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GENERAL BIOLOGY

Measurement Errors in Determining Tropospheric Bioaerosol Concentrations in the Southern Region of Western Siberia

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The Research Institute of Aerobiology of the State Research Center of Virology and Biotechnology "Vector" and the Institute of Atmosphere Optics of the Siberian Division, Russian Academy of Sciences have been systematically monitoring tropospheric biogenic aerosols (bioaerosols) in the southern region of Western Siberia since December 1998. Samples of atmospheric air are taken at altitudes of 0.5, 1, 1.5, 2, 3, 4, 5.5, and 7 km using a plane–laboratory Optik-E during one day in the last third of every month to determine the total protein content and the amount of viable microorganisms. The research methods and summarized results of the studies are described in detail elsewhere [1, 2].

The data obtained allowed us to determine seasonal variation in the biogenic component content of tropospheric aerosols, identify microorganisms constituting them, and locate the sources forming the bioaerosol background in the atmosphere of the southern region of Western Siberia. It has been demonstrated that the main sources of the biogenic component are remote from the region studied; apparently, they are located in Central Asia.

This may explain, e.g., why the concentration of tropospheric bioaerosols increases too early in spring and decreases too late in autumn to fit the "wakening–sleeping" cycle of animate nature in the southern part of Western Siberia.

The data obtained indicate, at the qualitative level, that the total protein concentration and the common logarithm of the concentration of viable microorganisms are very variable, the bioaerosol concentration being independent on altitude. This also confirms the hypothesis that the sources of bioaerosols are remote.

Statistical analysis of the results with the use of Student's *t* test has confirmed the hypothesis that bioaerosol concentration is independent on altitude at a confidence level of 95–97.5%. Therefore, the monthly values of concentrations obtained at eight altitudes are samples from the statistical ensemble of concentrations independent of the altitude of observation.

In the general case, the observed large variation of concentrations is accounted for by stochastic scattering of atmospheric admixtures because of atmosphere turbulence and measurement errors causing additional variation in the observed concentrations.

We used the entire set of experimental data on the total protein and viable microorganism concentrations obtained from 1999 to 2003 to estimate the contribution of measurement errors into the observed variation of the concentrations of tropospheric bioaerosols in the southern part of Western Siberia. Here, we considered the general relationships allowing the measurement errors to be taken into account and correct the observed variances of tropospheric bioaerosol concentrations.

Total atmospheric protein. The general form of the probability density of the total protein aerosol concentration was determined in [3]. Analysis of the data obtained permits its approximation with the normal distribution law:

$$f_p(C_p) \approx \frac{1}{\sqrt{2\pi}\sigma_p} \exp\left[-\frac{(C_p - \bar{C}_p)^2}{2\sigma_p^2}\right], \qquad (1)$$

where $\bar{C}_p$ and σ_p^2 are the mathematical expectation and the variance of the concentration.

Because of measurement errors when determining total protein aerosol concentrations, a value ξ_p will be obtained instead of the random value C_p. In the general case, the joint probability density of the result of measurement and the measured concentration are determined by the equation [4]

$$f_p(\xi_p, C_p) = h_p(\xi_p | C_p) f_p(C_p), \qquad (2)$$

where $h_p(\xi_p|C_p)$ is the conditional probability of the measured concentration ξ_p at a fixed C_p value to be measured.

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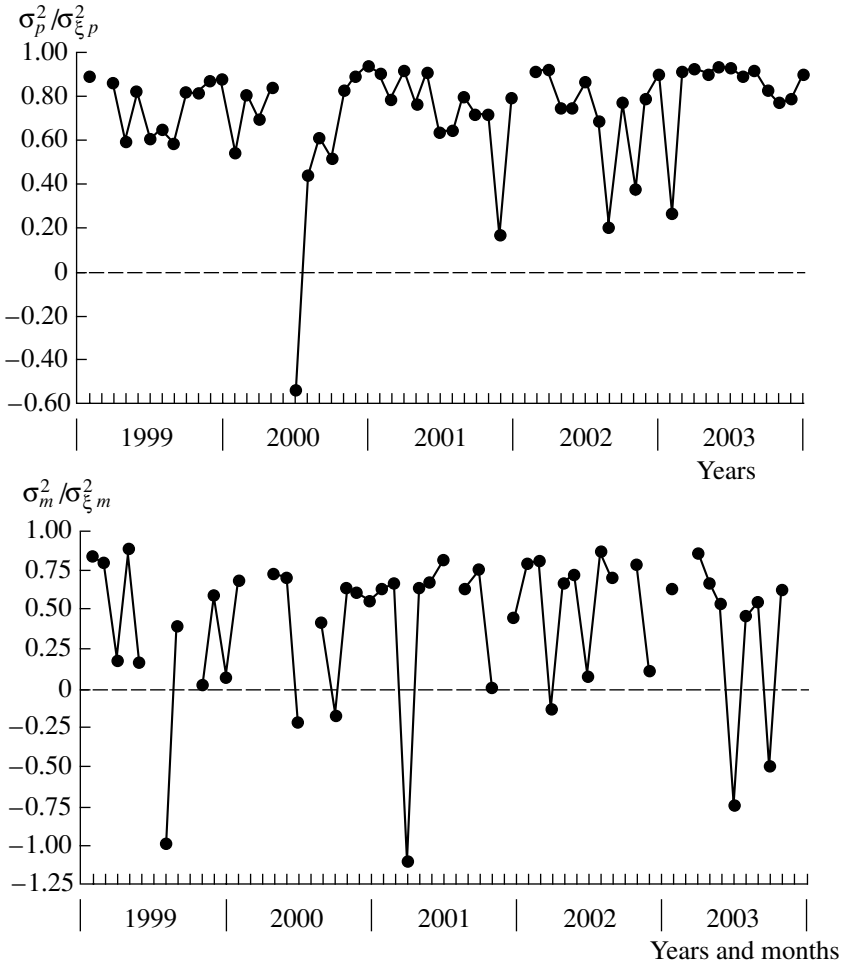

The ratios of the concentration variances corrected for the measurement errors to the measured values as dependent on the month of observation.

Let us assume that the method of measuring the total protein aerosol concentration has no systemic errors and the standard deviation of the measured concentration normalized to the mathematical expectation of the concentration is constant. Then, the conditional mathematical expectation and variance are $\bar{\xi}_{p\,cond} = C_p$; $\sigma^2_{\xi p\,cond} = \alpha_p^2 C_p^2$; $\alpha_p = \text{const}$. The measurement error of the total protein concentration is estimated at 20% [1, 2]; therefore, $\alpha_p \approx 0.2$.

Let us determine the variance of the measured total protein concentrations ($\sigma^2_{\xi p}$). The mathematical expectation of the square of the value measured is

$$\overline{\xi_p^2} = \int_0^\infty \xi_p^2 \int_0^\infty h(\xi_p|C_p) f_p(C_p) dC_p d\xi_p = \int_0^\infty \overline{\xi^2}_{p\,cond} f_p(C_p) dC_p. \quad (3)$$

Therefore, we obtain the following expression for the variance of the measurement result:

$$\sigma^2_{\xi p} = (1 + \alpha_p^2)\sigma_p^2 + \alpha_p^2 (\bar{C}_p)^2. \quad (4)$$

Viable microorganisms. The concentration of viable microorganism has been demonstrated to be distributed according to the Poisson law [3]. The observed concentrations of viable microorganisms are about several thousand per cubic meter; therefore, we may approximate the probability density function with a normal distribution:

$$f_m(C_m) \approx \frac{1}{\sqrt{2\pi \bar{C}_m}} \exp\left[-\frac{(C_m - \bar{C}_m)^2}{2\bar{C}_m}\right], \quad (5)$$

where $\bar{C}_m$ is the mathematical expectation of the number of viable microorganisms per cubic meter of air, which is equal to its variance in the given case.

The concentration of viable microorganisms is determined by averaging over two or three parallel inoculations on four or five types of nutrient media each

[1, 2]. Because of the measurement errors when determining the concentrations of viable microorganism aerosols, a value $\log C_m$ will be obtained instead of the random value $\log\xi_m$. Usually, the error of the estimated concentration of viable microorganisms is presented in the form of the 95% confidence interval within which the common logarithm of the results of measurement varies [5]. In the case considered here, this confidence interval is estimated as a value smaller than half the common logarithm [1, 2]. Let us assume that the method of the measurement of viable microorganism concentration has no systematic errors and the standard deviation of the logarithm of the measured concentration divided by its mathematical expectation is constant. Then, if measurements are performed at a fixed concentration, the conditional mathematical expectation and variance of concentration logarithm will be $\log\ \overline{\log\xi_{m\,cond}} = \log C_m$; $\overline{(\log\xi_m - \overline{\log C_m})^2}_{cond} = \alpha_m^2(\log C_m)^2$; α_m = const. Since the aforementioned 95% confidence interval is about the same order of magnitude as two standard deviations of the logarithm of the viable microorganism concentration, let $\alpha_m \approx 0.1$.

The expression for the variance of the logarithm of the measured viable microorganism concentration ($\sigma^2_{\xi m}$) is

$$\sigma^2_{\xi m} = \alpha_m^2\varphi(\bar{C}_m) + \sigma_m^2;$$
$$\varphi(\bar{C}_m) = \int_0^\infty (\log C_m)^2 f_m(C_m)dC_m, \qquad (6)$$

where σ_m^2 is the variance of the logarithm of the viable microorganism concentration undistorted by measurement errors.

Thus, the existing samples of monthly measurements of the total protein and viable microorganism concentrations can be used to obtain the $\bar{C}_p$, $\sigma^2_{\xi p}$, $\bar{C}_m$, and $\sigma^2_{\xi m}$ and then estimate σ_p^2 and σ_m^2 by Eqs. (5) and (6).

Analysis of experimental data. The figure shows the ratios of the variances of the total protein and viable microorganism concentrations corrected for the errors to the measured values as dependent on the month of observation. It can be seen from the figure that the obtained corrections are significant: they may be as large as 100%. Noteworthy is the series of negative σ_p^2 and σ_m^2 values. This violates the conditions of positive variances: $\sigma^2_{\xi p} \geq \alpha_p^2(\bar{C}_p)^2$ and $\sigma^2_{\xi m} \geq \alpha_m^2\varphi(\bar{C}_m)$ (see Eqs. (5) and (6)). This probably means that the actual errors of the measurement of bioaerosol concentrations are smaller than those indicated above [1, 2].

Since the variance of bioaerosol concentrations is determined by atmosphere turbulence and the characteristics of the sources of admixtures, it is interesting to estimate the consistency between the fluctuations of the total protein and viable microorganism concentrations. The coefficient of correlation between the estimated variances of concentrations is 0.02. This means that the total protein and viable microorganisms detected in the troposphere probably originate from different sources, i.e., they are independent from each other, despite the similar conditions of the spread of these admixtures.

Thus, we have demonstrated that estimating the contributions of measurement errors into the obtained concentrations of tropospheric bioaerosols is a necessary stage of summarizing and analyzing experimental data and that, apparently, the estimates of measurement method errors reported earlier should be corrected towards smaller values.

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