STATISTICAL CHARACTERISTICS OF SCATTERED SOLAR RADIATION INTENSITY IN THE ATMOSPHERE

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The results of statistical processing of the scattered solar radiation (SSR) intensity derived from the data of actinometric observations are presented. It is shown that the average–annual and most of average monthly functions of the SSR intensity distribution obey the exponential law.

It is impossible to estimate the operating efficiency and noiseproof of different atmospheric optical systems without knowledge of statistical characteristics of the natural background noise whose most important component is the scattered solar radiation (SSR).

The energy and spectral characteristics of the SSR in the atmosphere were studied elsewhere[1–5]. Thus in Ref. 2, based on the data of observations carried out in Oslo, empirical and several theoretical SSR intensity distributions were compared as functions of the solar elevation angle, but no unambiquous conclusions were drawn from these studies. At the same time in Ref. 3, where the data obtained at the meteorological observatory of the Moscow State University were used, the authors indicated a reasonable approximation of the changes in the average level of radiation intensity by log–normal distribution with the parameters being the functions of meteorological visual range. It was noted in Ref. 5 that in several spectral ranges the distribution of background radiation fluctuations obeyed the log–normal law and in those spectral ranges, where the SSR predominated, they obeyed the exponential law.

The aforementioned discrepancy in the measurements and their interpretation has stimulated the study of the law of distribution and the statistical moments of the SSR intensity I.

TABLE I.

Month	Parameter									
	$\overline{m}$, kW/m^2	$\overline{D}$	$\overline{\mu}_3$	$\overline{\mu}_4$	$\overline{\gamma}_1$	$\overline{\gamma}_2$	$\overline{\beta}_1$	$\overline{\beta}_2$	$\overline{m}\ /\ \overline{\sigma}$	σt, %
January	$3.61\cdot10^{-2}$	$7.41\cdot10^{-4}$	$2.44\cdot10^{-5}$	$2.31\cdot10^{-6}$	1.210	1.213	1.463	4.213	1.326	6.2
February	$7.46\cdot10^{-2}$	$2.24\cdot10^{-3}$	$1.19\cdot10^{-4}$	$2.34\cdot10^{-5}$	1.120	1.652	1.254	4.652	1.57	0
March	0.121	$5.35\cdot10^{-3}$	$2.05\cdot10^{-4}$	$8.25\cdot10^{-5}$	0.524	–0.120	0.275	2.880	1.659	4.3
April	0.128	$8.19\cdot10^{-3}$	$5.70\cdot10^{-4}$	$1.88\cdot10^{-4}$	0.770	–0.199	0.592	2.801	1.418	2.2
May	0.160	$9.80\cdot10^{-3}$	$8.43\cdot10^{-4}$	$2.95\cdot10^{-4}$	0.868	0.071	0.754	3.071	1.618	0.4
June	0.164	$8.31\cdot10^{-3}$	$6.73\cdot10^{-4}$	$2.34\cdot10^{-4}$	0.889	0.396	0.790	3.396	1.796	0
July	0.162	$8.90\cdot10^{-3}$	$7.70\cdot10^{-4}$	$2.59\cdot10^{-4}$	0.917	0.268	0.841	3.267	1.720	0
August	0.141	$9.80\cdot10^{-3}$	$7.80\cdot10^{-4}$	$2.99\cdot10^{-4}$	0.804	0.118	0.647	3.118	1.427	0.2
September	0.110	$6.33\cdot10^{-3}$	$2.98\cdot10^{-4}$	$9.32\cdot10^{-5}$	0.591	–0.675	0.349	2.325	1.384	2.3
October	$6.15\cdot10^{-2}$	$2.40\cdot10^{-3}$	$1.60\cdot10^{-4}$	$3.23\cdot10^{-5}$	1.358	2.615	1.843	5.015	1.225	4.5
November	0.042	$1.13\cdot10^{-3}$	$7.30\cdot10^{-5}$	$1.13\cdot10^{-5}$	1.926	5.883	3.709	8.883	1.259	9.6
December	$2.69\cdot10^{-2}$	$3.22\cdot10^{-4}$	$6.88\cdot10^{-6}$	$4.23\cdot10^{-7}$	1.191	1.079	1.418	4.079	1.501	16.7
Annualy meam	0.117	$8.41\cdot10^{-3}$	$8.25\cdot10^{-4}$	$2.67\cdot10^{-4}$	1.071	0.774	1.147	3.774	1.280	2.8

To this end, the computer processing of the data of diurnal standard (with 3–h intervals) observations of I (scattered short–wave solar radiation incident on a small area perpendicular to the direction of propagation of the solar radiation) was carried out at the meteorological station in Voeikovo of Leningrad region during three years (1980–1982). The total number of observations (length of sequence) was 3890. The entire range of variations of the values of I (kW/m^2) was divided into 19 intervals: 0–0.01, 0.01–0.02, 0.02–0.03, 0.03–0.04, 0.04–0.05, 0.05–0.06, 0.06–0.07, 0.07–0.08, 0.08–0.09, 0.09–0.1, 0.1–0.15, 0.15–0.2, 0.2–0.25, 0.25–0.3, 0.3–0.35, 0.35–0.4, 0.4–0.45, 0.45–0.5, and 0.5–0.55.

The measured values were processed using the technique described in Refs. 6 and 7. Table I presents the calculated results for the estimates of average $\overline{m}$, variance $\overline{D}$, third and fourth central sampling moments $\overline{\mu}_3$ and $\overline{\mu}_4$, and coefficients of asymmetry $\overline{\gamma}_1$ and excess $\overline{\gamma}_2$, as well as corresponding Pearson's coefficients β_1 and β_2 and the ratio of the average value to the standard deviation $\overline{m}/\overline{\sigma}$ for average monthly and annual measurements. The last column in the table presents the relative number of observations in per cent of the total number of observations, in which no SSR was recorded. The absence of such a SSR record in this case at the solar elevation angles larger than 0° was accounted for by the poor conditions of the SSR propagation under which the value of the SSR turned out to be lower than the sensitivity threshold of the measuring device.

The confidence interval of the estimates for sampling moments did not exceed 2.5% of their absolute values with a confidence level of 0.99.

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The value of the SSR intensity was affected by solar elevation angle, by transmission of the atmosphere, and by cloudiness[8]. The effect of these factors was interrelated and ambiguous. For example, the deteriorated transmission of the atmosphere associated with the increase in the number of scatterers or with the appearance of cloudiness resulted, on the one hand, in the increase of the scattered radiation intensity and, on the other hand, in its greater extinction. The increase in the solar elevation angle also resulted, on the one hand, in the decrease of the optical path length of interaction of radiation with scatterers and, on the other hand, in the decrease of radiation extinction.

Although the interaction between the aforementioned factors has a complicated nature, the analysis of the statistical studies for a general set of data makes it possible to draw some conclusions which are partially described in Table I. It can be seen from Table I that the largest average intensity of the SSR was observed in June when, as follows from the data of long standing in the same Leningrad region,[6,7] the average cloud amount was minimum, the meteorological visibility range was maximum, and moreover, as is well known the solar elevation angle was maximum (up to 53°). The lowest average intensity of the SSR was observed in December when, as in November, the average cloud amount was maximum and the optical length of the SSR path in clouds was maximum due to the minimum solar elevation angle (up to 6°). The inter comparison of the annual behavior of the average SSR intensity and the annual behavior of the average cloud amount[7] indicated that with an account of the solar elevation angle the average SSR was primarily determined by cloudiness and by the optical path length in the clouds.

The analysis of a general set of data on the SSR intensity and their comparison with the data on the cloud amount in the same region, given in actinometric monthly publications, shows that in recording the SSR we can identify two typical cases: 1) scattering primarily by clouds and 2) molecular and aerosol scattering. The former for the entire period of observations was typical of November–January, being especially sharply pronounced in December. The latter was most often observed in May–August, being particularly pronounced in June.

The empirical functions of the SSR intensity distribution $F(I)$ are shown in Figs. 1–3 in the following order: average annual, for December and March, and for June and September. The computer analysis revealed that in the first case (scattering by clouds) the best approximation for the empirical polygon measurements is the exponential distribution (Fig. 2, for December) and in the second case it is the Rayleigh distribution (Fig. 3, for June). The average annual polygon measurements are also well approximated by exponential distribution (Fig. 1).

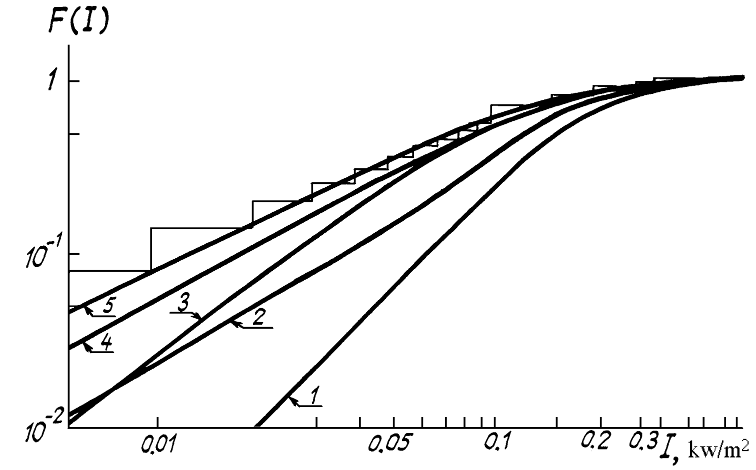

FIG. 1. Emperical (steplike curve) and theoretical average annual functions of the SSR intensity distribution: 1) truncated Rayleigh, 2) truncated regular, 3) γ – distribution, 4) β – distribution, and 5) truncated exponential.

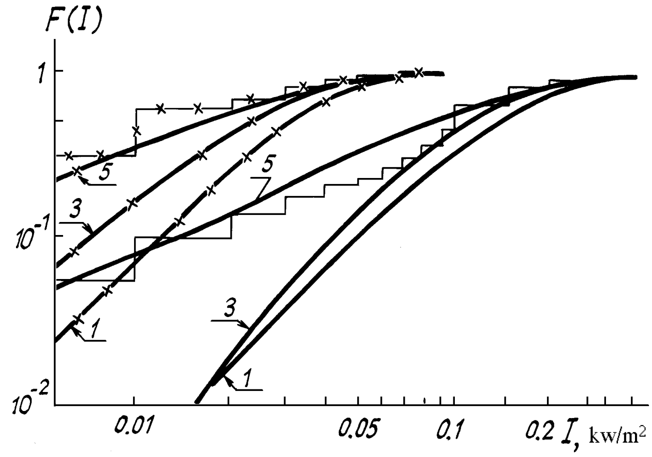

FIG. 2. Emperical (steplike curves) and theoretical functions of the SSR intensity distribution for March and December (curves with crosses). Figures at the curves denotes the same intensity distribution as in Fig. 1.

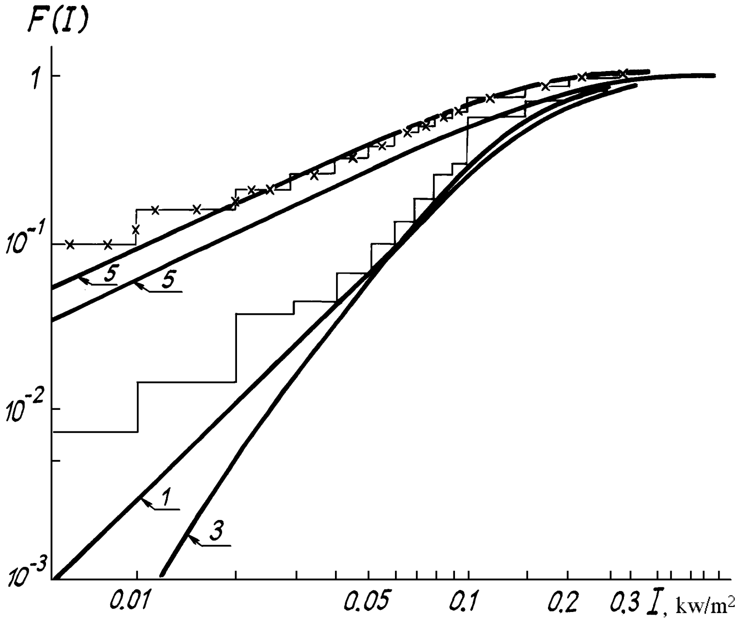

FIG. 3. Emperical (steplike curves) and theoretical functions of the SSR intensity distribution for June and September (curves with crosses). Figures at the curves denotes the same intensity distribution as in Fig. 1.

The polygon measurements for spring and fall months, when both cases were observed, were also satisfactorily described by the exponential law. At the same time, the larger the average monthly cloud amount, the more accurate is the exponential approximation (Figs. 2 and 3, for March and September).

Thus, we may conclude that the SSR intensity distribution function, in the cases in which the solar radiation is primarily scattered by clouds, is well described by the exponential law, which agreees with the results of Ref. 5, while in the cases of molecular and aerosol scattering the practical calculations require for the use of the Rayleigh law of the SSR intensity distribution.

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