SMALL-SCALE SPATIOTEMPORAL VARIABILITY OF THE ATMOSPHERIC TRANSMISSION AND SOLAR RADIATION

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We present analysis of regularities in the small-scale spatiotemporal variability of the transmission and radiative properties of the atmosphere revealed from the results of atmospheric optics investigations in Tomsk region. Three main aspects were treated: 1) diurnal variation of the atmospheric transmission components (aerosol, water vapor) causing a decrease in the solar radiation influx in the evening period; 2) peculiarities of variations of the atmospheric transmission in the neighboring regions (urban – forest area) and the urban effect on the radiation regime; 3) interrelations of synoptic variations of individual components and the influence of the air masses changes, typical for the West-Siberian region, on the parameters under study.

INTRODUCTION

One of the possibilities to improve the methods and schemes of radiation-climatic calculations is to account for peculiarities in the small-scale variability of radiative properties of the atmosphere. Among those there are duration of the sun shine (DSS), aerosol optical thickness (AOT), and water vapor column density (WVCD). The primary cause of the paucity of data regarding these problems, and sometimes their contradictory quality, is poor accuracy and low regularity of the relevant measurements. The development of information and measuring system for the radiation experiments based on the techniques from Refs. 1–3 makes it possible to perform complex and more detailed investigations into the variability of the atmospheric transmission components, DSS and their influence on the solar radiation influx. Some of the results have briefly been discussed earlier[4–5] but in this paper we present a comprehensive summary of these results.

1. DIURNAL VARIATION

According to data of long-term observations at the actinometric network,[6] diurnal variations of the DSS, total, Q, and direct, S, radiation are asymmetric relative to the noon time and counter directed, as the direct and total radiation in the afternoon have low values, although the sun shine duration increases. It is clear that the third factor, removing this contradiction, is diurnal variation of the atmospheric turbidity. To assess the influence of diurnal variation of integral transmission, we have used the results of investigations of AOT and WVCD during summer in Tomsk[7,8] supplemented by the data obtained in 1997. Figure 1 illustrates the averaged dependences of the normalized diurnal variation of AOT and WVCD with the emphasis on the statistical significance of the main extrema. Shown here are the calculated values of the integral transmission T_{Σ} in the spectral range from 0.35 to 0.5 μm and the atmospheric optical mass $m = 1$.

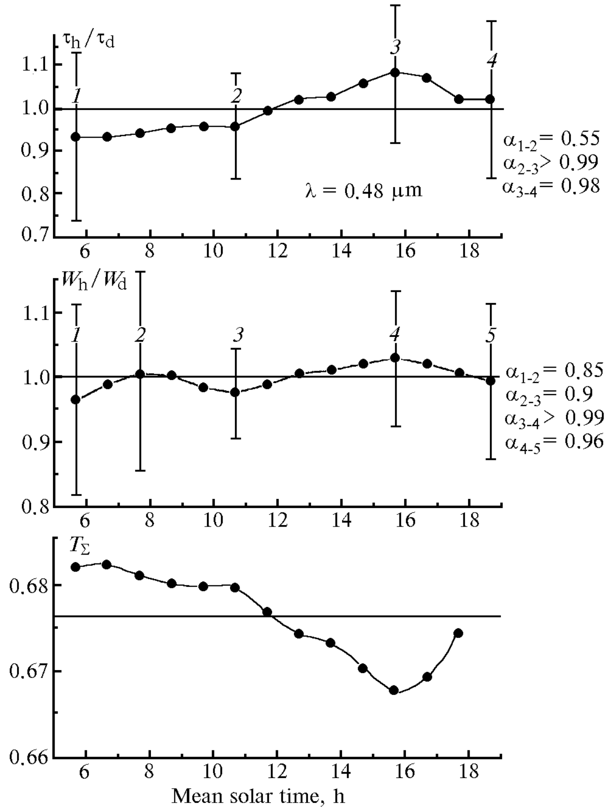

FIG. 1. Mean diurnal variation of AOT (τ), WVCD (W), and integral transmission of the atmosphere (T_{Σ}) over Tomsk in summer (α_i is the confidence probability calculated by Student criterion).

The calculations of direct solar radiation have shown the following. Due to the diurnal variation of cloudiness

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(DVC) at a constant transmission, the total influx of direct radiation during half a day is less by 1.3% than that during the second (evening) half of the day. At the same time, diurnal variation of the atmospheric transmission not only compensate for the effect of cloudiness but also decreases the radiation influx during the evening time. As a result, under the average conditions the evening radiation influx is 1% less than the morning one. Of course, other conditions may occur on particular dates in contrast to the average long-term data. For example, in summer experiments carried out in 1997 there was observed a relatively high atmospheric transmission without any marked diurnal variation. As a result, the Q and S quantities have been found to be affected only by cloudiness and large radiation influx was observed during the evening period too (Fig. 2).

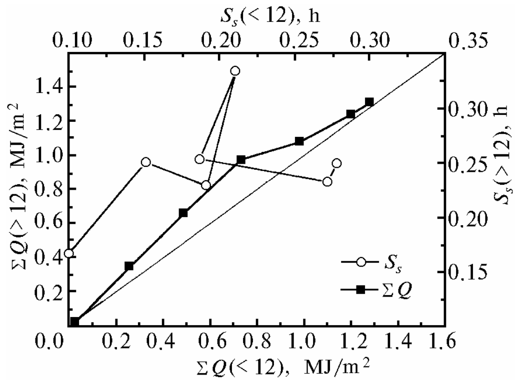

FIG. 2. Partial sums of the total radiation influx ΣQ and DSS *(S_s) at time moments symmetric relative to the noon as observed in 1997.*

2. INFLUENCE OF THE CITY

The increased atmospheric turbidity in the area of industrial centers is a known fact in small-scale regions. To obtain quantitative data on the atmospheric turbidity differences, quasi-synchronous measurements of the spectral transmission of the atmosphere have been conducted in Akademgorodok (Tomsk) and in a wood land area 60 km far from Tomsk. The variation of hourly mean values of the AOT and WVCD over a two-week period is shown in Fig. 3. Note, that because of the influence of cloudiness (its space-time distinctions) it was impossible to achieve the complete synchronization of the measurements. Even at a hour-long averaging of the data some results should be eliminated from the data set. Nevertheless, from the above data it follows that at the scale of synoptic variations of AOT and WVCD in the two areas vary consistently. In the diurnal variation of AOT the differences and shifts are observed. Table I gives the differences and interrelations of WVCD, AOT, and the Angstroem parameter α (that characterizes selectivity of the spectral behavior of τ^a). To evaluate the influence of the enhanced turbidity of the urban atmosphere on the radiation influx, the spectra of direct radiation were calculated for a horizontal surface taking into account the extinction of radiation by aerosols

$$S^a_\lambda = S_{0\lambda} \cos z \exp[-\tau^a_\lambda \, m(z)],$$

where $S_{0\lambda}$ is the extraterrestrial value of the solar constant; z is the solar zenith angle; m is the optical mass of the atmosphere. Besides, we also obtained the daily sums of the integral (over the spectrum) direct radiation and daily deficit of the radiation influx in the urban area. The calculations have shown that the difference in the direct radiation fluxes due to the difference in attenuation by aerosol reaches 7.5 W/m^2 at noon, even under conditions of a relatively high atmospheric transmission. Slight decrease in the radiation influx also occurs because of the WVCD variation. As a result of these calculations the total diurnal deficit of direct radiation in the city was 0.406 MJ/m^2 under cloudless conditions and about 0.17 MJ/m^2 under the average cloudiness (the relative decrease was 2%).

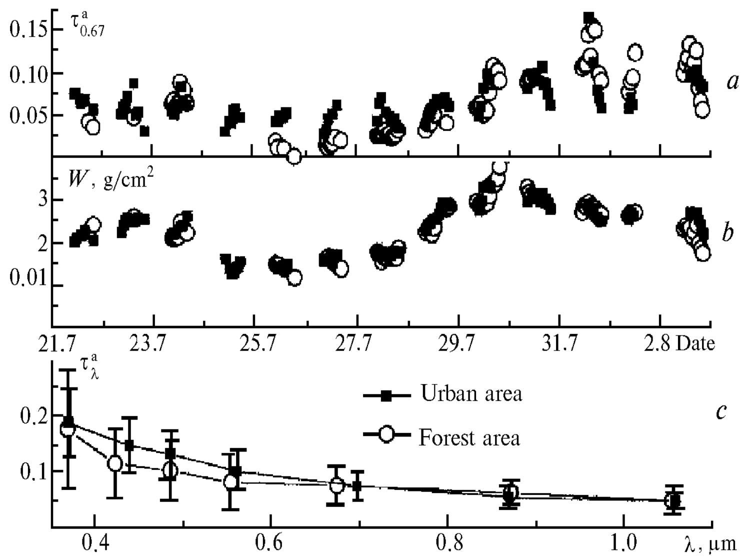

FIG. 3. Variation of the AOT (a), WVCD (b), and the mean spectral behavior of the AOT in two geographic regions (c).

TABLE I. Difference of the atmospheric turbidity in two regions.

Characteristics	Mean		SD	Coefficient of mutual correlation	Relative difference, %
	urban area	forest area			
An T (0.48 μm)	0.132	0.103	0.05	0.70	23
n b q , g/cm^2	2.64	2.51	0.35	0.76	5

3. SYNOPTIC EFFECT

Regardless of the obvious fact that synoptic processes effect the atmospheric transmission[7,9,10] and radiation, it is difficult to quantitatively estimate the influence of particular synoptic objects on the atmospheric transmission. A consideration of even the simplest question on the influence of air mass type, for the city of Tomsk, is a very complicated task since Tomsk is located deep within the continent. Taking into account the distance to the basic air-mass sources, the marked distinctions should be expected only when arctic air masses invade.

Figure 4 shows the variability of day-time values of basic characteristics indicating the type of air mass during the observations. One can see from this figure that, on the whole, the variations of AOT, WVCD and other quantities agree with the air mass change. It is also seen that in the CAA all the characteristics have, as a rule, lower values. From the histograms of the occurrence frequencies for τ, α, W (Fig. 5) it follows that under conditions of CMA the distributions have one mode which is located in the region of relatively large values.

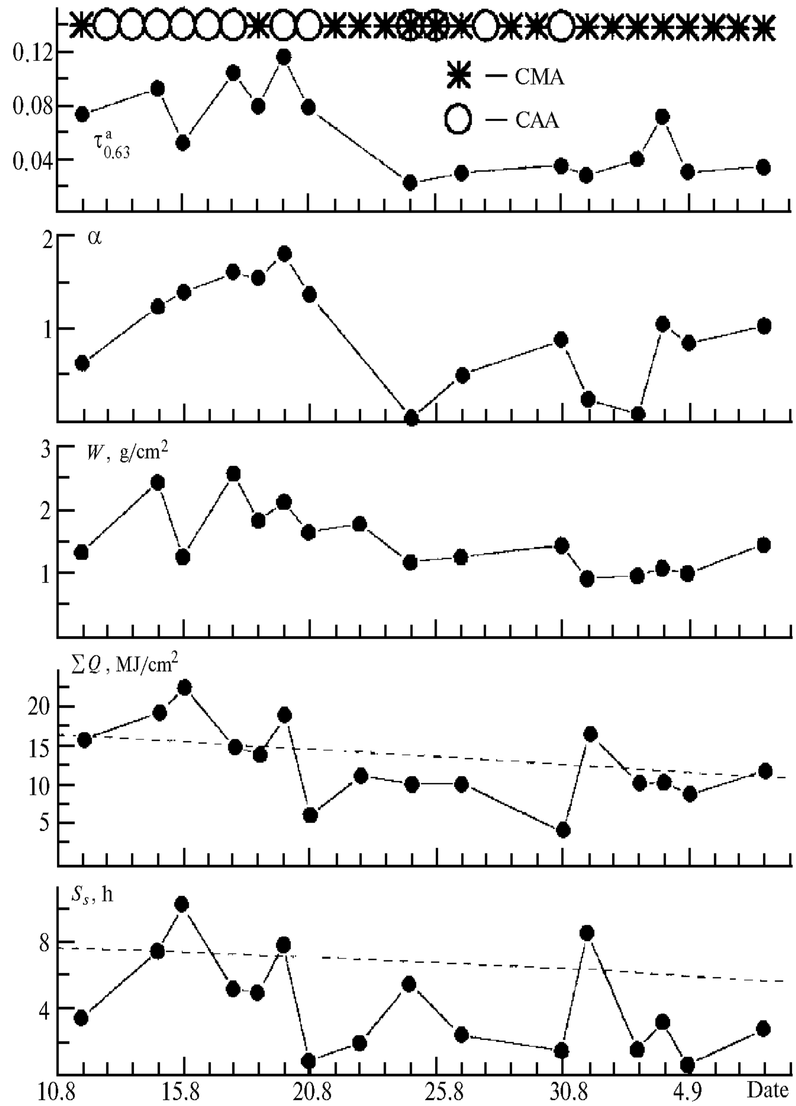

FIG. 4. Day-to-day variability of the AOT, Angstroem parameter α, WVCD, DSS, daily sums of total radiation ΣQ and the types of air mass – continental moderate (CMA), continental arctic air (CAA).

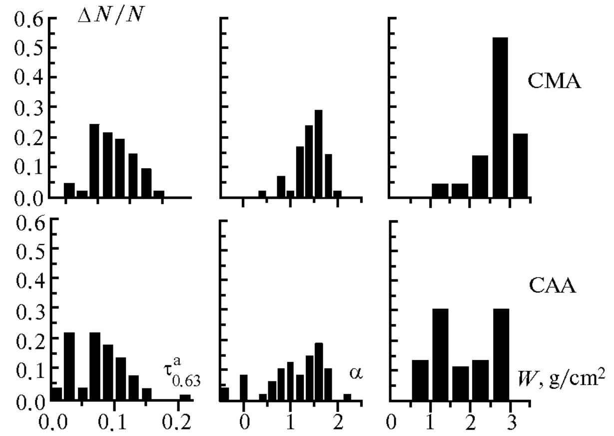

FIG. 5. Histograms of the occurrence frequencies for τ^α, α, and WVCD in air masses of two types.

For CAA in all the histograms we also observe the maximum similar to CMA and, besides, there exists the second mode in the region of low values. The broadening of the histogram and appearance of the second mode may be due to the transformation of CAA properties (aging of air mass) as air mass moves away from the source of its formation.

Synchronous variation of the total content of aerosol and moisture during the air mass change resulted in the occurrence of “synopticB interrelation among separate characteristics (see Table II and Fig. 6).

TABLE II. Matrices of the correlation coefficients (at the 0.95 *level those are* 0.27 *in CAA and* 0.31 *in CMA).*

Characteristics	CAA				CMA			
	$\tau^a_{0.48}$	$\tau^a_{0.87}$	α	W, g/cm^2	$\tau^a_{0.48}$	$\tau^a_{0.87}$	α	W, g/cm^2
$\tau^a_{0.48}$	–	0.65	0.74	0.84	–	0.69	0.79	0.40
$\tau^a_{0.87}$		–	0.22	0.59		–	0.24	0.49
α			–	0.71			–	0.40
W				–				–

The interrelation is closer for the AOT in the short-wave spectral range and in the arctic air mass. The latter can easily be explained by the fact that the variation range of τ^a, α, W in CAA may be determined from the minimum values characteristic of the formation zone (practically non-transformed mass) to the values typically observed in CMA in the case of arrival of an aged arctic mass. At middle latitudes the CMA is natural air mass and so its transformation is less essential. Therefore, within the CMA or when a large bulk of data (Fig. 7) is available the interrelation between τ^a and W breaks.

The only regularity in the above variability is the existence of the lower boundary $\tau^a_{\min}$, which increases as the moisture content grows. Similar result was obtained in Ref. 10, where a possibility of immediate effect of WVCD (in the range $W > 1$ g/cm^2) on the formation of the aerosol particle spectrum and τ^a_λ was proposed. Assuming this mechanism to be realistic, one may, however, offer more simple synoptic explanation of the dependence $\tau^a_{\min}(W)$. The minimum values of AOT are typical for arctic air, also characterized by the minimum WVCD. As CAA transforms and its properties change to moderate air, the magnitude of W and the value of the minimum possible turbidity $\tau^a_{\min}$ increase simultaneously.

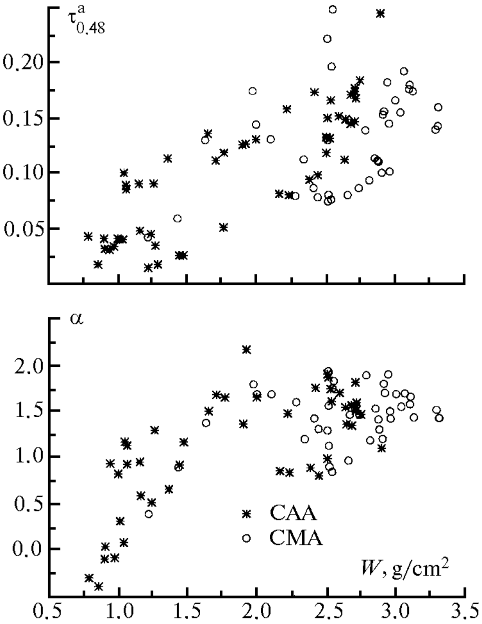

FIG. 6. Scatter diagrams for τ^a, α, and WVCD in air masses of two types.

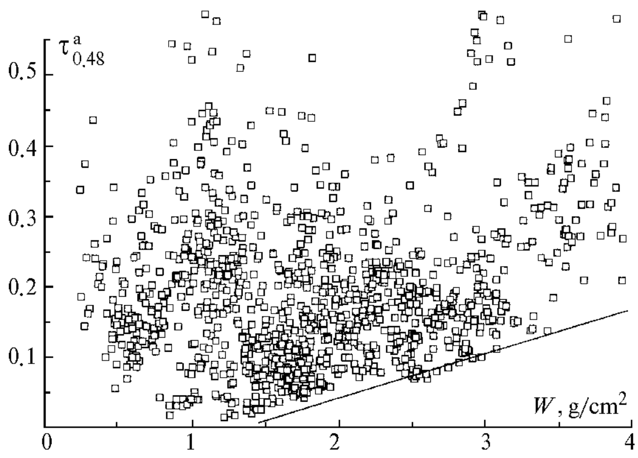

FIG. 7. Comparison of the AOT and WVCD values measured in Tomsk during summer time in the period from 1992 to 1997.

To determine the characteristics of transmittance and radiation of different air masses, we selected two periods of observations when either CMA (11 Aug. – 20 Aug.) or

CAA (24 Aug. – 07 Sept.) dominated. The data on the statistical characteristics obtained are given in Table III. Note, that samples of the values τ, α, W for these two periods turned out to be statistically distinguishable at the level of significance being 0.95. The mean values of the characteristics are much larger in CMA while their relative variability is more pronounced in CAA. The estimates of the effect of air mass differences on the solar radiation influx have been obtained with the use of a LOWTRAN-7 model. The calculations of diurnal sums of direct radiation ΣS^P for the middle of every period and clear sky conditions have shown that in a CAA the increase in the radiation influx is 7.4%. If the effect of the astronomic factor is excluded (seasonal 3.3% decrease in the radiation, see dashed lines in Fig. 4), then the differences between ΣS^P values, in the two air masses, may be even larger – 10.7%. Actually, under real conditions, the above-mentioned increase of direct and summed radiation was not observed because the change of air masses was accompanied by an essential drop of S_s because of the cloudiness. In particular, the magnitude of ΣQ decreased in CAA by 34.8%, regardless of an increase in the atmospheric transmittance.

TABLE III. Statistics of the quantities under study in different air masses.

Characteristics	$\tau^a_{0.63}$	α	β	W, g/cm^2	ΣS^P, MJ/m^2	ΣQ, MJ/m^2	S_s, h
11 and to 20 aug. 1997 (CMA)							
Mean	0.085	1.34	0.044	1.88	18.8	15.85	5.70
SD	0.022	0.38	0.012	0.53	–	5.20	3.03
Max	0.117	1.81	0.061	2.59	–	22.42	10.09
Min	0.052	0.62	0.022	1.24	–	6.16	0.95
N, days	7	7	7	7	–	7	7
24 and to 07 Sept. 1997 (CAA)							
Mean	0.037	0.59	0.029	1.15	20.2	10.33	3.34
SD	0.016	0.42	0.009	0.21	–	3.47	2.55
Max	0.073	1.05	0.043	1.46	–	16.62	8.56
Min	0.022	0.034	0.013	0.90	–	4.06	0.77
N, days	8	8	8	8	–	8	8

CONCLUSION

Based on the results obtained from the above described study of the small-scale variability of the atmospheric properties that may significantly influence radiation, we may come to the following conclusions.

1. The combined effect of the day-time variation of AOT and WVCD is the asymmetric diurnal variation of the integral transmittance, relative to the noon, with minimum at 3:30 p.m. and maximum in the morning. The result is the decrease of radiation influx in the afternoon.

2. Variations of the atmospheric turbidity are mainly due to synoptic oscillations, therefore the variations of AOT and WVCD in the two adjacent areas (urban and wood land areas) are quite similar. The enhanced turbidity of the urban atmosphere even at slight effect from industry results in a 2% decrease in the direct radiation influx.

3. The main types of air mass for Western Siberia strongly differ in the characteristics of the atmospheric transmittance since the mean values of τ^a, α, W. Thus, in CAA those values are 1.5–2.3 times lower than in CMA. The change of a CAA mass for an aged CAA (different degree of transformation) leads to appearance of correlation between the characteristics of aerosol and moisture turbidity of the atmosphere.

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