Results of Investigation of the Atmosphere and Cirrus Clouds by the Methods of Solar Photometry in Western Siberia

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Introduction

Solar photometry methods along with obtaining the data on downward radiation have made it possible to determine a series of basic characteristics of the atmosphere and cloudiness, which directly affect the global solar radiation (GSR), direct solar radiation (DSR), and diffuse solar radiation. The complex experiment performed in the Tomsk region allowed investigations to be made of some regularities of variability of the components of atmospheric transmittance, sunshine duration (SSD) and their influence on the shortwave radiation.

In the measurements of atmospheric-optical characteristics, a multiwave sunphotometer as well as the standard instruments, such as a pyranometer and a pyrheliometer, were used. The calculation procedure of spectral aerosol optical thicknesses (AOT) and columnar water vapor (CWV) was described by Kabanov et al. (1997) and Thome et al. (1994). At the first stage of investigation (21 July to 2 August) to determine the urban influence, atmospheric transmittance measurements were carried out in the vicinity of Tomsk and in the forest area (at the distance of 60 km). At the second stage (6 August to 12 September), the investigations were performed only in Tomsk, but with a wider range of problems to be solved. Here we consider the obtained results based on five main problems.

Urban Effect

Despite the incomplete synchronism of measurements (urban/forest), the results of investigations indicated (Figure 1) that on a scale of synoptic fluctuations the change of AOT and CWV correlated well. Table 1 gives the data characterizing the statistics and interconnection of AOT and CWV for the two areas. It should be noted that, in the AOT spectral behavior, the distinction of the atmospheric characteristics of the two areas is manifested in the visible range (Figure 1c). To determine the influence of the urban atmosphere on the downward radiation, we calculated the spectra of the DSR aerosol component on the horizontal surface S_λ^A (Figure 2a) and the diurnal sums of DSR. The difference of integral irradiance fluxes ΔS (Figure 2b) is 7.5 W/m^2 at noon. Besides, the small decrease of DSR afflux in the city occurs because of CWV. The calculations indicate that the deficiency of DSR afflux in the city per day is 0.406 Mj/m^2 in cloudless conditions and about 0.17 in average cloud conditions (the relative decrease is about 2%).

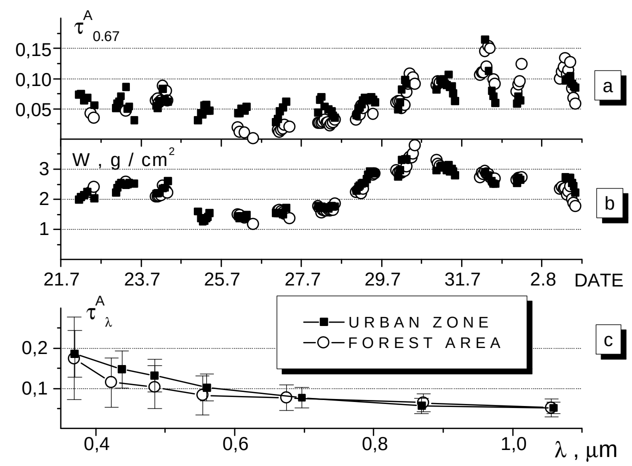

Figure 1. The results of investigations of AOT and CWV in the two areas.

Table 1. Statistical characteristics of AOT and CWV for urban (U) and forest (F) areas.

	Mean (U/F)	SD	$R_{U/F}$	$\delta_{U/F}$
$\tau_{0,48}$	0.132/0.103	0.05	0.70	23%
W, g/cm^2	2.64/2.51	0.35	0.76	5%

Diurnal Run

One of the features of the summer radiation regime in the Western-Siberian region is the asymmetric, relative to the noon, diurnal behavior of downward radiation and sunshine duration. In this case, the above dependencies are of opposite character: the DSR and GSR values in the afternoon are

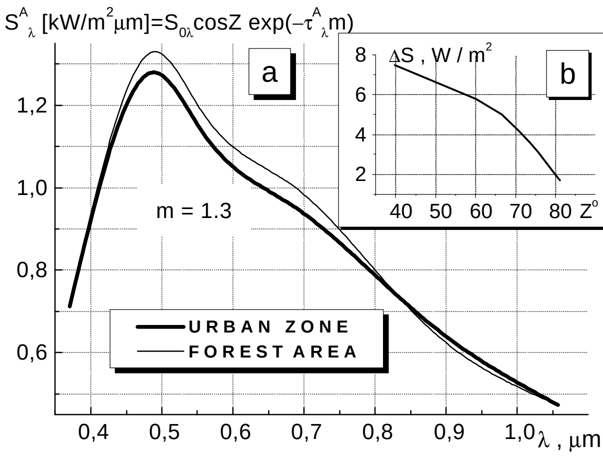

Figure 2. The results of calculations of the spectral direct solar radiation S_λ^A (a), and the deficiency of the integral radiation inflow $\Delta S = S_F^A - S_C^A$ in the urban conditions for different zenith angles Z (b).

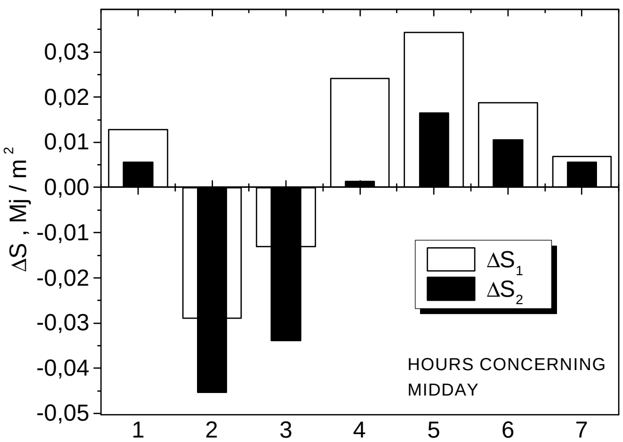

Figure 3. The differences of the direct radiation inflow ($\Delta S = S_{p.m.} - S_{a.m.}$) for the symmetric hours relative to noon because of diurnal variation of SSD (ΔS_1) and at additional influence of AOT and CWV (ΔS_2).

decreased and the SSD values are increased. Note that the diffuse solar radiation for hours symmetric relative to noon is practically identical. That is, another factor acts, which not only neutralizes the SSD influence but also results in the radiation decrease in the afternoon. An obvious explanation is the influence of diurnal variation of atmospheric transmittance. To estimate this effect, we analyzed the results of AOT and CWV measurements by Zuev et al. (1997) during summer periods of 1992-1997. The investigations of short-period variability of atmospheric transmittance have shown that the synoptic vacillations play a leading part; that is, the coefficients of variations of AOT and CWV are 30% to 50%. A smaller component of the diurnal run is constantly deformed by the change of air masses; therefore, it is manifested only when analyzing the continuous series of observations. So, from the averaged dependencies, it follows that the AOT diurnal run is characterized by the turbidity maximum during afternoon hours. In the diurnal behavior CWV, we may observe the two maxima (at 8-9^h and 15-16^h mean solar time) and one minimum before noon. Based on these data, we calculated the hour sums of DSR for average conditions, its transformed values under the action of the diurnal run of SSD, AOT, GWV and the difference of radiation afflux before and after noon (Figure 3).

Based on the estimates obtained, the total DSR afflux during half a day, due to the action of cloudiness, counts in favor of p.m. period: ΔS=0.0553 Mj/m^2. The presence of diurnal run of atmospheric transmittance decreases the DSR afternoon values by 2.24%. The result of the joint influence of SSD, AOT, CWV is the smaller DSR afternoon value: ΔS = - 0.0392 Mj/m^2. A qualitatively similar result is obtained when analyzing the GSR behavior (the diffuse radiation tends to smooth out a manifestation of the factors considered).

Contrary to the average long-term data during the 1997 investigations, the situation reversed. The variation of DSR and GSR turned out to be exposed to SSD only because during this period high transmittance was observed, and the diurnal run of AOT and CWV was not practically manifested. Therefore, the large radiation afflux was observed in the afternoon (Figure 4).

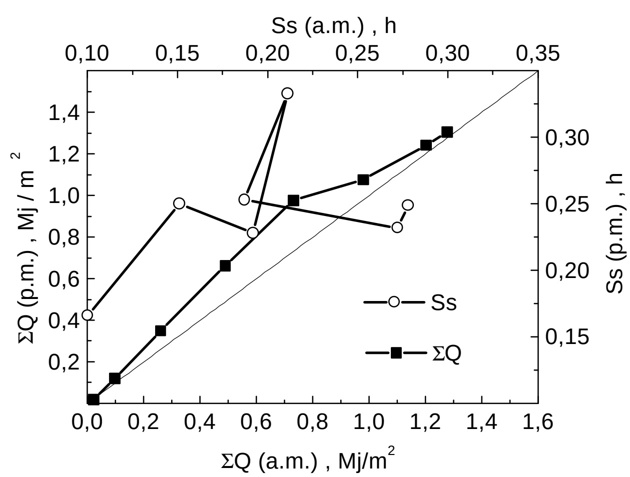

Figure 4. Results of the comparison of the average values of hour sums of GSR and SSD for the symmetric periods relative to noon (1997).

Synoptic Conditions

To determine the synoptic influence on the downward radiation, the two periods of measurements were analyzed. During the first period (from 2 to 20 August, 1997), the continental polar air masses prevailed, and during the second period (from 23 August to 8 September, 1997), the continental Arctic air masses prevailed. The average values of the characteristics under study (Table 2) indicate that a more transparent Arctic mass provides an appreciable increase of radiation, namely, 7.7% (see ΣS^C). In a particular example, this has appeared insufficient because simultaneous sunshine duration due to cloudiness decreased considerably.

Table 2. Mean values of measured characteristics as well as calculated diurnal sums of DSR (0 - in cloudless conditions, 1 - in the average cloud conditions) for two types of continental air mass.

Air mass type	$\tau^A_{0.55}$	W, g/cm^2	ΣS^C, M$_j$/m^2		ΣQ, M$_j$/m^2	S_S, h
			0	1		
Polar	0.106	1.88	18.8	7.5	15.85	5.7
Arctic	0.044	1.15	20.2	8.1	10.33	3.3

Optical Thicknesses and Aureole Scattering Phase Functions Ci

The experimental investigations made in 1997 present our first experience of studies of optical characteristics of semitransparent cloudiness. Therefore, much attention is given to the solution of methodical problems. In particular, we developed the two methods for determining the optical thickness Ci-τ_λ^{Ci}. For a small duration during the period «atmosphere - cloud - atmosphere», the traditional approach was used. Its essence consists in the interpolation of «atmospheric» signals U_A measured at the masses m_1 and m_3 on cloudy area (the mass m_2). In this case, the standard working formula is of the form:

$$\tau^{Ci} = \frac{\ln[U^i_{\grave{A}}(m_2)/U_{\tilde{N}+\grave{A}}(m_2)]}{m_2} \qquad (1)$$

where $U_A{}^i(m_2)$- is the interpolated value of the transmittance signal for cloudless conditions; $U_{\tilde{N}+A}(m_2)$-is the signal measured through the atmosphere and Ci. The second technique is intended for the «cloud - atmosphere» situations and is based on the extrapolation of the general function of atmospheric transmittance $T^G(m)$. This function is calculated using the spectral data of the LOWTRAN-7 model taking account of the transmittance signals $U_A(m_1)$ measured actually. The COT value in this case is determined by the formula:

$$\tau^{Ci} = \frac{\ln[U_0 T^G(m_2)/U_{\tilde{N}+\grave{A}}(m_2)]}{m_2} - \frac{\ln[U_0 T^G(m_1)/U_A(m_1)]}{m_1} \qquad (2)$$

where U_0 is signal of extraterrestrial irradiance (calibration constant). For the first case, the results are given in the wide spectral range (0.4-10.6 μm) but for a small number of situations (basically for thin Ci). The use of the second technique enabled us to interpret 28 realizations of Ci (Figure 5a). From the repetition histograms (Figure 5b) and statistics, it follows that, under summer conditions in Siberia, the majority of values τ^{Ci} are within a relatively narrow limit (Table 3). The coefficients of mutual correlation $R(\tau_{2,32}{}^{Ci}; \tau_\lambda{}^{Ci})$ are very large (not less than 0.98), which is indicative of the equal influence of different types and densities of Ci in the entire spectral range. In the shortwave range, the value $\tau_\lambda{}^{Ci}$ is lower because of the known contribution of scattering in the aureole range. In our case, the value of distinctions of $\tau_\lambda{}^{Ci}/\tau_{2,32}{}^{Ci}$ changes from 0.91 (1.06 μm) to 0.85 (0.42 μm). The data presented in Table 4 and Figure 6 characterize the average scattering phase functions of the atmosphere and Ci based on the Van de Hulst parameterization.

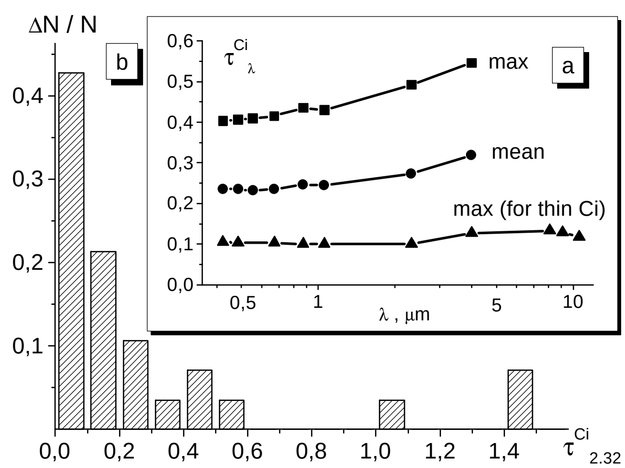

Figure 5. a) The averaged spectral dependencies of mean and maximum in cloud COT values for general data array (0.4 μm to 4 μm) and for thin Ci (0.4 μm to 10.6 μm); b) the histogram of repetitions of mean values of COT.

Table 3. Statistics of $\tau^{Ci}_{2.32}$.				
Type of data	**Mean**	**SD**	**Max**	**Median**
Single measurement	0,178	0,263	1,85	0,09
Means in every series	0,272	0,40	1,47	0,12
Max in every series	0,493	0,526	1,85	0,29

Table 4. Statistics for parameters of $\mu(\varphi)$.				
	A		**q**	
$\mu(\varphi)=A\cdot\varphi^{-q}$	**Mean**	**SD**	**Mean**	**SD**
Atmosphere				
0,42 μm	0,83	0,87	1,78	1,58
0,67 μm	1,55	1,19	2,05	0,81
1,06 μm	1,88	1,48	2,32	0,75
C_i cloud				
0,42 μm	5,78	8,02	1,67	0,66
0,67 μm	13,4	16,9	1,79	0.58
1,06 μm	18,1	16,2	2,01	0.64

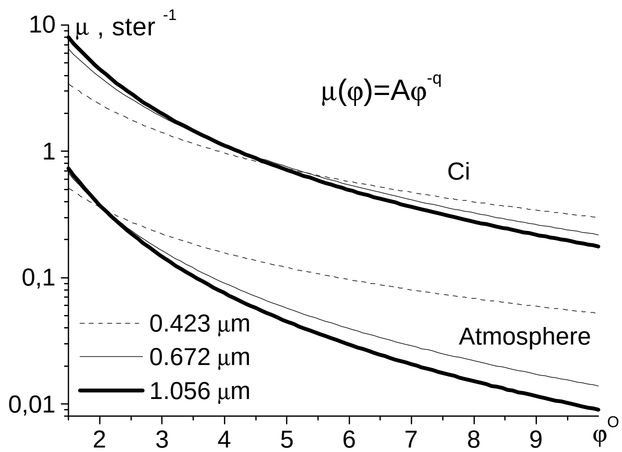

Figure 6. The aureole scattering phase functions of the atmosphere and Ci.

Determination of Cloud Size Distributions From Solar Aureole Measurements

Aureole measurements of the scattering phase functions of thin Ci were used to estimate disperse composition of optically active cloud particles. A regularizing algorithm based on the Tikhonov method was used to solve the corresponding inverse problem for the first-order integral equation. In so doing, the cross-section size distribution function of particles $s(r)$ was determined by solving the Euler equation for the finite difference analog of regularizing functional. Discretization of the integral equation was carried out by the scheme analogous to Zuev et al. (1983). Figure 7 shows the results of inversion of the aureole scattering phase function μ/φ (λ=0.67 μm) measured on August 14, 1997. The measurements had been performed for one hour before noon.

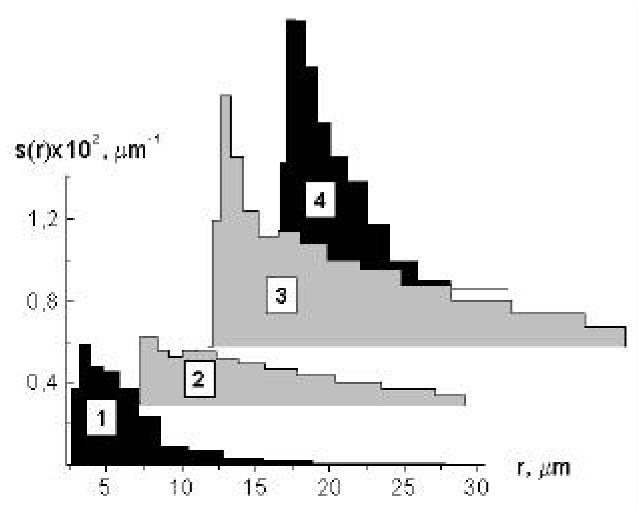

Figure 7. Inverted particle cross-section size distributions of thin Ci.

Table 5 gives the estimated optical thicknesses $\tau = 2S/m, S = \int_{(R)} s(r)dr$, for the reconstructed particle size distributions.

Table 5. Optical thickness of Ci reconstructed from their microstructure.				
N	**1**	**2**	**3**	**4**
$\tau^{Ci}_{0.67}$	0.027	0.044	0.121	0.069

Simultaneous direct measurements of $\tau^{Ci}_{0.67}$ yielded 0.018 and 0.035 for the first two columns of Table 5.

References

Kabanov, D. M., and S. M. Sakerin, 1997: The correct taking into account of the function of transmission of gases in the task of determination aerosol optical thickness. *J. Aerosol Sci*., **28**, Supp. 1.1. p. 247-248.

Thome, K., and M. Smith, et al., 1994: Three-channel solar radiometer for determination of atmospheric columnar water vapor. *Appl. Opt*., **33**(24):5811-5819.

Zuev, V. E., and I. E. Naats, 1983: *Inverse Problems of Lidar Sensing of the Atmosphere*. Springer-Verlag, Berlin-Heidelburg-New York, 260 pp.

Zuev, V. V., B. D. Belan, Y. .A. Pkhalagov, and S. M. Sakerin, 1997: Some results of aerosol and radiation measurements in Siberia under the SATOR program of the IAO. In *Proceedings of the Sixth ARM Science Team Meeting*, p. 379-382, CONF-96-3149, U.S. Department of Energy, Washington, D.C.