DISTRIBUTION OF MEAN INTENSITY OF A LASER BEAM PASSED THROUGH SNOWFALL OVER THE FOCAL PLANE OF A RECEIVING LENS

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Measurement results in the distribution of mean intensity of a narrow diverging laser beam passed through tsnowfall over the receiving lens focal plane are presented. Qualitative proofs of the theoretically derived conclusions on the two–scale character of the diffraction pattern formed by such a beam on the focal plane of a receiving lens when passed through precipitations are given.

Distribution of the mean light intensity over the focal plane of a receiving lens in a turbulent atmosphere has been discussed at length in the literature and is successfully used in practice for measuring the structural characteristic of the refractive index C_n^2 and the internal scale of the turbulence l_0. Mironov and Tuzova[2] have analyzed a character of spreading out the mean diffraction pattern in a focal plane of a receiving lens in rain and established a two–scale character of its variation what, from the authors' point of view, can be used for estimating C_n^2 in rain as well as the rain intensity at small optical depth $\tau < 1$. A possibility of determining the scattering medium characteristics from light distribution over the focal plane of the receiving lens under multiple scattering has been demonstrated in a model experiment.[3]

The present paper deals with the analysis of mean light intensity distribution and some other characteristics in snowfall.

In our study we used the technique described in Ref. 1. A diverging laser beam from the main output of a laser propagated through a 964–m path and reached the receiving lens. A high–quality collimator of an optical bench OBC–3 in combination with a high–precision two–coordinate table supporting a slit and a photodetector were used as a receiving system. The slit position was visually controlled with readings of a digital coordinate device of the type of UTsP–1M.

The slit moved in the plane of the minimum–size focal spot which was determinated by a discrete lengthwise displacement of the slit. To do this, a screen with two round holes was inserted in front of the lens of the collimator.

The width of the slit was 10 μm. The slit moved along the horizontal direction with the velocity 0.228 mm/min. A signal from a PM–28 photomultiplier located behind the slit entered an A5–10 amplifier and then through the RC–circuit simultaneously entered an EZ–10 recorder and a printer enabling one to record a signal in the amplitude range of 60 DB above the level of several millivolt. The time constant of the RC–circuit was shorter then 5 s. A blind 2 m long and 23 cm in diameter was used to decrease the background noise due to extraneous light. The angle of the laser beam divergence was $5\cdot10^{-4}$ rad ($\lambda = 0.63286$ μm). The beam diameter in the reception plane was 1 m.

To damp mechanical vibrations the receiving and transmitting systems were installed on heavy concrete blocks, and the blind did not come into contact with the collimater.

According to our estimates the error of measurements of the slit coordinate y and the mean signal value at the level of $0.05\ V_0$, where V_0 is the mean signal at the center of distribution, was better then 10%. The optical depth of snowfall τ was calculated using data of the meteorological VRR–3 visual range recorder using the same procedure as in Ref. 4. The measurements were carried out in snowfall with the maximum size of snowflakes between 1 and 5 mm. The size of snowflakes was determined visually after they had been collected onto a soft backing.

When the wind velocity and the precipitation strength changes but slightly during the measurements, the intensity distribution is almost symmetric in the vicinity of its maximum. Each distribution was recorded during 40–50 s. A total number of 52 distributions recorded in three snowfalls were selected for the analysis.

Figure 1 shows three normalized distributions $V_n(y) = V(y)/V_0$ as functions of the slit coordinate z.

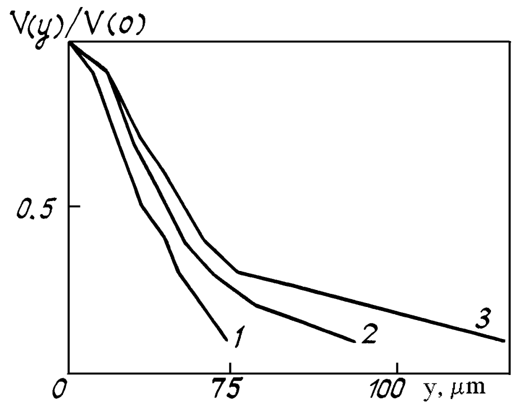

FIG. 1. Distribution of the mean intensity over the focal plane of the receiving lens at different values of optical depth τ*: 1)* 0.6, *2)* 3.1, *and 3)* 3.9.

As can be seen from the figure the normalized curves are constructed to the level $0.1\ V_0$. It is evident that the increase in optical depth causes a broadening of the entire profile. Moreover, with increase y the signal first drops sharply and then falls off more slowly. We believe that this feature assumes a two–scale distribution. To qualitatively verify this fact we have constructed experimentally observed distributions in coordinates used in Ref. 2 for several typical distributions. The results are shown in Fig. 2. The same figure shows the calculated distribution from Ref. 2 for the same parameters of the lens and for $C_n^2 = 1\cdot10^{-16}$ cm$^{-2/3}$, and $\tau = 2.4$ (rain) and $L = 1300$ m. A two–scale character of the distribution is quite evident from this figure. It should be noted that the influence of the second scale becomes noticeable at the slit displacement from the center of the distribution of two diffraction size of the lens image (i.e., at P = 2). To elucidate the origin of these

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scales we measured a temporal spectrum of fluctuations at different slit positions. The results are shown in Fig. 3.

The spectrum broadens to the high–frequency range as the slit moves from the distribution center. From our point of view this is indicative of the fact that the second scale in the mean intensity profile is mostly caused by snowflakes since their existence results in the broadening of the intensity fluctuation spectrum both in the direct beam[4] and in scattered radiation outside the beam.[5] It is also important that low–frequency (turbulent) components in the spectrum decrease with slit displacement.

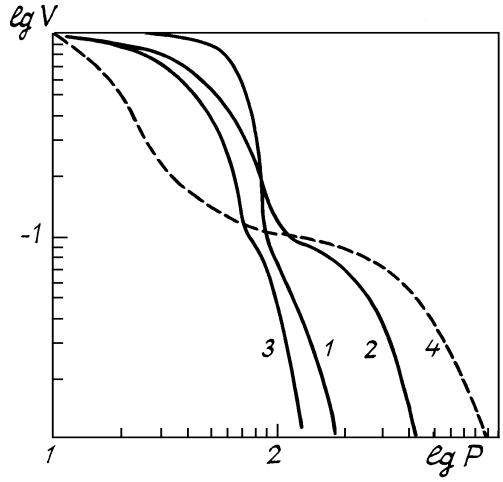

FIG. 2. Dependence of the function V(p) on the parameter P = $2\kappa Ry/F$ *at different* τ, where k = $2\pi/\lambda$, *R is the lens radius, F is the focal length, and y is the slit displacement. 1)* 0, *2)* 4.3, *3)* 0.9, *and 4)* 2.4 *calculation.*[2]

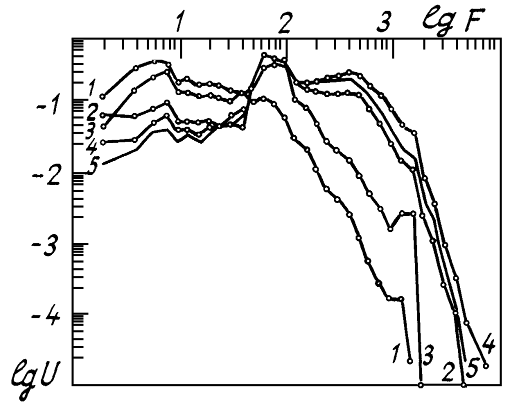

FIG 3. Intensity fluctuation spectrum $U(f) = \dfrac{fW(f)}{\int W(f)\mathrm{d}f}$ *where W(f) is the spectral density at frequency f with different slit displacements from the center of diffraction pattern (y is in μm) 1)* 0, *2)* 60, *3)* 25, *4)* 85, *and 5)* 110.

Variations of the first scale y_1 as a function of the optical depth τ were analyzed at the level 0.5 V_0, while those of the second scale y_2 were taken at the level 0.05 V_0. As a result the relations were obtained

$$y_1 = 184 + 18\,\tau,\ y_2 = 300 + 285\,\tau\ . \tag{1}$$

Both these scales increase with τ. However, the relative variation of the second scale in the region of values τ that took place in the experiment exceeds that of the first scale.

Let us determine the radius of coherence of a wave incident on the lens. To do this, we make use of the known relation between the field spatial coherence radius ρ_c and the laser source image size in the focal plane y_1 (see Ref. 2)

$$\rho_c = \frac{2\sqrt{\ln 2}\cdot F}{\kappa y_1}\ , \tag{2}$$

where $\kappa = 2\pi/\lambda$.

When the optical depth varies between 0.5 and 4.3 (τ = 0.5–4.3) the following expression for ρ_c (cm) well describes the calculated values

$$\rho_c = 1.5\text{–}0.12\,\tau\ . \tag{3}$$

At the maximum value $\tau = 4.3$ which was observed in our measurements, Eq. (3) gives ρ_c = 1 cm. It should be noted that since the snowflakes size recorded in the experiment did not exceed 5 mm (i.e., they were from 1 to 5 mm) we had the case when the field coherence radius exceeded the size of snowflakes.

Let us now estimate the C_n^2 value in the clear atmosphere which would provide the same radius of coherence on the path 964 m long. For this purpose we shall make use of the formula for calculating ρ_c of a spherical wave[6]

$$\rho_c = (0.55\, C_n^2\, \kappa^2 L)^{-3/5}\ . \tag{4}$$

The calculation by Eq. (4) gives C_n^2 equal to $1.2\cdot10^{-15}$ cm$^{-2/3}$. This value of C_n^2 is about two orders of magnitude smaller than the maximum value of C_n^2 in the ground layer of the atmosphere. We may thus come to a conclusion that a decrease of the spatial coherence of a narrow diverging laser beam even in a strong snowfall (τ = 4.3 and L = 964 m) does not exceed the maximum effect of a turbulent atmosphere, in the absence of precipitation, on the beam coherence. The same was pointed out in Ref. 4 where we made a comparison between the action of turbulence and precipitation on the level of fluctuations in a narrow diverging laser beam.

Thus the experiment in snowfall qualitatively confirms theoretical predictions of a two–scale diffraction pattern in the lens focus.

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