AUTOCORRELATION FUNCTION OF THE LASER-BEAM FLUCTUATIONS IN SNOWFALLS

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Autocorrelation function of fluctuations of a narrow diverging laser beam ($\lambda = 0.6328$ μm), propagating through snowfalls has been studied at six propagation paths with lengths from 130 to 1928 m. It was found from these studies that the correlation time increases with increase of the receiver diameter and size of particles.

A characteristic feature of the fluctuations of laser radiation, which propagates under conditions of atmospheric precipitations, is an essential extension of the frequency spectrum of these fluctuations within the high–frequency interval compared to that in a nonturbid atmosphere other atmospheric parameters being the same.[1,2] This fact was successfully used for detection and identification of precipitation species.[3,4]

Since the spectrum and the autocorrelation function (ACF) of the signal are interrelated, an occurrence of precipitations along the laser–beam propagation path should affect the ACF. At present, only little information about the effect of snowfall on the laser–radiation ACF is available. Few experiments, carried out during snowfall, yielded an appreciably shorter correlation time for high–frequency fluctuations than in a clear atmosphere (without precipitations),[5–7] but data are not sufficient to predict its values under different meteorological conditions.

In this paper we analyze the ACF of a narrow divergent laser beam under conditions of snowfall. The analysis presented in this paper is based on the measurements, performed under the same conditions like those in Ref. 8, in which the fluctuation level has been studied.

The measurements have been carried out along the paths 130, 260, 390, 650, 964, and 1928 m long. On the paths of 260, 390, and 650 m in length the laser beam was reflected from flat mirrors (details can be found in Refs. 1 and 2), which had been placed at a distance of 130 m, and on the path of 1928 m this beam was reflected from a mirror, which had been placed at a distance of 964 m. We employed an LG–38 He–Ne laser with wavelength of radiation λ equal to 0.6328 μm, operating in a quasisingle–mode and possessing a divergence angle of $5\cdot10^{-4}$ rad. A PMT–38 served as the detector. The measurements have been located simultaneously on two paths using the receivers of the same size $D_r = 0.1$ mm or using a single beam on the path 964 m long but using essentially different receivers with the diameter D_r equal to 160 and 0.1 mm. For the larger receiver we used a lens objective 160 mm in diameter with focal length of 1.6 m. The viewing angle of the large receiver was equal to 0.1 rad, and that of the small equaled $5\cdot10^{-4}$ rad. Near the lens objective (7 cm from its edge) we placed another PMT with a blind and a diaphragm of 0.1 mm in front of the photocathode. In order to improve the signal–to–noise ratio at optical thickness $\tau = 4 - 7$ another diaphragm with a diameter of 1.6 mm was used instead of the diaphragm with the 0.1 mm diameter.

Let the atmospheric conditions be described by the optical thickness τ, the wind velocity V, the perpendicular wind velocity $V_\perp$, and by the maximum snowflake size D_m. The optical thickness was measured with the help of a RDV–3 visual–range meter on the path 2*100 m. The maximum size of snowflakes was estimated visually upon catching them onto a soft material.

The autocorrelation function was measured with the help of an X6–4 dual–channel correlator. The averaging time in the experiments did not exceed 5 s. The signal discretization in time was performed at a time step of 10 and 100 μs. Sometimes, these intervals were extended by 3.33 times. The total number of 125 ACF's, measured during 15 snowfalls, has been analyzed. Figure 1 presents some of the ACF's, the analysis of which has shown that at close values of $V_\perp$ the correlation time at the level $t_c = 0.37$ (i.e., $1/e$) decreases as the particle size increases. One can well see this process in Fig. 1*b* for the path 964 m long and in Fig. 1*a* for the path 260 m long (curves *1* and *2*). The same situation has been observed with all other paths.

As the detector diameter grows the correlation time t_c increases (Fig. 1*a*, curves *3*, *4*, and *5*). It is pertinent to note that when the detector diameter equals 160 mm the correlation time at the level 0.37 exceeds that for the diameter $D_r = 0.1$ mm almost by a factor of 10.

By virtue of the fact that the frequency of the high–frequency maximum in the fluctuation spectrum is proportional to the ratio of the perpendicular motion velocity to the particle size D_m (see Refs. 8 and 9) the correlation time should depend on these quantities, i.e., $t_c = A\, D_m/V_\perp$.

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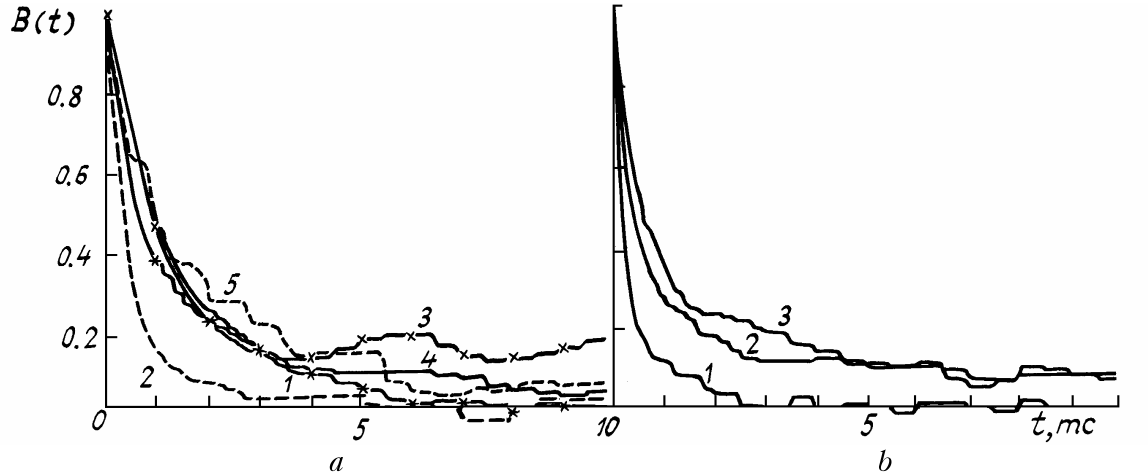

FIG. 1. The temporal ACF:

a) March 21, 1990: L = 260 m, τ = 0.85, V = 6 – 7 m/s, $V_{\perp}$ = 0.7 m/s, D_m = 3 – 5 mm, *and* D_r = 0.1 mm *(curve 1)*; L = 260 m, τ = 0.9, V = 6 – 7 m/s, $V_{\perp}$ = 0.7 m/s, D_m = 1 mm, *and* D_r = 0.1 mm *(curve 2)*; L = 964 m, τ = 3.1, V = 6 – 7 m/s, $V_{\perp}$= 1.1 m/s, D_m = 1 – 3 mm, *and* D_r = 160 mm *(curve 3)*; L = 954 m, τ = 3.1, V = 6 – 7 m/s, $V_{\perp}$ = 1.1 m/s, D_m = 1 – 3 mm, *and* D_r = 0.1 mm *(curve 4)*; *and, December 5, 1989*: L = 964 m, τ = 6.7, V = 7 – 8 m/s, $V_{\perp}$ = 2.3 m/s, D_m = 1 – 3 mm, *and,* D_r = 0.1 mm *(curve 5)*.

b) February 28, 1990: L = 964 m, τ = 2.1, V = 4 m/s, $V_{\perp}$ = 0.7 m/s, $D_m \le$ 20 mm, *and* D_r = 0.1 mm *(curve 1)*; L = 964 m, τ = 2.8, V = 4 m/s, $V_{\perp}$ = 0.7 m/s, $D_m \le$ 7 mm, *and* D_r = 0.1 mm *(curve 2)*; and, L = 964 m, τ = 0.5, V = 6 m/s, $V_{\perp}$ = 3.6 m/s, $D_m \le$ 2 mm, *and* D_r = 0.1 mm *(curve 3)*.

TABLE I.

Date	D_m, mm	τ	$V_{\perp}$, m/s	$t_{0.5}$, μs	$t_{0.37}$, μs	A	D_r, mm	C, 1/μs	α_0	α	N
14.11.89	1	2.5	3.4	132	178	0.62	0.1	$4.5 \cdot 10^{-4}$	—	—	8
14.11.89	2	2.5	2.7	205	263	0.39	1.6	—	—	—	4
5.12.89	2	6.2	2.3	115	192	0.22	1.6	—	0.27	1.95	2
28.02.90	20	2.1	1.9	420	970	0.15	0.1	$9 \cdot 10^{-4}$	—	—	1
19.12.89	5—7	2.3	1.8	80	140	0.4	0.1	—	—	—	1
21.03.90	3—5	3.4	2.0	141	207	0.1	0.1	$3.65 \cdot 10^{-3}$	0.42	2.95	4
21.03.90	1—3	3.1	2.0	840	1305	1.82	160	$5.95 \cdot 10^{-4}$	0.62	29.2	2

The computational results for the mean values of A for the path 964 m long are given in Table I. We have averaged the ACF's measured at close values of the quantities D_m and $V_{\perp}$. The number of ACF's involved in the averaging is given in the right column of Table I. The cases in which the angle between the wind direction and the path was less than 10° were excluded from the analysis. The correlation–time values measured at half–maximum level are tabulated also.

As follows from the table (and from the entire analysis) the value of the proportionality coefficient A varies within a wide range from 0.04 to 0.73 when the detector diameter equals 0.1 mm, and, in addition there exists a trend toward a decrease in A with growth of the particle size. Such a large spread in the values of A is apparently caused by a poor accuracy of measuring the maximum particle size. This is especially true in the case of large floccular particles, which possess quite complex internal structure and external shape. It is obvious that these two factors are to be manifested in the shadow–pattern details in the detection plane produced by the particles at small distances.

It should be especially noted that for $D_m \approx$ 1 mm and D_r = 0.1 mm, and for the values of the ratio $D_m / V_{\perp}$ close to 0.3, an increase in the optical thickness from 1.2 to 3.8 does not give rise to a decrease in the correlation time, which is predicted in theoretical studies (see, e.g., Ref. 9).

The ACF shape is quite variable, and the normalized ACF's may be conditionally grouped into three types according to their shapes, viz., the power type ($B = \alpha_0 t^{-\alpha}$), comprising 30%; the linear one ($\beta = 1 - Ct$), comprising 50%; and the remaining ACF's comprising 20% of all the observed ACF's.

Conclusions: The experimentally investigated ACF's under conditions of snowfalls show that depending on the experimental conditions the correlation time t_c may vary within a wide range. Moreover, it increases as the particle size and the detector diameter increase under other conditions being the same. On the whole, the observed peculiarities of the ACF's are logically expectable from the fluctuation spectrum.

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