On selection of AERONET data. Part III: Cloudiness and sun photometers efficiency in South Siberia regions

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The mean characteristics of cloudiness, based on meteorological data for southern Siberia regions, are presented. It is shown that the sky is absolutely clear in 15% of all observed situations; hence, only measuring data on spectral brightness and transparency of the atmosphere for these situations can be used for aerosol radiation modeling. Based on data of cloud observations in Tomsk, the efficiency of AERONET data selection is estimated to exclude the cloudiness situations from the presented spectral brightness series in solar almucantar and vertical position.

It is well known that discontinuous cloudiness affects the daytime sky brightness essentially and unpredictably. Therefore, only cloudless situations should be considered when studying optical properties of aerosol on the base of observation data on spectral atmospheric transmittance and sky radiation intensity. Otherwise, when solving the radiation transfer equation, used in recovery of aerosol optical parameters, many uncertainties arise due to necessity of excluding the influence of cloudy formations on the brightness. At the same time, global aerosol study in the total column is of current importance, since the problem of aerosol effect on the Earth's climate is far from solution.[1]

Based on these reasons, NASA mounted more than a hundred of CIMEL sun photometers all over the Earth to monitor atmospheric optical depth τ_a, daytime sky brightness $B(Z_0, Z, \Psi)$ in solar almucantar and vertical position, as well as some other atmospheric parameters at $0.38 \le \lambda \le 1.02$ μm. Here Z_0 and Z are zenith angles of the Sun and an observation point; Ψ is the sky point azimuth, count off from the plane of solar vertical. The observation data are available on the AERONET site.[2] Two such sun photometers operate now in South Siberia, in Tomsk and in Irkutsk. For some time, two devices operated in Barnaul[3] and Krasnoyarsk.

Observation results are primarily analyzed by NASA specialists to reveal clouds and exclude them from the experimental brightness series. However, careful study of AERONET $B(Z_0, Z, \Psi)$ values, even of the highest confidence Level-2, shows that clouds often have been excluded incompletely. Therefore, when solving a number of radiation problems, e.g., on particle spectra reconstruction from the measured τ_a and $B(Z_0, Z, \Psi)$, there is a need in additional, quite thorough selection of the measurement data.[4–6] Such selection noticeably reduces the quantity of observation data, upon which optical aerosol models of atmosphere are developed.

As is known, cloud modulation of direct sunlight, passing though the atmosphere, results in noticeable variation of physical aerosol parameters in lower atmosphere.[7] However, an essential part of aerosol is concentrated just here, under clouds, and above urban territories. Hence, the question arises to which degree the optical aerosol parameters, determined from solving the inverse problems on spectral atmospheric transmittance and daytime sky brightness in cloudless days, are typical for the region under study as a whole?

To answer this question, it is necessary to analyze statistically long-term cloudiness data obtained at South Siberia weather stations. The following information on cloudiness behavior in South Siberia was obtained, using reference data for previous years[8,9] and observation results for the last decade. The obtained information directly relates to the problem under study.

The means of total cloud amount n (in t.c.a.) are given in the Table. The most complete data are presented for the Altai territory. The data cover more than 40-year period from 1936 to 1980. In view of well-known statements about climate changes on the Earth, including South Siberia, such long-term information can serve as a starting point for further investigations of climate changes in the region.

As is seen from the Table, the average cloud amount in the south of Siberia is quite high and equal to 6.4. In other words, cloudy weather dominates in the whole region. The average value for Altai equals to 6.1, which insignificantly differs from the average value for the whole South Siberia.

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Table. Monthly and yearly average total cloud amount in South Siberia

Observation point	Month												Year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Barnaul*	6.4	6.1	5.9	6.2	6.2	6.0	5.9	5.9	5.8	7.3	7.3	6.9	6.8
Biisk-Zonal'noe *	6.1	6.2	6.1	6.2	6.1	5.8	5.7	5.7	5.7	7.2	7.2	6.7	6.2
Zmeinogorsk*	5.9	5.7	6.1	6.0	5.9	5.7	5.5	5.4	5.4	6.8	6.9	6.6	6.0
Irkutsk	6.7	6.0	6.0	6.8	7.1	7.1	7.0	6.9	6.5	6.4	7.2	7.7	6.8
Kemerovo	6.9	6.5	6.4	6.4	6.7	6.6	6.3	6.6	6.8	7.9	7.8	7.3	6.8
Kluchi*	5.4	5.1	5.4	5.4	5.2	5.2	5.0	5.2	5.0	6.5	6.6	6.1	5.5
Krasnoyarsk	6.6	6.4	6.4	6.5	6.7	6.4	6.2	6.5	6.8	7.6	7.5	6.9	6.7
Novosibirsk (Ogurtsovo)	6.9	6.6	6.6	6.5	6.7	6.3	6.4	6.7	6.7	7.9	7.7	7.3	6.9
Omsk	6.3	5.7	5.7	5.9	6.0	6.1	6.2	6.2	6.4	7.4	7.3	6.6	6.3
Slavgorod*	5.7	5.4	5.7	5.7	5.6	5.6	5.4	5.5	5.3	6.9	6.9	6.3	5.8
Tomsk	6.7	6.2	6.4	6.2	6.7	6.5	6.2	6.6	6.8	8.1	7.8	7.2	6.8

* The observation point is in Altai region.

The cloud amount values, given in the Table, do not answer the question about efficiency of the sun photometers in data acquisition on spectral transmittance and sky brightness for developing aerosol models of atmosphere. For this purpose, cloudless days should be selected from the available data array.

In meteorology, the sky is considered as clear if the total cloud amount is from 0 to 2. Figure 1 shows the mean seasonal frequency distribution of repetition of such situations for all observation points, calculated with respect to the total number of observations (curve *1*). The winter period includes months from November to March, the spring one – April and May, the summer period – from June to August, and autumn includes September and November. The repetition decreases from winter to autumn with accounting for the rms spread; it is about 30% for South Siberia as a whole. This number can well answer the question on "typical" situations, when discontinuous cloudiness minimally affects the radiation properties of aerosol in the region under study.

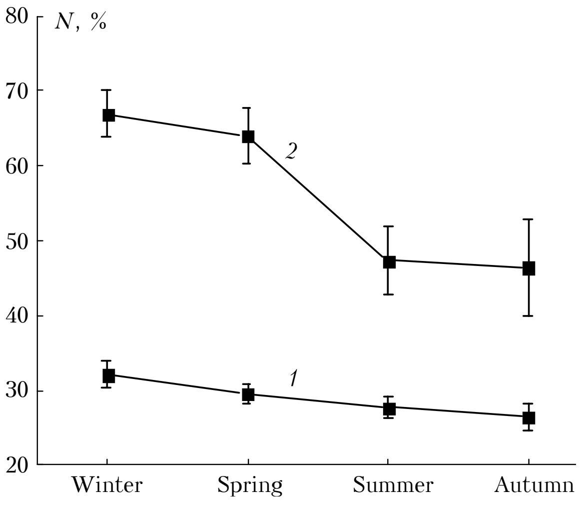

Fig. 1. Seasonal frequency distribution of 0–2 t.c.a. cloudiness according to the data of weather stations in South Siberia (*1*) and of absolutely clear sky among the cases of 0–2 t.c.a. cloudiness according to the data of IMCES SB RAS weather station in Tomsk (*2*).

As it was said above, the inverse problem on recovering optical parameters of particles from observed sky brightness can be solved reliably by means of the radiation transfer equation only in the complete absence of clouds, i.e., when the total cloud amount equals to 0. We have a possibility to estimate the number of totally cloudless situations (0 t.c.a.) with respect to the number of situations with 0–2 t.c.a. in Tomsk. These data are also shown in Fig. 1 (curve *2*); they cover the period from 1994 to 2005.

As for the case of 0–2 t.c.a., there is a trend toward decrease from winter to autumn in absolutely clear sky frequency distribution. An average value of this parameter is a little higher than 50%.

As is follows from Fig. 1, the experimental data on sky brightness, recorded in not more than 15% of atmospheric situations in Tomsk, can be used in solving the inverse problems on radiation aerosol properties. The number of the situations decreases if to use only the data, meeting the condition of uniform horizontal distribution of atmospheric turbidity over the sky.[9]

Taking into account repetition of atmospheric processes over South Siberia, it can be supposed that the above values should be similar at other points of this region.

The information about cloud presence on the sky at specific points of time allows estimating the efficiency of techniques for using sky brightness monitoring results from AERONET tables for selecting cloudless days. Such estimation is important in the cases, when direct information on cloudiness is absent. As it was shown earlier,[10] the angular brightness gradient in solar almucantar $\Delta B/\Delta\varphi$ regularly decreases with an increase of the scattering angle φ up to $\varphi_{\min}$ in conditions of absolutely cloudless atmosphere. The angle $\varphi_{\min}$ approximately corresponds to a minimum in angular brightness distribution, i.e., usually is 85–120°. It was decided to apply this criterion in an extended form to analysis of Tomsk data by extending it to the solar vertical plane, i.e., to the sky points, where Ψ equals to 0 and 180°.

To preliminary testing such technique, the values $B(Z_0, Z, \Psi)$, measured in the south-east of

Kazakhstan, were analyzed.[11] They were obtained in the absolutely fair stable weather in a wide spectral range from UV to IR. It is necessary to mention, that the scattering angle φ for the points, lying in the solar vertical plane above the Sun, is defined as $\varphi = Z - Z_0$ for $\Psi = 0°$ and $\varphi = Z + Z_0$ for $\Psi = 180°$.

The calculations of $\Delta B(Z_0, Z, \Psi)/\Delta\varphi$ by measured brightness have shown clearly that in most cases the angular brightness gradient really decreases with an increase of φ and passes through zero near $\varphi_{min} \approx 80 \div 90°$. After passing through φ_{min}, the gradient $B(Z_0, Z, \Psi)/\Delta\varphi$ becomes negative while its module $|\Delta B/\Delta\varphi|$ increases with an increase of φ. The examples of such angular dependences of $|\Delta B/\Delta\varphi|$ in visible and near-IR spectral regions are shown in Figs. 2 and 3 ($\Delta\varphi$ is in degrees).

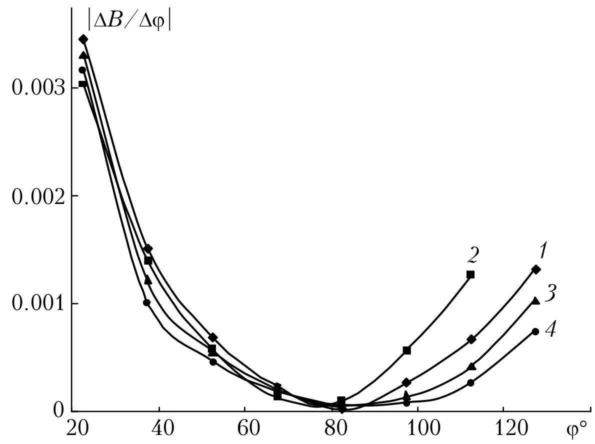

Fig. 2. Examples of angular dependences of the module of brightness gradient $\Delta B/\Delta\varphi$ in solar vertical in the visible spectral range, September 7, 1967 before noon: $\lambda = 0.454$ μm and $Z_0 = 60°$ (*1*); 0.454 μm and 45° (*2*); 0.548 μm and 60° (*3*); 0.645 μm and 60° (*4*).

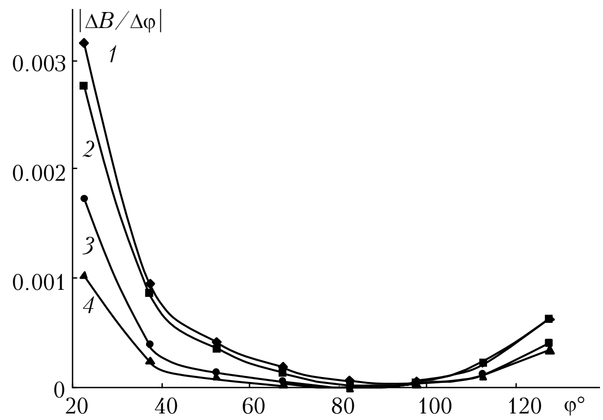

Fig. 3. The same as in Fig. 2, but in the IR spectrum range for $Z = 60°$: September 7, 1967 before noon (curves *1* and *2*), $\lambda = 0.7$ (*1*) and 0.772 μm (*2*); June 14 ($\lambda = 1.01$ μm) (curve *3*); September 24, 1971 before noon ($\lambda = 0.85$ μm) (curve *4*).

Note, that the sky brightness (and, hence, ΔB) is defined in the S units (πS is the spectral solar constant) by binding it to a standard screen illuminated by perpendicular sunbeams. Sometimes, at $80° \le \varphi_{min} \le 100°$, the sign of $\Delta B/\Delta\varphi$ can change twice or more times most often, that is due to measurement errors for little differing brightness $B(Z_0, Z, \Psi = 180°)$. If there is a cloud at the line of sighting, the above-described angular dependence of $\Delta B/\Delta\varphi$ is sharply broken.

The proposed technique for cloud detection was used in analysis of the AERONET data on sky brightness, measured with a CIMEL photometer in the period from October 24, 2002 to December 13, 2005, in Tomsk. The angular brightness gradients $\Delta B/\Delta\varphi$ were calculated in solar almucantar and vertical, and their angular dependences were analyzed. In all, 15 400 angular distributions of brightness in both planes were analyzed. Finally, only 354 angular brightness distributions in solar almucantar and 425 – in vertical satisfy the condition of systematic decrease of $|\Delta B(Z_0, Z, \Psi)/\Delta\varphi|$ at $\varphi < \varphi_{min}$ and its increase at $\varphi > \varphi_{min}$. Taking the smaller value as a basis, it can be stated than only 2.3% of the total number of measured distributions $B(Z_0, Z, \Psi)$ can be used for further comparison with the cloudiness data for the observation period.

As was mentioned above, cloud quantity is recorded at weather stations every 3 hours. 566 cases of 0–2 t.c.a. cloudiness were recorded from October 14, 2002 to December 13, 2005; the cloudiness was zero in 387 cases.

The cloudiness observation moments at weather stations seldom coincide with moments of photometer measurements of the sky brightness; hence, assume that zero cloudiness, fixed at the moment t_0, can be extended to the interval $t_0 \pm 1$ h. In this case, among 354 angular brightness distributions $B(Z_0, Z, \Psi)$, selected on the principle of systematic angular variation of gradient in any observation series in solar almucantar and vertical position, lasting only several minutes, only 177 fall into the above interval $t_0 \pm 1$ h, when the sky is considered as absolutely clear based on the meteorological data; this is only 1.1% of the total number of initially measured distributions (15 400).

Thus, only a half of situations, considered as cloudless according to the observation data on sky brightness in solar almucantar and vertical position simultaneously, actually correspond to the absence of clouds in the sky.

Clouds beyond the photometer's line of sighting in solar almucantar and vertical position undoubtedly increase brightness of cloudless sky areas. This is especially true for high-level clouds.[5] Hence, not integral[6] but difference techniques should be applied in the absence of direct information on the cloud amount, when using brightness observation data in order to determine aerosol optical scattering depths τ_a and particle albedo Λ_a. In this case, in statistical treatment of the final τ_a and Λ_a for extensive observation series, the final contribution of clouds, randomly distributed over the sky, into the brightness of the cloudless areas, where photometer's lines of sighting pass, can well be considered equal for forward and backward sky hemispheres.

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