TEMPORAL AND SPATIAL VARIABILITY OF FIELDS OF THE OPTICAL AND AEROSOL CHARACTERISTICS IN THE ATMOSPHERE. III. SIMULATION OF THE SPATIAL DISTRIBUTION OF AEROSOL CHARACTERISTICS IN THE ATMOSPHERE

S.D. Andreev and L.S. Ivlev

Scientific-Research Institute of Physics
at the St.-Petersburg State University
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The results of simulation of the influence of inhomogeneity in the spatial structure of aerosol field on the observed optical characteristics of the propagation path (its optical thickness or the effective extinction coefficient determined on its basis) are analyzed. It is shown that the random distribution of aerosol characteristics leads to the biased estimates of the average atmospheric optical thickness. In the case in which the spatial aerosol distribution is described by fractal regularities, a polymodal character of the probability of the optical thickness observation is revealed.

Evidence of fractal structure of temporal variability of the aerosol extinction in the atmosphere discussed in Refs. 1 and 2 leads to the suggestion that the spatial inhomogeneity of the atmospheric aerosol field is one of the probable reasons for the effect being observed. It can be described based on the laws of the fractal geometry.

The idea of the inhomogeneity of spatial distribution of atmospheric aerosols is trivial and is repeatedly supported experimentally.[2–4] However, thorough investigations of the aerosol field structure that can be used to analyze the quantitative regularities or to simulate actual atmospheric situation have not yet been made primarily due to the lack of fairly reliable and complete experimental data arrays.

It seems to us that the estimates of time series structure of the atmospheric optical and aerosol characteristics obtained in Refs. 1 and 2 provide a certain basis for the investigation of this kind. As noted in Ref. 1, the Hurst constant H is connected with the fractal dimension of the examined process D. By assigning the reason for the peculiarities of temporal aerosol characteristics established in Refs. 1 and 2 to the inhomogeneity of the spatial structure of aerosol field, it would be reasonable to describe it by the corresponding regularities.

As the first step of investigations, the numerical simulation method was chosen. A series of numerical experiments on simulation of possible manifestations of the inhomogeneity in the spatial distribution of the optical aerosol characteristics was carried out as part of experimental investigations described in Ref. 5 (measurement of the spectral atmospheric transmission along horizontal paths is the simplest experiment of this kind from the viewpoint of its interpretation).

The optical characteristics of atmospheric aerosols are the complicated functions of the atmospheric state (and primarily of such characteristics of the state as air humidity, degree of development of convective flows, and structure of the atmospheric turbulence) and characteristics of the underlying surface, which is one of the main sources (and sinks) of aerosol particles. Many of these characteristics are simulated successfully by the methods of the fractal system theory. This provides a basis for testing of the adequacy of such an approach to the description of the aerosol field structure in the atmosphere.

At this stage of investigations we did not pose the problem to follow the effect of peculiarities in the spatial distribution of all the aerosol characteristics that determine to some extent their optical properties on the atmospheric characteristics. It is suggested that the atmosphere consists of two components. The optical characteristics of the first component (molecular) are constant and uniformly distributed along the path. The optical characteristics of the second component (aerosol) have spatially inhomogeneous structure. For simplicity we assume that at this stage the aerosol field in the region R, where the path L is located along which the optical thickness is measured, either can be homogeneous but simultaneously varying with time at all points of the examined region or can have the structure analogous to a cloud one. In this case, the optical characteristics in the regions of aerosol concentrations are identical and all regions have the same characteristic size l.

Under these conditions, the domains of the parameters R and l are defined sufficiently arbitrarily (for convenience of calculations, the normalized characteristics $R' = R/L$ and $L' = L/l$ are used, so that formally their actual values are not considered).

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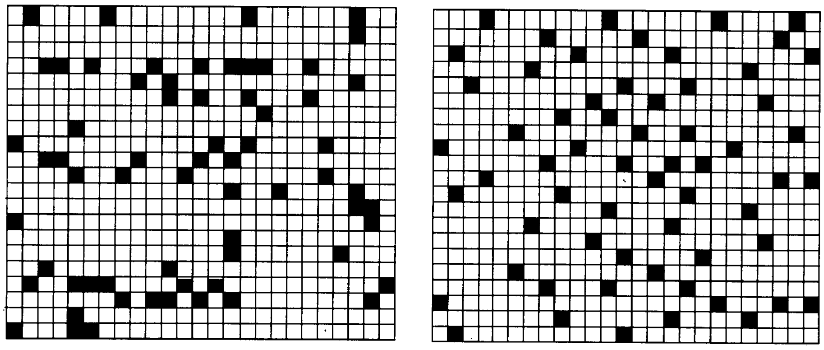
However, because an effort is made to simulate the path measurements described in Ref. 5, we can state that the size of model cells l is assumed of the order of several tens or several hundreds of meters and the path length L ~ (1...10) km. The typical size R is several tens of meters. Thus in this case the conditions are simulated analogous to those described in Refs. 2 and 3 rather than the situations described in Ref. 4.

The assumption that the aerosol field spatial structure is fractal means that the regions of aerosol concentration obey the law $N \sim r^D$, where N is the number of cells with linear size l and D is the fractal dimension. For this cellular structure of the fields, $N_0 = I{\cdot}R^D$ is the maximum possible number of cells in the region R filled with the aerosol. Thus, as a fill factor ω $(0 \le \omega \le 1)$, which for random distribution may be set arbitrarily, the quantity $\omega = l^3R^D/R^2$ is used. For $l \ll R$, its range of variation is limited and its maximum value is determined by the fractal dimension.

Examples of realizations of spatial distribution of inhomogeneities for the models used in calculations are shown in Fig. 1. It should be noted that it is difficult to estimate visually the differences between the spatial structures in the examined cases. In this connection, we note that the random distribution, in general, should be considered as a special case of the fractal distribution with the fractal dimension D = 1.5.



a *b*

FIG. 1. Fragments of model aerosol fields: a) random distribution; b) fractal (D = 1.7) distribution.

Some results of the numerical experiment are shown in Figs. 2 and 3 that illustrate the calculated recurrence of observations of definite optical thicknesses of the atmospheric layer under various assumptions on the spatial distribution of the aerosol extinction.

If the regions of aerosol concentrations are uniformly distributed along the entire path, the aerosol extinction coefficients vary randomly with time simultaneously on the entire path: the measurements (the average measurable extinction coefficient and its variance) reflect adequately the actual situation (curve *1* in Fig. 2).

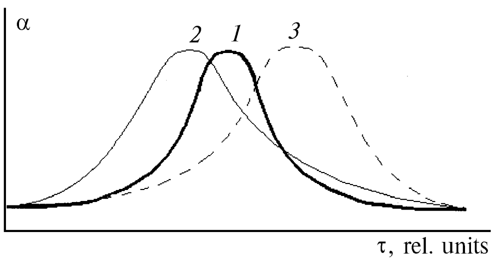


FIG. 2. Recurrence α (in rel. units) of observations of the optical thickness on the horizontally-inhomogeneous path: 1) homogeneous path with simultaneous random variations of the aerosol characteristics; 2, 3) random distribution of aerosol "clouds" along the path for $L \ll R$, ω = 0.2 (2) and $L \to R$ (3), ω = 0.7.

When the field of the aerosol characteristics is assumed to be inhomogeneous (recall that the inhomogeneity is simulated as a "cloudyB structure), the experiment leads to the biased estimates. For random distribution of inhomogeneities, the bias is a complicated function of the relation of the inhomogeneity size l, variance, the path length L, the characteristic size of the examined spatial region R, and the fill factor ω. It should be noted that at this stage the problem of thorough investigation of this dependence is not posed by us. We only restricted ourselves to the model calculations for some specific situations (curves *2* and *3* in Fig. 2).

The assumption about the fractal character of the spatial structure of inhomogeneities leads to polymodal distributions of the observation probability of the aerosol extinction coefficient. In this case, the position and relationships of modes are determined by the same parameters as in the previous case and by the fractal dimension D as well (see Fig. 3).

In this case, the horizontally-inhomogeneous (plane) field is considered. The fractal dimension is within the limits $1 < D < 2$. As noted above, the experimental data on the aerosol field spatial structure under conditions of the real atmosphere (especially, on any regularities of the distribution of inhomogeneities) are lacking. For this reason it is very difficult and practically impossible to select the fractal dimension D. Taking into account the data from Refs. 1 and 2 about the estimates of the Hurst constant, in our calculations (whose results are illustrated by curves in Fig. 3) we used $D \approx 1.3$ and 1.7.

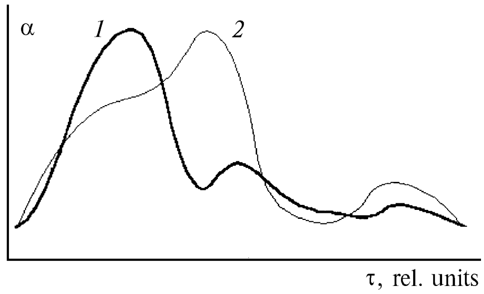


FIG. 3. Recurrence α *(in rel. units) of observations of the optical thickness along the horizontally-inhomogeneous path. Fractal structure of aerosol fields: 1)* $D = 1.3$; *2)* $D = 1.5$.

Undoubtedly, the results obtained in the numerical experiment and presented in this paper are preliminary and hypothetical in nature and need further checking and experimental verification. Moreover, the results of numerical simulation presented here do not exhaust the variety of possible situations and are only rough estimates semiqualitative in character. We think that more careful estimates will be made only when the reliable data are obtained on the actual nature of the spatial distribution. At present, in our opinion, the only method can be used for checking of the adequacy of the assumption on the fractal nature of the aerosol field spatial structure, namely, an analysis of recurrence of the measurements of the atmospheric spectral transmittance on extended horizontal paths (experimental investigations described in Ref. 5). Nevertheless, in connection with plausibility of this assumption and fundamental importance of consideration of its consequences when solving numerous problems that require information about the spatial distribution of various characteristics of atmospheric aerosols (the practical problems of such kind are, first of all, the problems of remote sensing of the atmosphere and Earth's surface as well as the problems of optical communication), we believe that it is necessary to call the researchers' attention to this possibility.

It also should be noted that in the literature the data were presented on polymodal character of actual curves of the atmospheric transmittance observation probability (see, for example, Ref. 6).

However, it seems to us that because for such conclusions the results of long-term investigations are used for all seasons and the variety of synoptic situations, the data reported in Ref. 6 that are similar to our data and are probably of analogous nature describe somewhat different natural processes, first of all, the processes characterized by greatly different time scales than those considered in this case. It also seems possible that the cloud structure of aerosol field similar to that described in Ref. 4 affects the data reported in Ref. 6, although in this paper it is emphasized that the above-mentioned cloud structures are rather rare.

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