over more than 30 years (1976–2007) corresponds to the model of global atmospheric aerosol distribution over Eurasia and the satellite AED monitoring results, presented in the 3rd and 4th IPCC reports [4, 5]; it shows a decrease in the aerosol turbidity from southwest to northeast. The events of summer 2010 (abnormal heat and forest and peatbog fires) evidently changed both the average values of air turbidity and the character of its spatial variations. Therefore, our estimates are of interest in the analysis [6] of the situation on the European Part of Russia (EPR) in summer 2010.

The integral air transparency

$$P = (S/S_0)^{1/2}, \tag{1}$$

where S is the direct solar radiation to the normal-to-flux surface, reduced to the average distance between the Earth and the Sun and a solar altitude of 30°; S_0 is the solar constant equal to 1.367 kW/m^2.

The Linke turbidity factor is unambiguously correlated with P:

$$T = \lg P/\lg Pi = (\lg S_0 - \lg S)/(\lg S_0 - \lg S_i) = -\lg P/0.0433, \tag{2}$$

where $S_0 = 1.367$ kW/m^2, S_i is the value of direct solar radiation near the underlying surface in the ideal atmosphere at the optical air mass $m = 2$ (solar altitude is 30°). The parameter T shows how many times the attenuation of solar radiation in the real atmosphere is stronger than in the ideal one [3, 7, 8]. It is evident that variations in the turbidity factor during the abnormally hot summer of 2010 were mainly determined by the aerosol component of the atmosphere, which was caused by the income of aerosol from mass peatbog and forest fires.

Table 1 presents the coordinates of solar radiometry stations on the EPR [9]; data from it were used in this work. The long-term annual average (over a "postvolcanic" period of 1994–2009) values T_{post} for summer months and the corresponding monthly values T_{2010} for 2010 are given in Table 2, along with the monthly average maxima of T and the relative difference (%) $D = (T_{2010} - T_{post})/T_{post}$. As is seen, the average July and August T in 2010 and in the "postvolcanic" period differ by −6% and +4%, respectively (the differences D vary from −28% to +11% of the average value for a certain station in June and from −22% to +25% in July). The value of $D = (T_{2010} - T_{post})/T_{post}$ is 14% in

August (for the region) and varies from −11% to +48% for certain stations.

The values of T were averaged over decades (10-day intervals) for the summer months of 2010 and compared with the long-term monthly average (1994–2009) values. The comparison results are presented in Table 3 for both regional average and maxima. It can be seen from Table 3 that the maximum turbidity effects were observed in the 3rd decade of July and the 1st and 2nd decades of August, which is in a good agreement with the published information [6, 10, 11, 14]. Anomalies of the atmospheric gas composition and AED (according to the ground-based measurements and satellite data for summer 2010) show that the central part of the EPR was under the conditions of a stationary blocking anticyclone from the middle of July to the middle of August. The anticyclone favored the accumulation of gaseous and aerosol components in the atmosphere, which was maximally manifested in the 1st decade of August.

Spatial variations in T are shown in the maps in Fig. 1. To interpolate the data of the stations to the whole region under study (Table 1), we used features of the MATLAB package, i.e., the option for creating a homogeneous grid for the EPR region under study, the option of bilinear (horizontal and vertical) interpolation of data from 18 stations to the territory (40°–70° N, 30°–60° E), and the projection of the function $T = F(\varphi, \lambda)$ (where φ and λ are the longitude and latitude, respectively, for each of the observational points) to the grid.

The spatial distribution of the mean T_{post} (for June, July, and August) for the "postvolcanic" period corresponds to the results obtained earlier [1] for the long-term annual average AOD. In this period, T_{post} quasi-monotonically decreased from southwest to northeast; the regions of localization of regional tropospheric aerosol sources are invisible (except for Archangelsk). The June–July average values of T at the Archangelsk station have been increased during the "postvolcanic" period: a local (and/or regional) atmospheric aerosol source is traceable; it can be both frequent natural forest fires and anthropogenic industrial factors in this Russian region.

The pattern differed significantly before 2010. In June, the spatial variations in T were close to distributions of T_{post} with a certain northward shift of the regions of maximum transparency ($T = 2$–2.5) with a decrease in means for June (Table 2) throughout the region in comparison with the "postvolcanic" period. In July, the monotonicity in a decrease in the turbidity was obviously disturbed in the northeast direction. A south-to-north "tongue" of increased values of the turbidity factor is observed ($T = 3.5$–4.0). Finally, in August, an epicenter (closed region) of anomalous air turbidity ($T = 4.5$–5.5) was formed within the region 48°–55° N and 37°–42° E, which is located to the south of Moscow and covering the Moscow region by its periphery ($T = 4.0$–4.5). This pattern resulted from the action of the blocking anticyclone, which prevented air mass ingress from the west, provided for closed air circulation in the EPR, and a favored temperature rise over the EPR and a rapid increase in the forest fire area. Fire aerosols accumulated in the atmosphere through this period. This process was the most pronounced in the 1st decade of August. Our pattern of spatial distribution of T in August 2010, obtained from ground-based measurements of the direct solar radiation flux, is in a good agreement with

Table 1. Coordinates of solar radiometry stations

Latitude	Longitude	Name
67.0	51.2	Kotkino
66.7	34.3	Umba
64.6	40.5	Archangelsk
64.4	55.2	Irael'
62.2	50.4	Ust-Vym'
61.5	39.0	Kargopol'
60.3	30.3	St. Petersburg
58.8	56.2	Chermoz
58.0	33.3	Valdai
57.6	44.9	Nolinsk
51.9	43.7	Rostoshi
51.6	38.4	Nizhnedevitsk
51.4	48.3	Ershov
51.1	40.7	Kamennaya Step'
47.7	42.1	Tsimlyansk
46.5	41.3	Gigant
45.1	39.0	Krasnodar
43.5	39.8	Sochi

Table 2. Long-term monthly average values of the turbidity factor T and the corresponding values for summer 2010 along with the regional maximum values of mean T

Period	Month	Mean (maximum)	Excess of $D = (T_{2010} - T_{post})/T_{post}$	Standard deviation in the series of monthly average values for different stations
1994–2009	June	3.0 (3.9)		13%
	July	3.2 (4.2)		13%
	August	3.2 (4.3)		14%
2010	June (165)	2.95 (4)	–6%	18%
	July (250)	3.42 (4.1)	+4%	19%
	August (125)	3.73 (5.3)	14%	21%

Note: The number of daily average values of T used in the averaging is mentioned in the parenthesis in the second column.

Table 3. Excess of regional 10-day mean and maximum values of T in summer 2010 over the long-term values in the "postvolcanic" period (1994–2009) $D_{dec} = (T_{dec} - T_{month})/T_{month}$ in the EPR

Period	Dates of month	$D_{dec} = (T_{dec} - T_{month})/T_{month}$ for EPR means	$D_{dec} = (T_{dec} - T_{month})/T_{month}$ for EPR maxima
2010, June	1–10	–8%	0%
	11–20	–6%	+14%
	21–30	–6%	+6%
2010, July	1–10	–1%	–3%
	11–20	–5%	4%
	21–31	+17%	+27%
2010, August	1–10	+29%	+50%
	11–20	+16%	+121%
	21–31	–14%	–17%

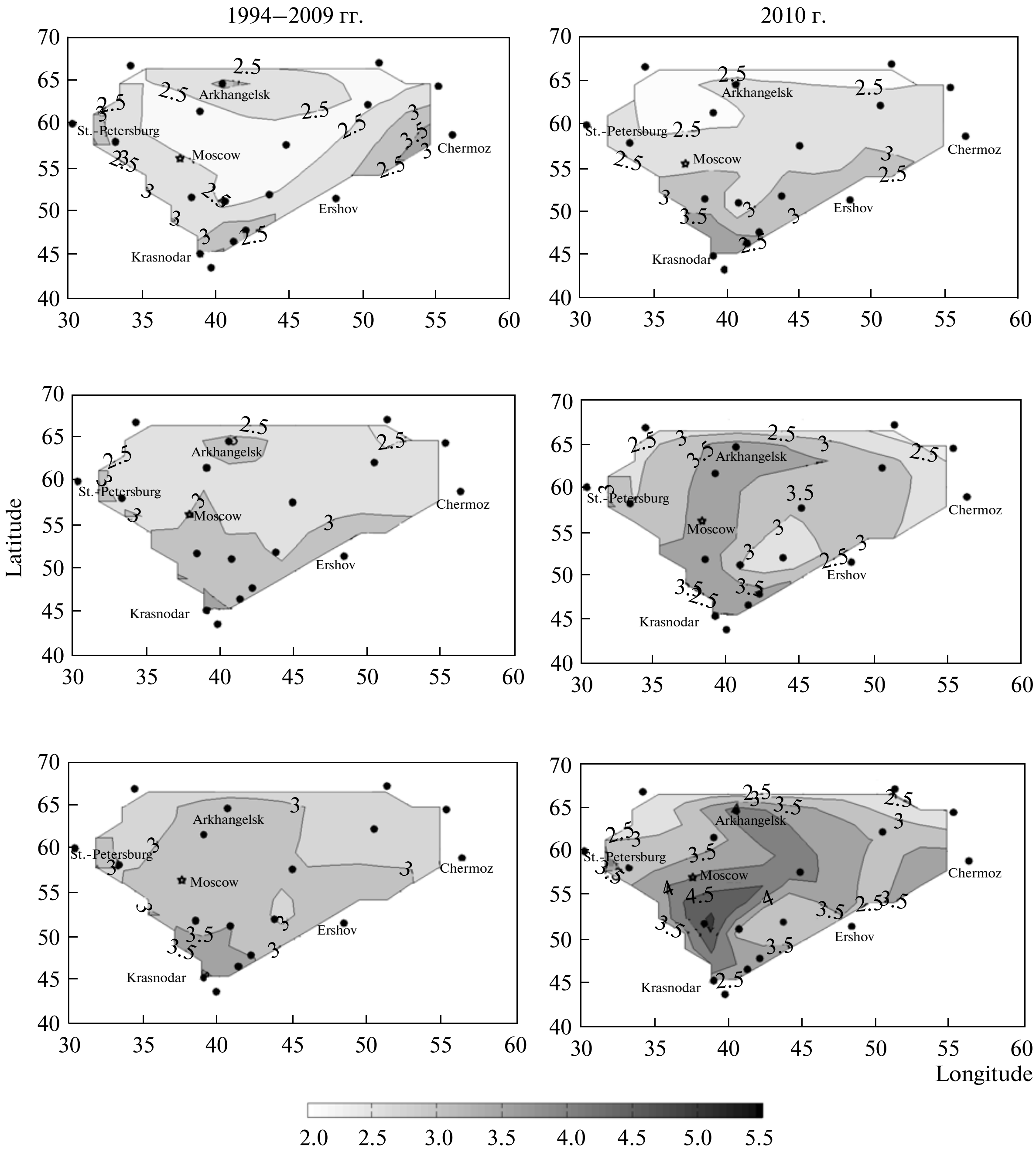

Fig. 1. Spatial distribution of mean values of the turbidity factor T for June, July, and August in 1994–2009 (left) and in summer 2010 (right).

the map of AOD distribution in the EPR (within the region 50°–65° N, 30°–55° E) in the 1st decade of August presented in [11].

Figure 2 shows the evolution of spatial variations of T in June–July 2010 (over 10-day periods) in more detail. The air turbidity was maximal in August; therefore, the mapping of such spatial variations is difficult due to data incompleteness. However, the time variations in anomalies of mean T as compared with long-term data are evident from Table 3; they sharply increased in the 3rd decade of July (from –5 to +17%) and reached their maximum in the 1st decade of August (29%). A sharper drop was observed in the 3rd decade of August (from 16 to –14%). The processes of turbidity increase and the following decrease are more evident from variations in the T maxima in the region.

Mutual correspondence in the ground-based (the turbidity factor T) and satellite (AOD) estimates of the

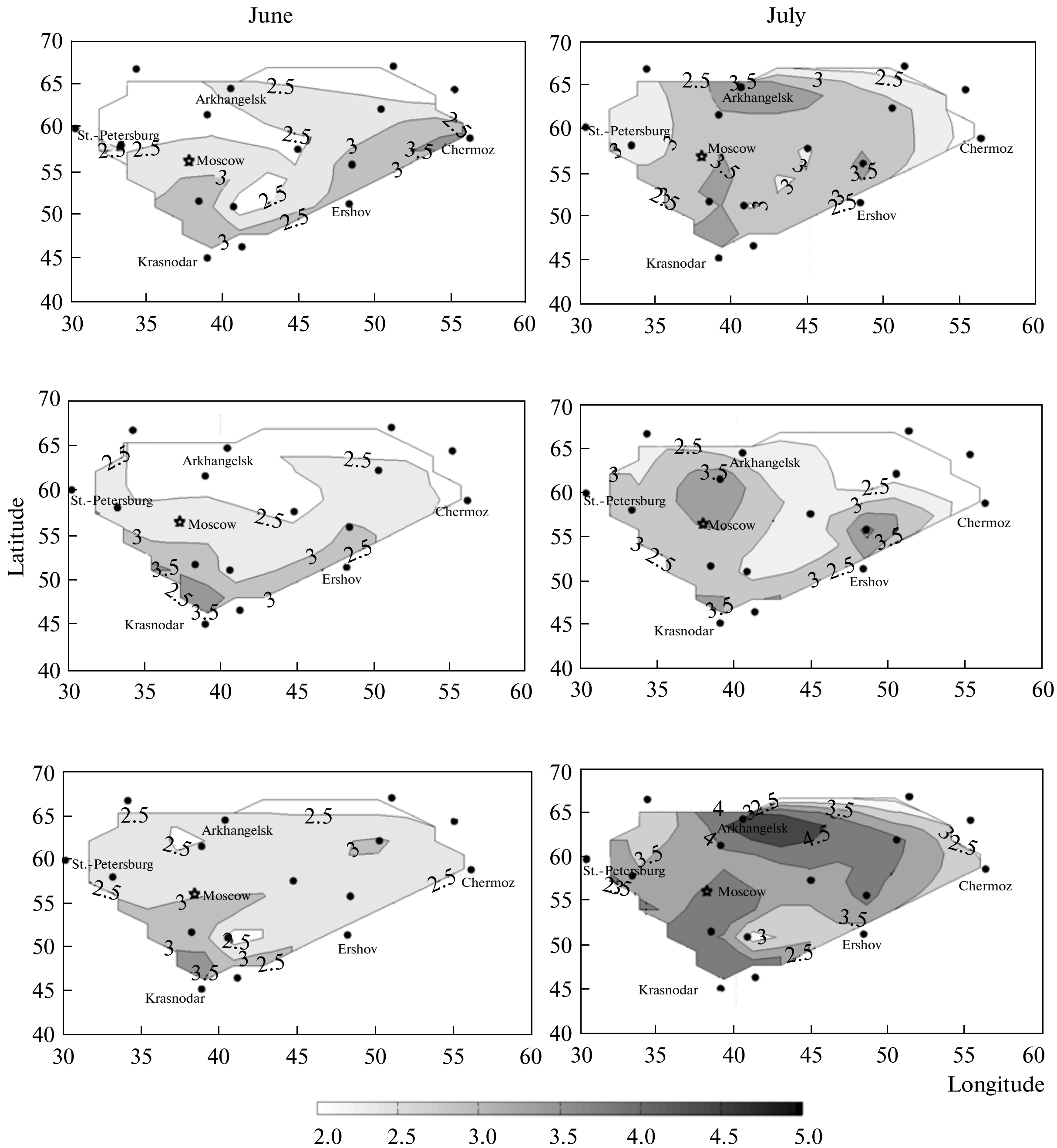

Fig. 2. Spatial distribution of 10-day average values of the turbidity factor for June and July of 2010. Top down: the 1st–10th, the 11th–21st, and the 21st–30th days of the month.

daily average values was analyzed for several stations in the conditions of high differences in the aerosol turbidity of the atmosphere during the anomalous summer of 2010. Level-3 data for cells of 111 × 63 km were used in the analysis and estimation of AOD from the MODIS data [12–14]. The results of a coordination of the temporal variations in two signals are shown in Fig. 3 for the Nizhnedevitsk station (from June 3 to September 27, 2010). The quite satisfactorily correlation $R^2 = 0.8$ was obtained; it is less with another coordination. The reason for the divergences is evident: distortions of ground-based signals due to the fall of scattered light into a receiver and distortions of both satellite and ground-based signals due to thin high-level clouds.

Thus, we have ascertained the peculiarities of spatial variations in the air turbidity factor in summer 2010 in comparison with the long-term average spatial variations, which have been manifested in both distri-

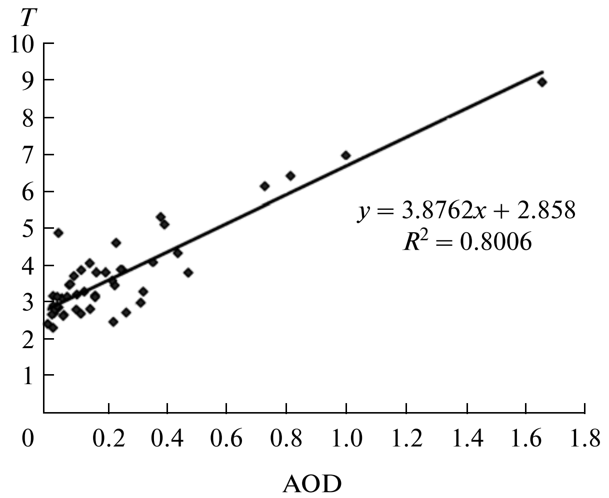

Fig. 3. Comparison of daily average AOD estimated from the MODIS data [11–13] and the ground-based measured turbidity factor T for the Nizhnedevitsk station from June 3 to September 27, 2010.

bution character and the value of the anomalies of the turbidity factor.

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