Intensity fluctuations of radiation scattered in the near-ground atmospheric layer from a focused laser beam. Part 2. Rains and fogs

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Received November 1, 1999

Fluctuation characteristics of a focused laser beam upon scattering in fog and rain are analyzed. It is found that the temporal frequency spectrum can be used for identification of the weather conditions.

Experimental investigations into the fluctuations of radiation scattered in the atmosphere from a focused laser beam and determination of optical fluctuation characteristics of scattered radiation for identification of the weather conditions are not new problems in atmospheric optics. These problems have already been discussed in some detail in Refs. 1 and 2. From these references it is clear that the mean value of the optical signal in a beam and its close vicinity does not provide for the unambiguous answer to the question on the weather conditions in the atmosphere.

As follows from our previous papers,[3–6] temporal fluctuations of the received radiation bear information on the presence of precipitation. This information can be obtained by analyzing the time spectrum of a signal both within the beam and in its close vicinity. Atmospheric turbulence inevitably restricts such measurements, especially, in the region of low frequencies, which should be decreased in developing an indicator of weather conditions. From Refs. 3–6 it follows that fluctuations of scattered radiation are less subject to the action of turbulence as compared with fluctuations at the beam center. On the other hand, it is known that a decrease of the scattering angle near the beam results in a significant increase of the scattered radiation flux. In this respect, the focused beam is very useful. Beam focusing allows the beam size of several millimeters to be obtained in the focal plane. Thus, it becomes possible to measure the scattered radiation within very small scattering angles with a small-size detector. Until now the data on peculiarities of the radiation scattered within small scattering angles are very few. The published results refer only to snowfalls.[3–6]

1. Measurement technique

Let us describe briefly the measurement technique. As a radiation source, we used a LGN–215 commercially available He–Ne laser emitting at the wavelength $\lambda = 0.6328$ μm. Its output power $P \leq 70$ mW. The path length was $L = 130$ m. The initial diameter of the beam was about 16 cm. The beam diameter in the receiving plane was no more than 5 mm. The diameter of the receiving diaphragm was 0.01 cm. The photoreceiver's field of view was $2.7\cdot10^{-2}$ rad. The photoreceiver was set at a distance $\Delta L = 10$ mm from the beam center. Radiation was received in the focal plane of the laser beam. The photoreceiver was first set at the optical axis of the focused beam and then displaced by 10 mm off the axis. The frequency spectrum, autocorrelation function, and histogram of the probability distribution of temporal fluctuations of the scattered radiation were measured simultaneously.

2. Measurement results

Figure 1 shows (on the logarithmic scale) the temporal spectrum in four significantly different situations: fog (*1*), drizzle (*2*), snow (*3*), and rain (*4*). Note that the measurements in fog were conducted under calm weather conditions. On the whole, we have found that the spectra of radiation scattered from a focused laser beam had markedly different shapes in fog and precipitation with close in value optical thickness. The spectrum in fog had markedly lower frequency than that in rain, snow, and drizzle. A similar situation also took place at the center of a narrow diverging laser beam.[1] It seems natural to use such differences in the spectrum for identification of the type of weather. To do this, we can use peculiarities in the shape of the spectrum as a whole. To simplify the measurements, while taking into account the above-mentioned differences in the spectrum, we can use the well known approach described in Ref. 7, which employs the ratios of signals measured in narrow frequency ranges. For example, signals at the output of 25 and 500 Hz filters can be used for the situation shown in the figure. In this case, the second-to-first signal ratio is very small (0.0015) in fog, while in drizzle, rain, and snow it is 0.39, 3.35, and 3.34, respectively. In rain and snow this ratio is almost the same. Therefore, one more filter can be introduced, for example, a filter with the central

0235-6880/99/12 1111-02 $02.00

frequency at 2.5 kHz. In this case, the third-to-second signal ratio is equal to 0.28 in rain and 0.08 in snow, what provides for a possibility of distinguishing between snow and rain. To choose the central frequency of a filter, we should take into account the mean wind velocity or, what is better, its component normal to the path.[8] However, to choose a specific algorithm, further investigations are needed.

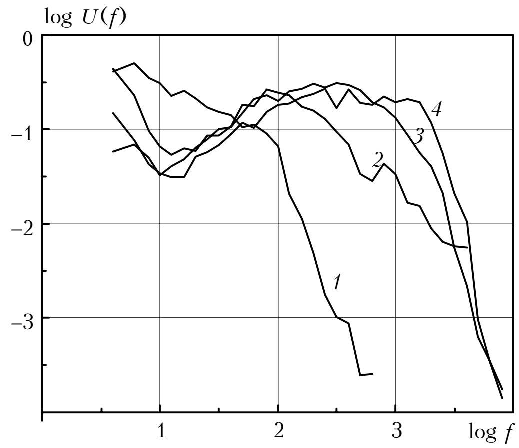

Fig. 1. Temporal frequency spectrum of fluctuations of scattered radiation: fog, $\tau = 0.145$, $V = 0$ (*1*); drizzle, $\tau = 0.07$, $V = 4$ m/s, $\bar{V} = 210°$ (*2*); snow, $\tau = 0.16$, $V = 4$ m/s, $\bar{V} = 210°$ (*3*); rain, $\tau = 0.16$, $V = 2$ m/s, $\bar{V} = 290°$ (*4*).

The correlation time in fog exceeds that in rain, snow, and drizzle by an order of magnitude and even more. In our experiments we obtained 14 normalized correlation functions for fog. The optical thickness in this experiment varied from 0.14 to 0.5 at the wind velocity close to zero. The mean correlation time at the levels of 0.5, 0.367, 0.1, and 0 was 7.78, 13.3, 42.2, and 73.16 ms, respectively. Its minimum values were equal to 3.08, 4.31, 30, and 48 ms, while the maximum values were 15.5, 21, 65, and 95 ms. We did not find in the data array analyzed the dependence of the correlation time on optical thickness.

The probability density distribution of intensity fluctuations of radiation scattered from a focused laser beam has right-hand sided asymmetry in snowfall[5,6] and in rains and fogs. The experimental distributions are most closely described by the gamma distribution.

Conclusion

Analyzing the experimental data on the intensity fluctuations of radiation scattered from a focused laser beam in fog and rain, we have revealed some peculiarities in them. In our opinion, the temporal frequency spectrum is most suitable for identification of the weather conditions, and information on weather can be obtained from the shape of the entire spectrum, as well as from the ratios among signals measured in narrow spectral intervals. To choose specific intervals, some additional measurements are needed.

Acknowledgments

The authors are thankful to A.G. Borovoi for useful advice on the problem discussed.

This work was partially supported by the Russian Foundation for Basic Research, Project No. 99–02–16923.

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