Analysis of the Factors of Variability of the Atmospheric Transparency Under Conditions of Smokes of Peatbog and Forest Fires

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Introduction

Studying smoke aerosols generated from forest and peatbog fires is very important when analyzing the specific manner of formation of the optical state of the atmosphere in Siberian regions. It is particularly important to focus on the conditions of appearance and propagation of the smoke aerosols. Solving this problem is imperative to estimating the priorities of different factors determining the optical transparency change of the atmosphere in the summer, when the intensity of such events dramatically increases. A large amount of aerosols and heat is produced during forest fires. Also, thermal sublimation processes of volatile species and aerosol-producing gas (APG) emissions from wood become more intense.

The purpose of this paper is to study the factors that determine the specific manner in which the optical state of tropospheric haze is disturbed by intensive smoke-aerosol emissions from different large-scale burning sources. The main focus is on studying the peculiarities in developing the disperse composition of aerosol particles at different smoke-spreading stages. There is a particular focus on remote smokes and local-origin smokes because they can change the spectral transparency of the atmosphere.

Investigation Technique

The analysis of optical-microphysical property changes for various types of smoke aerosols was executed based on the results of inverting the optical measurement data using four instrumentation complexes.

In particular, analysis of the specific manner of transformation involving the optical-microphysical properties of a tropospheric haze containing great smoke disturbance was executed based on simultaneous field measurement data. The field measurement data included the aerosol optical thickness

(AOT) in the wavelength range λ ~0.35 to 1.06 μm and the spectral transparency of the atmosphere on a near-ground path in the wavelength range λ ~ 0.44 to 3.9 μm. Besides, aerosol characteristic measurement data that were obtained using the nephelometer FAN were attracted for estimating the current refractive index values and more accurately determining the accumulative aerosol fraction size spectrum. The directed scattering coefficient values at a 45° angle and at three wavelengths 0.41, 0.51, and 0.63 μm and two polarized components of scattered radiation at a 90° angle were inverted to the size spectrum.

Finally, the peculiarities when transforming the smoke microstructures at their local anomalous accumulation stages were individually studied laboratory experiment frameworks. In particular, spectral nephelometric measurement data of the polarized components of the directed scattering coefficient at five fixed angles, θ = 15, 45, 110, 135, and 165°, in the wavelength range λ = 0.44 to 0.69 μm, can be used to obtain the aerosol fractions light scattering characteristic data in the 0.05 to 6.0 μm range. So the specific manner of smoke generation in an aerosol chamber was considered in a laboratory experiment series. Some peculiarities when transforming the size spectrum and some refractive index changes were studied.

The multi-wavelength solar photometer measured the spectral transparency of the atmosphere. Device specifications are given in Table 1. Measurements were performed in series of 5 to 30 minutes, when the sun was free of clouds. Then, the hourly mean values were calculated. The techniques for calibrating the photometer and determining the atmosphere AOT using the LOWTRAN–7 software are described by D. M. Kabanov and S. M. Sakerin (1997). The columnar water vapor W was measured simultaneously with the aerosol characteristics.

Table 1. Specification of the solar photometer.

Maxima of the transmission bands of the interference filters, μm	0.35. 0.37, 0.44; 0.48; 0.52; 0.55; 0.67; 0.87; 0.94, 1.06
Filter transmission half-width, nm	5–10
Angle of the field of view, degrees	0.75
Duration of measurement of individual spectrum, sec	40–60
Error in determining τ(λ)	0.01

The hourly mean values of the atmosphere AOT were used for solving the inverse problem aimed at retrieving the diurnal and day-to-day dynamics of the aerosol particle size spectrum. The regularizing algorithm based a smoothing function construction by the A.N. Tikhonov method and direct minimizing in the k-dimension space was applied for inversion. The inversion technique peculiarities are considered by V. E. Zuev (1983).

Results and Discussion

In Figure 1, the AOT temporal variability in two wavelength ranges is shown. These measurements were taken during July and August 1999 near the city of Tomsk. The fires caused two essential events that increased the atmospheric turbidity during this period. The AOT daily mean spectral dependencies under different optical conditions are shown in Figure 2. The transparency decrease on July 8 to July 22 was related to the peatbog fires occurring 10 to 20 km from the observation site. The second atmospheric turbidity increase, which took place between July 24 and the first week of August, was caused by the remote transfer of smoke aerosol from forest fires in the Krasnoyarsk region. The optical data (Figures 1 and 2) demonstrates that the general peculiarity of both cases (peatbog and forest fires) is the aerosol turbidity increase (approximately four fold) in the shortwave range. The principal peculiarities of the size spectrum transformation are seen in Figure 3, where the particle volume distributions retrieved from the Figure 2 data are shown. The accumulative fraction particle volume concentration ($r \sim 0.05 \div 0.35$ μm) with the volume distribution mode, $r_m = 0.2$ μm, increases under smoke conditions by more than magnitude. At the same time, the smoke events with different prehistory have some specific peculiarities.

When smoke from local sources (peatbog smoldering) has appeared, the content of coarse particles larger than 0.4 μm decreases simultaneously with the increase of small particles. The AOT spectral dependence under these conditions, within the accuracy limits of optical measurements, is considered by the accumulative fraction particles. Since July 17-23, as the smoke aerosol source has weakened and the transparency increased, the content of particles of $r > 0.4$ μm gradually increased, but it has not reached the level observed before the fire. Insufficient data do not allow us to unambiguously relate the peatbog burning with the coarse particle deficiency. It can be assumed that this effect is caused by convection and turbulence (emission of particles) process at the radiative heating decrease of the underlying surface, the change of air mass before the smoke event, and weak wind during peatbog burning.

At the same time, the results of the spectral dependency inversion of the aerosol extinction coefficients on a near-ground horizontal path show the enhanced content of intermediately dispersed and coarse aerosols.

The increase in 0.4 to 1.1 μm-particle concentration was observed under the remote transfer of smoke from forest fires in the Krasnoyarsk region. The total volume of these particles is two to three times greater than that under clear atmosphere conditions. The optical contribution of intermediately dispersed particles ($r > 0.4$ μm) is about 15% at the wavelength of 0.48 μm and increases up to 50% in the infrared (IR) range (Figure 4). Another peculiarity is seen in the diurnal dynamics of the columnar intermediately dispersed fraction. The size spectrum of this fraction varies during the day relatively with no pronounced diurnal behavior, while the maximum is observed at noon in the smokeless atmosphere (Figure 5). It can be assumed that the accumulative fraction transformation of smoke aerosol inside the atmosphere (graduate growth and transition to the size range $r > 0.4$ μm) is one factor that increases the concentration of intermediately dispersed aerosol.

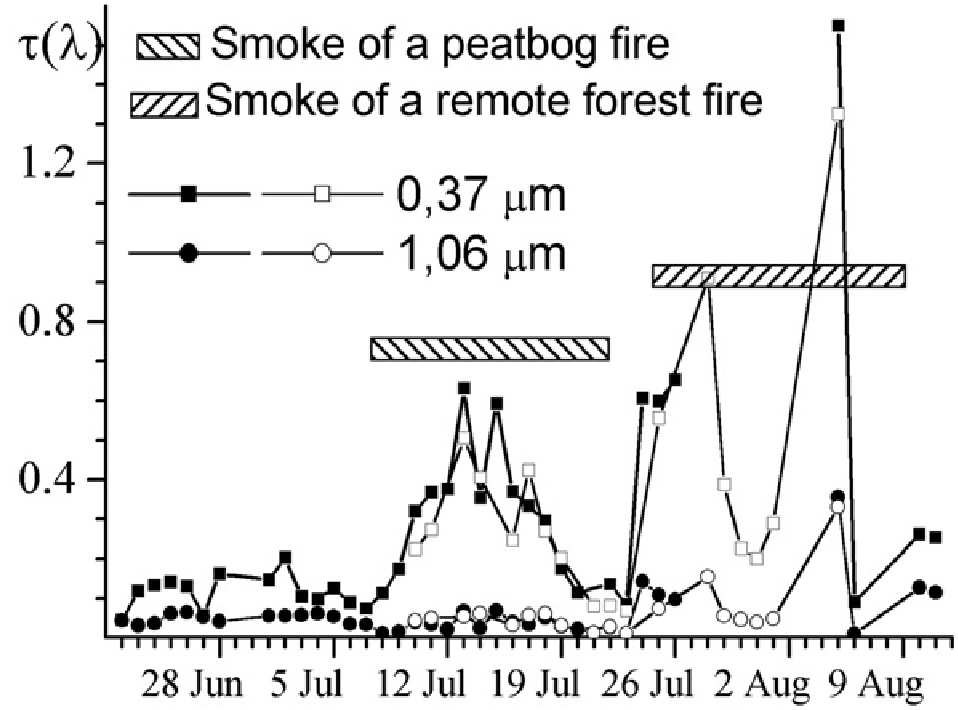

Figure 1. AOT temporal variations of the atmosphere in two wavelength ranges during July and August 1999.

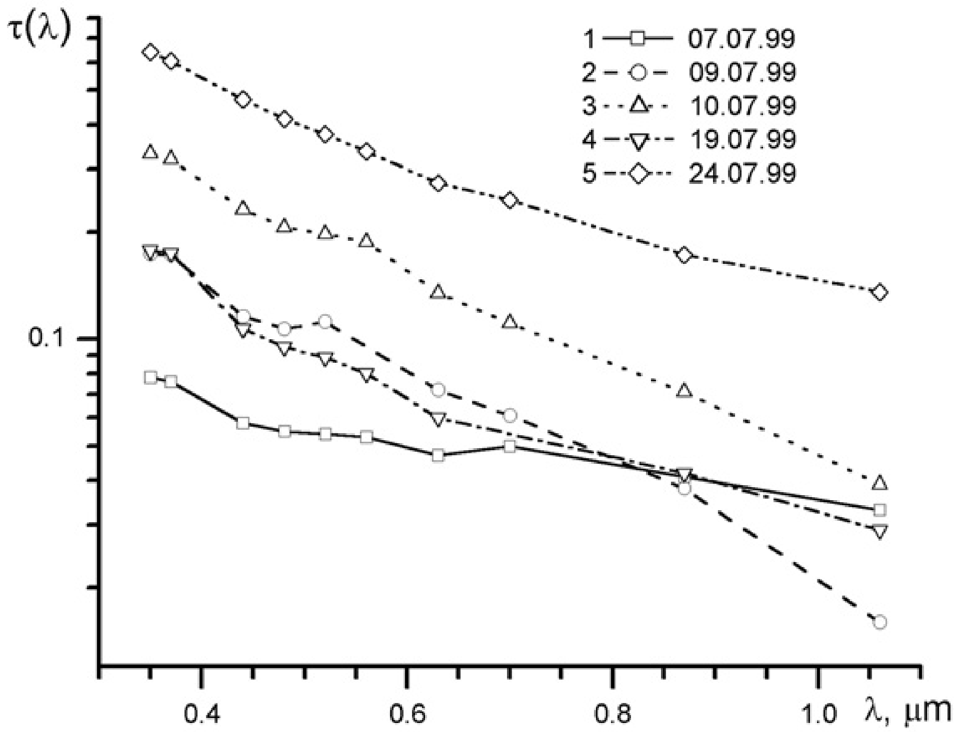

Figure 2. AOT spectra transformation during the fire period. (1) Before fire (July 7, 1999), (2-5) in local fires (peatbog burning in the vicinity of Tomsk, July 9–19), and (6) in the remote fire smoke (forest fires in Krasnoyarsk region, July 24).

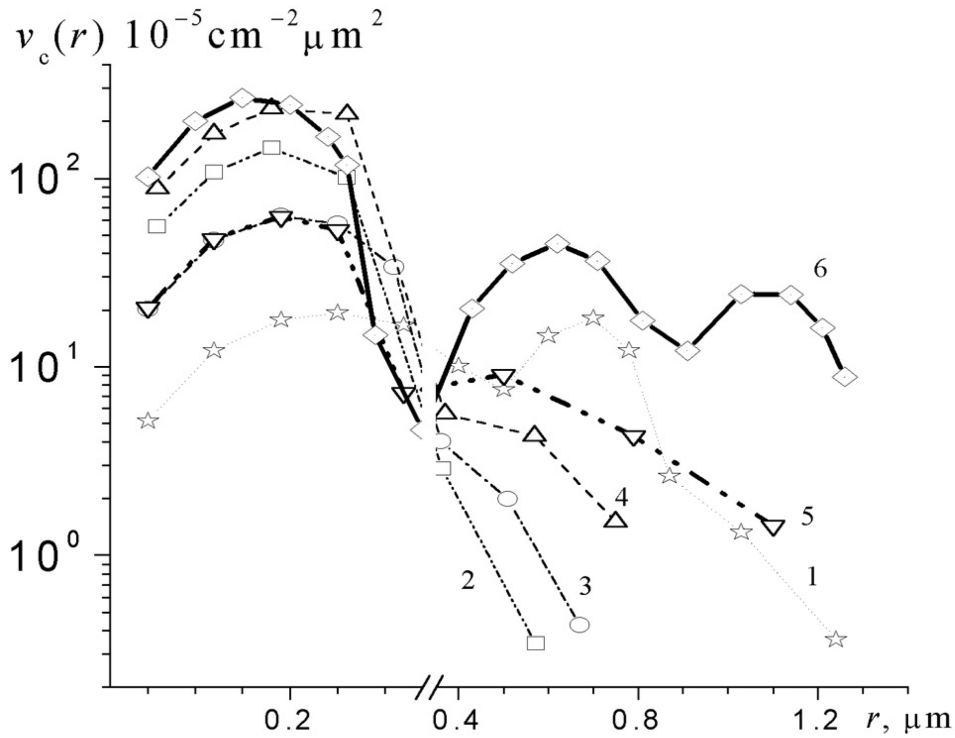

Figure 3. Characteristic peculiarities of the columnar volume size distribution. (1) Before fire (July 7, 1999), (2–5) in local fires (peatbog burning in the vicinity of Tomsk, July 9–19), and (6) in the remote fire smoke (forest fires in Krasnoyarsk region, July 24).

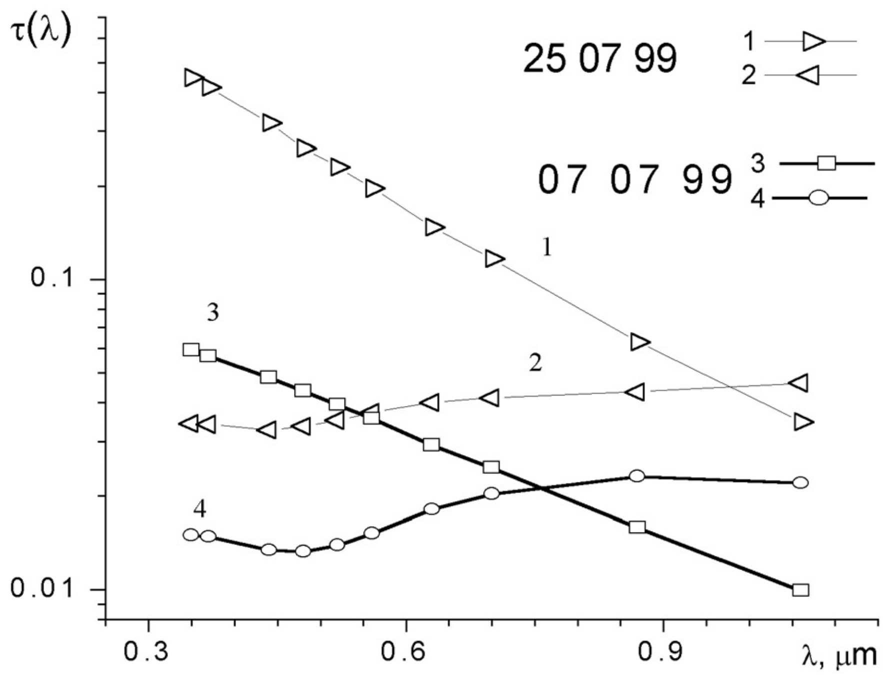

Figure 4. Relative contributions of accumulative and intermediately dispersed particles in Krasnoyarsk forest fire smoke into AOT (curves 1 and 2, respectively) and under smokeless conditions (curves 3 and 4, respectively).

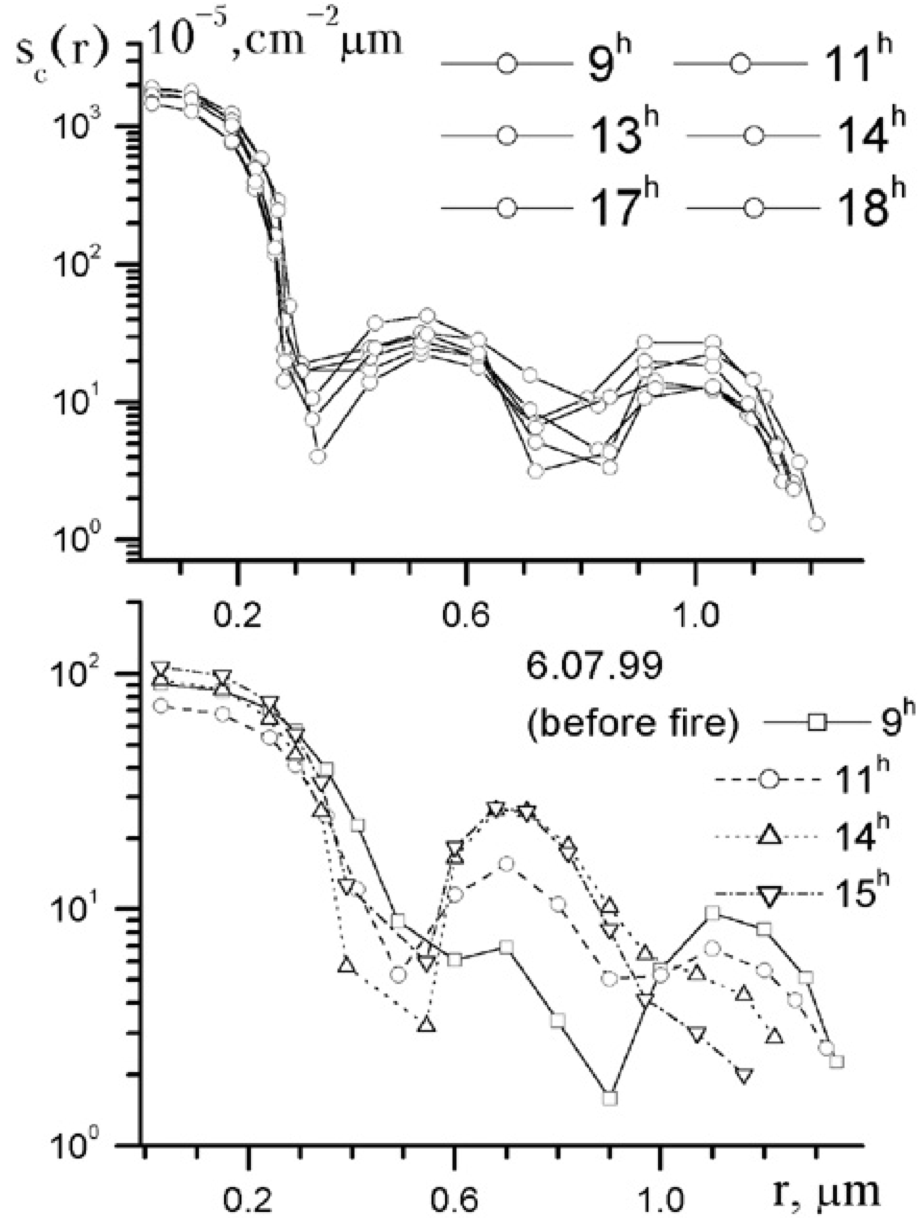

Figure 5. Diurnal variations of the geometric cross section distribution at the presence of remote fire smoke in the atmosphere (upper part) and under smokeless conditions.

The particle size distributions retrieved from the optical data inversion obtained in September 2002, when the atmosphere was affected by the remote transfer of smoke from intensive peatbog fires in the Moscow region, are close to each other. Examples of such distributions are shown in Figure 6. The real part of the refractive index was estimated using the spectral nephelometer data, as n = 1.55. The distributions retrieved from the data on AOT and the aerosol extinction coefficients on near-ground path are obtained for n = 1.5.

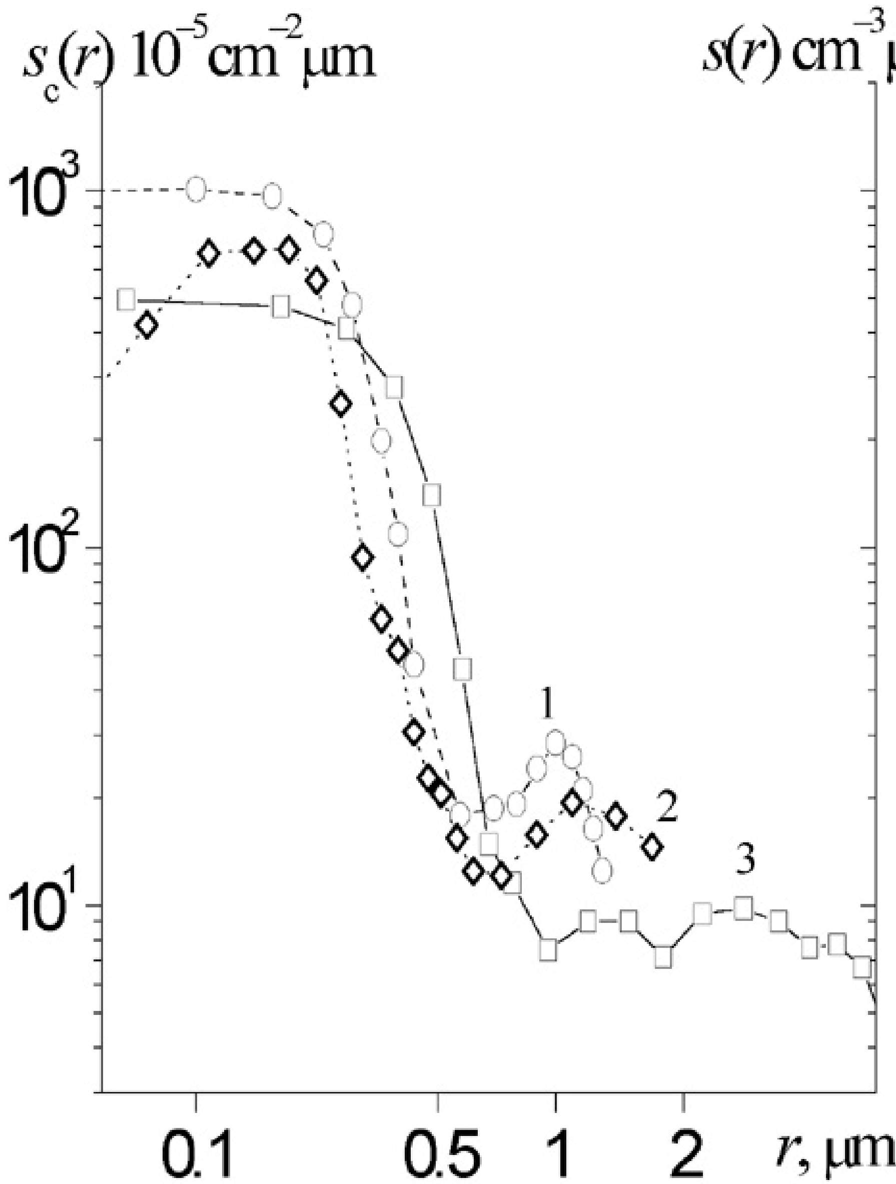

Figure 6. Distributions s(r) at presence of remote fire smoke in the atmosphere (September 12, 2002, peatbog fires in the Moscow region) retrieved from the data of different devices. (1) $s_c(r)$ from the data on AOT, s(r) from the data obtained by a spectral nephelometer (FAN) and from the data on the spectral transparency on a near-ground path (curves 2 and 3, respectively).

The laboratory experiment results show that the microstructure of smokes generated at pyrolysis of coniferous wood is close to that of aerosol generated from the sublimation of rosin. In particular, the range of the real part of the refractive index is 1.45 to 1.54, and the range of the imaginary part is 0.001 to 0.005. The observed variations of the refractive index of laboratory smokes are caused by variations of the water vapor content in the air inside the chamber. The greater is absolute humidity, the less is the real part of the refractive index.

Besides, it was revealed in experiments with different regimes of aerosol generation in the chamber that even at low heating of coniferous wood (~55°C), the reached level of APG emission in closed volume is sufficient for generating finely dispersed aerosol fraction particles (r ~0.05 to 0.2 μm) of optically detectable concentration.

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References

Kabanov, D. M. and S. M. Sakerin, 1997: *Atmos. Oceanic Opt*. **10**, 866–874.

Zuev, V. E., 1983: Inverse problem of lidar sensing of the atmosphere. Springer-Verlag, p. 260.