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THE SCATTERING OF LIGHT IN THE SURFACE LAYER AND ATMOSPHERIC AE--ETC(U)
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THE SCATTERING OF LIGHT IN THE SURFACE LAYER AND ATMOSPHERIC AEROSOL

By

T. P. Toropova

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EDITED TRANSLATION

FTD-ID(RS)T-1479-78 27 September 1978

MICROFICHE NR: FTD-78-C-001314

CSL74219262

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English pages: 9

Source: Rasseyaniye Sveta v Zemnoy Atmosfere,
Izd-Vo Nauka, Alma-Ata, 1972,
pp. 74-81

Country of Origin: USSR
Translated by: Bernard L. Tauber
Requester: FTD/WE
Approved for public release; distribution unlimited.

PREPARED BY:

TRANSLATION DIVISION
FOREIGN TECHNOLOGY DIVISION
WP-AFB, OHIO.

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Block	Italic	Transliteration	Block	Italic	Transliteration
А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere.
When written as ё in Russian, transliterate as yё or ё.

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English	Russian	English	Russian	English
sin	sin	sh	sinh	arc sh	$\sinh^{-1}$
cos	cos	ch	cosh	arc ch	$\cosh^{-1}$
tg	tan	th	tanh	arc th	$\tanh^{-1}$
ctg	cot	cth	coth	arc cth	$\coth^{-1}$
sec	sec	sch	sech	arc sch	sech^{-1}
cosec	csc	csch	csch	arc csch	csch^{-1}

Russian	English
rot	curl
lg	log

THE SCATTERING OF LIGHT IN THE SURFACE LAYER AND ATMOSPHERIC AEROSOL

T. P. Toropova

The results of measurements of the extinction and indicatrices of scattering in the surface layer of the atmosphere are given. The observations have been made at the Mountain Observatory of the Astrophysical Institute near Alma-Ata (the height above the sea level 1450 m).

The spectra of aerosol particles and refractive index are determined.

The basic reason for the instability of optical properties of the Earth's atmosphere is the presence of atmospheric aerosols in it - fine solid and liquid particles suspended in the air (dust, droplets). Their mass is infinitesimally small in comparison with the mass of the gas component of atmospheric air, but as a result of the extreme optical activity they have a substantial influence on the optical properties of the atmosphere [1]. The number, properties, and dimensions of the particles vary with time. This is caused by a change in the brightness of the sky, the size of the solar aureole, and the transparency of the atmosphere. The processes of cloud formation and so forth are linked with the presence of aerosols. An explanation of the interconnection between the optical properties of the atmosphere and the physical properties in dimensions of aerosol particles is one of the basic and rather complex problems of atmospheric optics. It is connected with the solution of the inverse problems on light scattering. With the appropriate formulation of a complex experiment which consists of the simultaneous measurement of several optical characteristics of the atmosphere, we can obtain valuable information on the properties of the scattering particles, for example, about their distribution by sizes. For this, it is necessary that one portion of the optical characteristics being determined experimentally be sensitive to the presence of large particles and the other part - to the presence of small particles.

For a number of years, the AFI (Astrophysical Institute) of the Academy of Sciences, Kazakh SSR, has conducted measurements of a complex of optical characteristics of the atmosphere, accomplished theoretical calculations of the same values, and made attempts to utilize data from observation and calculations to disclose the ties between the dimensions, quantity, and physical properties of aerosols and the optical characteristics - the course of the transparency, type of scatter indicatrix, and so forth.

Transparency

The transparency of the atmosphere's surface layer is measured in the visual region of the spectrum ($400\text{ nm} < \lambda \leq 700\text{ nm}$) on a course of 300 and 600 m [3], partially in the daytime and partially in the evening. Some difference in the mean spectral course of light attenuation was discovered for autumn observations in 1963 (45 days) and winter observations in 1964 (90 days) and summer-autumn night observations in 1967 (26 evenings). The mean attenuation attained in the winter period of 1964 was virtually independent of wavelength (a small bulge on the middle curve $D_\lambda(\lambda)$ is observed which, however, is within the limits of measurement errors for $\lambda \approx 522$ mμ). The attenuation which was calculated from the observation data in the autumn of 1963 did not depend on λ for $\lambda \geq 522$ mμ, but in the short-wave region of the spectrum a sharp increase in optical density was noted. Observations accomplished in the night time in the summer-autumn period of 1967 testify to the small increase in attenuation with a decrease in wavelength. The mean dependence of D_λ on λ is represented well here by the expression

$$D_\lambda = \frac{c}{\lambda}. \qquad (1)$$

Scatter Indicatrices

Scatter indicatrices of the atmosphere's surface layer were obtained using both a thermal source of light - a searchlight with filters (1957-1961) as well as a searchlight and laser (1967-1969). In the latter case, a special photoelectric unit was used with three photometers which permit measuring the indicatrices in the region $2° \leq \theta \leq 170°$ with angular resolution $\Delta\theta = 6'$ for $\theta < 10°$ and $\Delta\theta = 40'$ for $\theta > 10°$. When a gas laser (HeNeλ = 6328 Å) was used as the light source, it was placed so that the light's polarization plane was oriented at an angle of 45° to the plane of vision. The flux asymmetry coefficients were determined for all the scatter indicatrices which were obtained

$$\eta = \frac{\int_0^{\frac{\pi}{2}} \mu(\theta) \sin \theta d\theta}{\int_{\frac{\pi}{2}}^{0} \mu(\theta) \sin \theta d\theta}$$

and the correlation ties were established for a number of measured values. Thus, the results of the measurements of scatter indicatrices are reduced to the following:

1. The mean scatter indicatrices in the region $10° \leq \theta \leq 170°$ which were obtained in the evening in the absence of fog and precipitation in 1957-1960 (57 days) and in 1968 (45 days) are extremely close as is evident from Table 1.

Table 1. Mean scatter indicatrices of the atmosphere's surface layer.

θ 1 Время	10°	20°	30°	40°	60°	80°	90°	100°	120°	140°
1957—1960 гг.	28,8	10,2	5,60	3,62	2,05	1,22	1,00	0,89	0,95	0,97
1968 г.	24,0	12,6	7,55	4,69	2,84	1,23	1,00	0,79	0,85	1,00

KEY: (1) Time.

Thus, it can evidently be considered that such an indicatrix is typical for the average conditions of the Mountain Observatory of the Academy of Sciences of the Kazakh SSR (1450 m above sea level) on days without fog.

2. The values of the asymmetry coefficient η fluctuated within limits of $1.2 \leq \eta \leq 18.9$. However, in the overwhelming majority of cases (90%) the values of η varied from 2.9 to 5.5.

3. In the region of small scatter angles the indicatrices of the surface layer had a rather gently sloping course which is presented in a satisfactory manner by the expression

$$\mu(\Theta) = c\cdot\Theta^{-n};\ n \approx 1.$$

Here, it should be kept in mind that the biggest particles evidently dropped out of consideration [4].

4. In the region of large scatter angles $\theta > 170°$, the coefficient of directional light scatter increases with an increase in θ. The mean scatter intensity with $\theta = 178°$ exceeded the corresponding intensity with $\theta = 170°$ 1.3-fold.

5. The scatter indicatrices of natural haze which were measured with conventional thermal sources - a search light and laser, coincided. (The plane of polarization of the laser light was oriented at an angle of 45° to the plane of vision.)

6. The correlation coefficient r between the attenuation of the light σ and asymmetry η of the scatter indicatrix and between σ and μ(Θ) were calculated. The results are presented in Table 2.

Table 2. Correlation ties between optical characteristics of the atmosphere's surface layer.

Угол рассеяния, град. 1	**Коэффициент корреляции между интенсивностью рассеяния света при разных углах рассеяния и коэффициентом ослабления** 2		Вероятная ошибка 3	
	1957—1960 гг.	1968—1969 гг.	1957—1960 гг.	1968—1969 гг.
10	0,966	0,623	0,0061	0,055
20	0,934	0,953	0,0115	0,074
30	0,957	0,952	0,0075	0,0191
40	0,961	0,991	0,0068	0,0019
50	0,975	0,978	0,0043	0,0047
60	0,931	0,972	0,0120	0,0059
70	0,970	0,984	0,0053	0,0033
80	0,914	0,964	0,0148	0,0076
90	0,949	0,917	0,089	0,017
100	0,928	0,955	0,0125	0,0094
110	0,717	0,961	0,0434	0,081
120	0,774	0,943	0,0358	0,0119
130	0,898	0,926	0,0173	0,0153
140	0,910	0,918	0,0153	0,0168
150	0,810	0,877	0,0308	0,025
160	0,803	0,935	0,0318	0,014
170	0,758	0,955	0,0381	0,0094
η*	0,5749	0,899	0,0599	0,055

$$* \ \eta = \frac{\int_0^{\frac{\pi}{2}} \mu(\Theta) \sin\Theta d\Theta}{\int_{\frac{\pi}{2}}^{\pi} \mu(\Theta) \sin\Theta d\Theta}.$$

KEY: (1) Scatter angle, degrees; (2) Correlation coefficient between the intensity of light scatter at various scatter angles and the attenuation factor; (3) Probability error.

Comparison of observed data with calculated data

The observed scatter indicatrices of the surface layer are the consequence of molecular and aerosol scattering of the light. With great cloudiness of the atmosphere, the aerosol scatter considerably exceeds the molecular and the effect of the latter can be disregarded. Under mountain conditions, however, there are frequent cases where visibility is good (greater than 50 km). Then, molecular scattering makes a considerable contribution and must be considered when distingushing the aerosol scatter indicatrix. This requires absolute measurements connected with inevitable errors. If we talk about interpretation of observations of the daytime sky's brightness, then it is even more difficult to distinguish the aerosol scatter indicatrix due to the effect of the repeated scattering and albedo of the underlying surface on the observed brightness indicatrix. However the asymmetry of the scatter functions of the surface layer and the indicatrix of the sky's brightness is connected exclusively with the action of the aerosol particles since, for the case of the Rayleigh scatter, the relationship

$$\mu(\Theta)=\mu(180^\circ-\Theta).$$

is valid.

In order to utilize relative measurements, we accepted the following relationship as the optical characteristic of the aerosol medium

$$K=\frac{\mu(10^\circ)-\mu(170^\circ)}{\mu(70^\circ)-\mu(110^\circ)}.$$

As is evident from Figs. 1 and 2, this value is extremely sensitive both to the refraction coefficient of the scattering medium as well as to the parameter of particle distribution by sizes. With a change in the parameter of the Junge distribution from 5 to 3, K changes 5-fold for media with a refraction index

m_3 = 1.25 and three-fold for media with m_2 = 1.50. With a mean Junge distribution and change in the refraction coefficient from 1.50 to 1.25, K changes three-fold, and with a change from 2.10 to 1.25 - 9-fold [7].

According to our data, the mean value of K for the surface layer of the atmosphere according to observations in 1957-1960 was 38.2, and for observations in 1968 — 27.9. The mean value of K in accordance with measurements of the sky's brightness indicatrix on the Sun's almucantar proved to be equal to 29.6. Thus, the value of K which characterizes the mean scatter indicatrix of aerosols contained in the atmosphere is close to the value of K which was measured from the mean scatter indicatrix of the surface layer which was obtained at the Mountain Observatory on fogless days.

We compared the observation data on the optical properties of the surface layer (indicatrices in the region $\theta \leq 170°$, spectral course of transparency $D_\lambda = \frac{1}{\lambda}$, coefficient K, angular course of scatter indicatrix in the region of small angles $\theta < 10°$) with the theoretical calculations of the same values for media with different distributions of particles with regard to dimensions and with different refraction coefficients. As a result, it was obtained that the mean optical properties of the atmosphere's surface layer in the night time on days without fog and precepitation agree in the best manner with the assumption that the refraction coefficient of the surface layer is close to 1.50 while the aerosol particles on the average have a Junge distribution for dimensions of $dN/d \log r = c/r^3$ with an admixture of large particles. This conclusion does not contradict the conclusion which we drew earlier that on individual days, with the encompassing of all meteorological situations to include dense haze and fog, we can expect various distibutions of aerosol particles by dimensions, i.e., we cannot speak about a universal Junge's distribution. For even with the interpretation of mean values, the angular course of the indicatrices in region $\theta \leq 10°$ testifies to the additional admixture of bigger particles. How the aerosol composition changes in the surface layer of the atmosphere from day to day and for different points of observation can be judged from the data of O. D. Barten'yeva [5]. Figure 3 presents the dependence of the coefficient K on the class number of the gently-sloping indicatrices of work [5] which characterizes the elongated nature of the surface layer's indicatrix. From Fig. 3 it follows that K for different meteorological conditions varies from 20 to 200. According to our data, for individual days the value K varied from 10.4 to 81 to include days with fog and dense haze. If we limit ourselves to observations in accordance with which the mean value of K which was used in our work was obtained, then the limits of change in K for individual days are great. From this it follows that for individual days the distribution of aerosol particles by dimensions can fluctuate greatly.

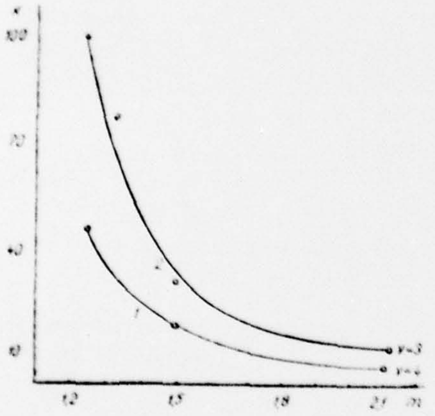

Fig. 1.

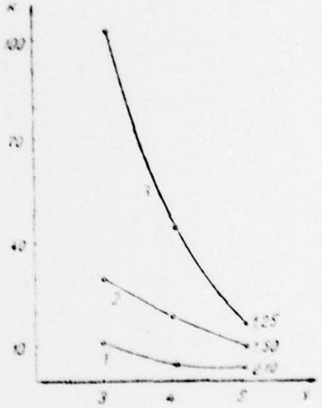

Fig. 2.

Fig. 1. Dependence of the parameter of aerosol scatter indicatrix $K=\frac{\mu(10^\circ)-\mu(170^\circ)}{\mu(70^\circ)-\mu(110^\circ)}$ on the refraction coefficient of the scattering medium m obtained from the results of theoretical calculations for the medium with a Junge-type distribution of particles by sizes: $\nu = 4$ (curve 1) and $\nu = 3$ (curve 2).

Fig. 2. Dependence of the parameter of aerosol scatter indicatrix $K=\frac{\mu(10^\circ)-\mu(170^\circ)}{\mu(70^\circ)-\mu(110^\circ)}$ on the parameter of a Junge distribution for a medium with refraction coefficient $m_1 = 2.10$ (curve 1), $m_2 = 1.50$ (curve 2), and $m_3 = 1.25$ (curve 3).

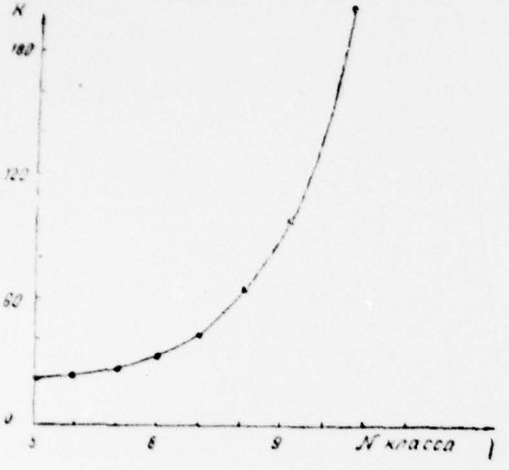

Fig. 3. Dependence of the parameter of aerosol scatter indicatrix $K=\frac{\mu(10^\circ)-\mu(170^\circ)}{\mu(70^\circ)-\mu(110^\circ)}$ on the asymmetry of the observed scatter indicatrix of the surface layer [5].

KEY: (1) class.

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