SATURATION OF THE INTENSITY FLUCTUATIONS OF LASER RADIATION PROPAGATING IN SNOWFALL

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The dependence of the level of laser radiation intensity fluctuations of a narrow divergent beam propagating in snowfall on the path length has been experimentally investigated under the similar atmospheric conditions. The saturation level of fluctuations has been found and the governing role of the section of a path adjacent to a receiver has been supported.

As is evident from general physical concepts, voluminous experimental results,[1] and theoretical estimates[2–4] the variance of the intensity fluctuations of laser beams propagating through the turbulent atmosphere under precipitation conditions is a complex function of the parameters of precipitation, turbulence, and geometrical beam characteristics.

If we fix the beam parameters and exclude the effect of turbulence from measurements, the experimentally measured variance will be a function of the following parameters:

$$\sigma^2_{\text{exp}} = F(L,\ D,\ C)\ , \tag{1}$$

where L is the path length, D is the maximum size of snowfall particles, and C is the particle concentration. It should be noted that in the experiment we usually measure not the particle concentration but the optical depth τ along the fixed path:

$$\tau = C\,\sigma\,L\ , \tag{2}$$

where σ is the extinction cross section of an individual particle. By now the dependence of the variance of the intensity fluctuations of a narrow divergent beam propagating in snowfall has been experimentally studied fairly well[5]

$$\sigma^2_{\text{exp}} = F(\tau) \tag{3}$$

with the known values of L and D.

In this paper we report the results of investigation of the dependence

$$\sigma_{\text{exp}} = F(L) \tag{4}$$

with fixed values of D and C based on a set of the experimental data.[1,5]

The turbulence contribution σ^2_{t} was excluded from the experimentally measured variance of the intensity fluctuations
σ^2_{exp} according to the approximate relation

$$\sigma^2_{\text{exp}} = \sigma^2_{\text{t}} + \sigma^2_{\text{s}} \tag{5}$$

where σ^2_{s} is the snowfall contribution.

To investigate the function $\sigma^2_{\text{s}} = F(L)$, we analyzed the snow contribution on the paths of lengths $L = 130$, 390, 650, 910, 964, and 1928 m with close values of particle concentration in snowfall. An optical thickness of precipitation $\tau_0 = C\,s\,L$ along 130 m path was taken as an equivalent to the particle concentration per unit volume. It was calculated from the transmission of the atmosphere measured on (2×100) m path using the PDV–3 visibility range meter. With fixed values of D, out of all the results obtained for 130 m path we choose such values of τ_0 for which it was possible to find the corresponding closest values of τ measured on the aforementioned paths. In spite of a large volume of measurement data (more than 3000 pairs of values of σ_{exp} and τ), their number selected by this scheme was small. To increase the volume of data, we also included the values of σ_{exp} at $\tau \pm 0.1$ for all the paths.

Depicted in Figs. 1 and 2 are σ_{exp} and σ_{s} for three values of τ_0 and two values of D. The snow and turbulence contributions were separated only for the path of length $L = 650$ m (daytime measurements), since only in this case the spectrum possessed a clearly pronounced turbulent maximum. In the remaining cases the turbulence contribution was negligible, and we assume $\sigma_{\text{exp}} = \sigma_{\text{s}}$. And only on 1928 m path the spectrum in the low–frequency range was significant but had no maximum, so that the turbulence made an appreciable contribution which cannot be estimated by this method. Moreover, it should be noted that 1928 m path was particularly distinguished from the remaining ones since the size of the reflector (40×40) cm was smaller than the beam diameter (1 m).

As evident from the figures, the intensity fluctuations are saturated first as the path length increases. It should be particularly emphasized that this fact was observed for close values of particle concentration in snowfall. It is significant to note that the level of saturation and the path lengths along which the saturation occurs depend on the maximum size of particles. Namely, for $D = 3$–5 mm the regime of saturated fluctuations starts at $L = 650$ m and for $D = 1$– 3 mm even at $L = 390$ m.

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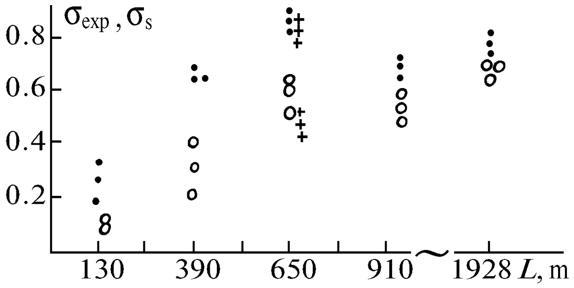

FIG. 1. A plot of $\sigma_{\rm exp}$ *and* $\sigma_{\rm s}$ *vs the path length L for* $D = 3$–5 mm: $\sigma_{\rm exp}$ *is shown at* $\tau_0 = 0.08$ *(dots) and* 0.24 *(empty circles).* $\sigma_{\rm s}$ *is shown by pluses at* $\tau_0 = 00.8$ *and* 0.24.

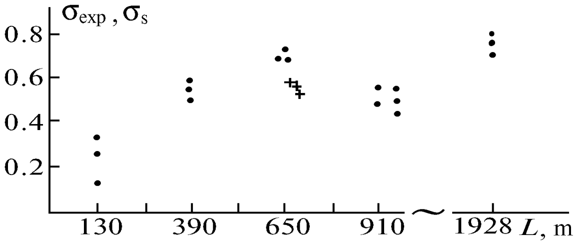

FIG. 2. A plot of $\sigma_{\rm exp}$ *(dots) and* $\sigma_{\rm s}$ *(pluses) vs the path length L for* $D = 1$–3 mm *at* $\tau_0 = 0.16$.

These facts are in qualitative agreement with the model proposed previously in Ref. 2. In accordance with this model, the intensity fluctuations in snowfalls are primarily due to the particle layer adjacent to a radiation receiver. The depth of this layer depends on the particle size

$$l = \text{const}\; S\,, \tag{6}$$

where S is the area of projection of an individual particle. The regime of saturated fluctuations starts when $L > l$. In this case the level of saturation is determined by the formula[6]

$$\sigma_l = \sqrt{(\exp\,(\tau_l\,/\,2)) - 1}\,, \tag{7}$$

where τ_l is the optical depth of the adjacent layer.

The experimental data presented here cannot be used to check formula (6), since the area of particle projection in snowfall was not specially measured. However, the values of the adjacent layer lengths l | 650 m for $D = 3$–5 mm and l | 390 m for $D = 1$–3 mm in snowfall are in qualitative agreement with the previously obtained estimate $l = 200$ m for rain in which the average diameter of droplets was close to 1 mm (see Ref. 2).

At the same time, the formula (7) turns out to be in good quantitative agreement with the experimental results. Namely, in Fig. 1 the saturation level σ_l is approximately equal to 0.5 at $\tau_0 = 0.08$ ($\tau_{650} = 0.4$), and the calculation by formula (7) yields 0.47. Accordingly, at $\tau_0 = 0.24$ ($\tau_{650} = 1.2$) the experimental value is $\sigma_{\rm s} = 0.75$ and the calculated one is 0.9. In Fig. 2 the experimental value is about 0.5 and the calculated one is approximately 0.52.

Thus the results described, along with those from Ref. 2, support the decisive role of the layer adjacent to a receiver in the formation of the laser radiation intensity fluctuations under conditions of precipitation.

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