Altitude and seasonal variability of the concentration of biogenic component of tropospheric aerosol in Southwestern Siberia

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The SRC VB "Vector" and Institute of Atmospheric Optics SB RAS have been systematically studying the biogenic component of tropospheric aerosol in Southwestern Siberia. The biogenic component has two most important constituents: total protein and viable microorganisms. Analysis and generalization of experimental data accumulated over the period of observations are considered. Regression relationships between the concentration of total protein and viable microorganisms and the height above the surface and the month of observation have been obtained.

Since December 1998 by now the State Research Center of Virology and Biotechnology "Vector" and the Institute of Atmospheric Optics SB RAS have been systematically studying the biogenic component of tropospheric aerosol in Southwestern Siberia. The biogenic component has two most important constituents: total protein, as a basis of all living substances, and viable microorganisms. Methodical aspects, results, and our attempts to generalize the data obtained are presented in Refs. 1–3. The main features of the concentration fields of the biogenic component of tropospheric aerosol can be briefly summarized as follows:

– data of observations are widely spread;

– the observations show that the concentrations of total protein and viable microorganisms show in their time behavior a pronounced annual cycle;

– there is no pronounced height dependence in the concentration of total protein and viable microorganisms.

The accumulated array of experimental information about the concentration of the biogenic component of tropospheric aerosol in Southwestern Siberia can be used in various practical applications. It may be useful for solution of applied problems in global aerosol climatology, atmospheric optics problems, medical and ecological problems, and others. Such information, especially at the stage of data accumulation and generalization, is of interest for basic sciences. In connection with the above-said, we undertake in this paper an attempt to generalize the experimental data obtained for the whole period of observations. The results are presented as simple regression dependences. Generally, such dependences are understood as a set of equations, which allow one to estimate the normalized concentration of the total protein and viable microorganisms for the given height, for the given month, as well as for the given month and height. The ensemble of the total protein concentrations considered in this paper is represented by 245 experimental values, and the ensemble of concentrations of viable microorganisms by 197 values.

Let us now pass on to the analysis of the height profiles of total protein. The total protein concentration C_p is shown by dots in Fig. 1*a* as a function of the flight altitude h. These values are normalized to the ensemble-mean value C_{ph} at the height h and denoted as $\varphi_p = C_p/C_{ph}$. The vertical bars show the standard deviations of the normalized concentration of protein molecules $\sigma_{\varphi p}$. The straight line in Fig. 1 is drawn by the least-squares method. One can see that the mean total protein concentration found slightly decrease with height. Figure 1*b* generalizes the information about the height dependence of $\sigma_{\varphi p}$. The straight line is a regression of experimental data. In this case, we can see that $\sigma_{\varphi p}$ slightly increases with height.

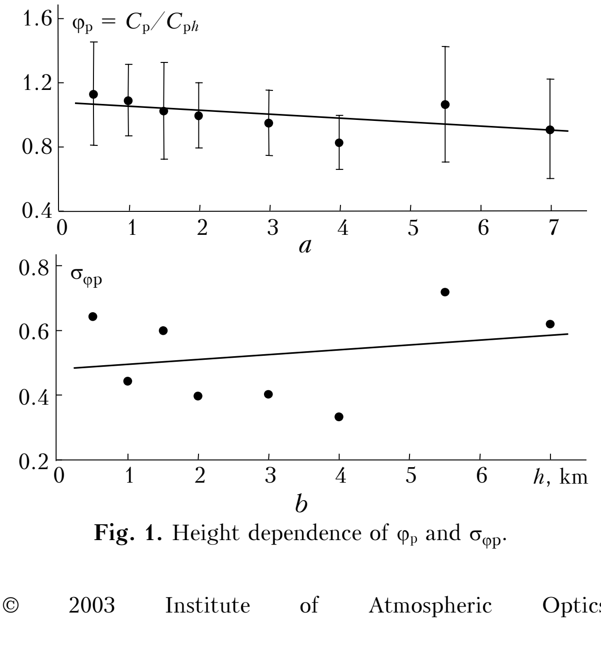

Fig. 1. Height dependence of φ_p and $\sigma_{\varphi p}$.

The observed height behavior of the total protein concentration was analyzed in Refs. 1 and 3, and it was concluded that the concentration profiles are formed due to remote and even far remote sources. Mathematical simulation of the process of diffusion of atmospheric admixtures with the use of actual weather data showed[4,5] that the observed total protein concentrations for the spread time of about one month may be caused with the probability up to tens percent by sources located in Central Asia and Kazakhstan.

An indirect, but heavy confirmation of this fact is the spring increase of the atmospheric concentration of protein molecules and its autumn decrease. According to the experimental data, the concentration of protein molecules in Southwestern Siberia begins to grow in April and to decrease in November. Such a behavior corresponds to the typical "awakening–sleeping" cycle of plants in Central Asia and Kazakhstan and does not correlate with the typical terms of this process in Southwestern Siberia, where plants "awake" in late May–early June and fall asleep in late September. Calculations showed that there exists a confident probability of the effect of northern areas of the American and African continents on the observed concentrations of protein molecules in the troposphere of Southwestern Siberia. The comparative analysis of the data of high-altitude and simultaneous ground-based observations shows that local sources of biogenic aerosol likely do not affect significantly the concentration profiles. Thus, the total protein concentration profiles in the atmosphere of Southwestern Siberia are largely formed by remote sources, and therefore they weakly depend on height.

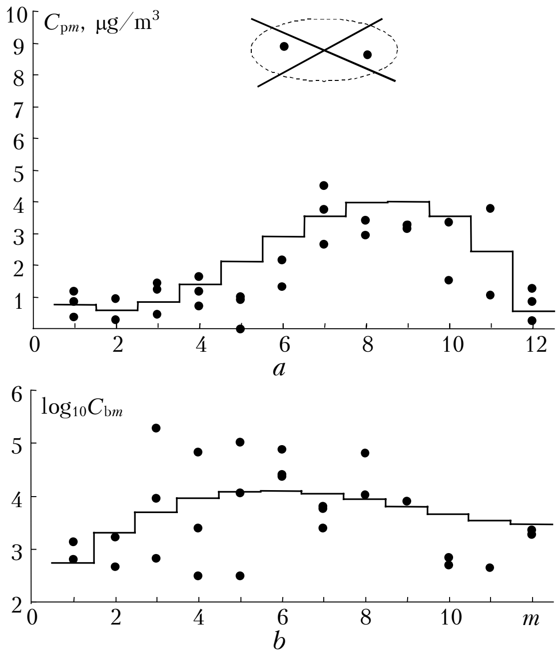

Fig. 2. C_{pm} and $\log_{10}C_{bm}$ as functions of m.

Consider the dependence of the average (for every height) total protein concentration C_{pm} on the month of observation period m. These data are depicted in Fig. 2*a*. Dots show the ensemble of observations. Two dots in the crossed oval Fig. 2 that obviously fall out from the ensemble were rejected. The height of columns in the histogram was determined by the least-squares method. We can see the pronounced annual behavior of the total protein concentration. Indeed, the marked growth of the total protein concentration is observed since April, and the corresponding decrease shows itself since November. The above-said allows us to suggest the regression dependence of the normalized concentration of total protein of the tropospheric aerosol in Southwestern Siberia on m and h, which is presented in Table 1.

Table 1. Regression dependence of the total protein concentration in tropospheric aerosol of Southwestern Siberia on *m* and *h*

Dependence of C_{pm} (μg/m^3) on m: $C_{pm} = 1.49 - 1.07m + 0.35m^2 - 0.02m^3$								
Dependence of φ_p on h (km): $\varphi_p = C_p/C_{ph} = 1.08 - 2.5\cdot10^{-2}\ h$								
Dependence of the standard deviation of φ_p on h (km): $\sigma_{\varphi p} = 0.48 + 1.5\cdot10^{-2}\ h$								
h, km	0.5	1.0	1.5	2.0	3.0	4.0	5.5	7.0
C_{ph}, μg/m^3	1.13	1.10	1.03	1.00	0.95	0.83	1.07	0.91

Also, it should be noted that of the mean annual values calculated reveal the tendency in the total protein concentration to increase in the troposphere. The mean annual concentrations of the total protein were 1.7, 2.1, and 3.1 μg/m^3 in 1999, 2000, and 2001, respectively.

Consider now the tropospheric aerosol component containing viable microorganisms. Dots in Fig. 3*a* show the concentration of viable microorganisms C_b depending on the flight altitude h. These values are normalized to the ensemble-mean concentration of viable organisms C_{bh} at the height h and denoted as $\varphi_b = C_b/C_{bh}$. The vertical bars indicate the standard deviation of the normalized concentration of viable microorganisms $\sigma_{\varphi b}$. The straight line in Fig. 3 is obtained by the least-squares method. We can see that the averaged profile of the concentration of viable microorganisms increases slightly with height. Figure 3*b* generalizes the information about the height dependence of $\sigma_{\varphi b}$. The straight line is a regression of experimental data. We can see a slight growth of $\sigma_{\varphi b}$ with height.

The above reasoning that the height profiles of the atmospheric protein concentration in Southwestern Siberia are formed due to remote sources and thus being almost height-independent applies also to the height profiles of the concentration of viable microorganisms.

Finally, Fig. 2*b* depicts the log month dependence of the concentration of viable microorganisms $\log_{10}C_{bm}$ averaged for every height. The ensemble of observations is shown by dots. The height of histogram columns was determined by the least-squares method.

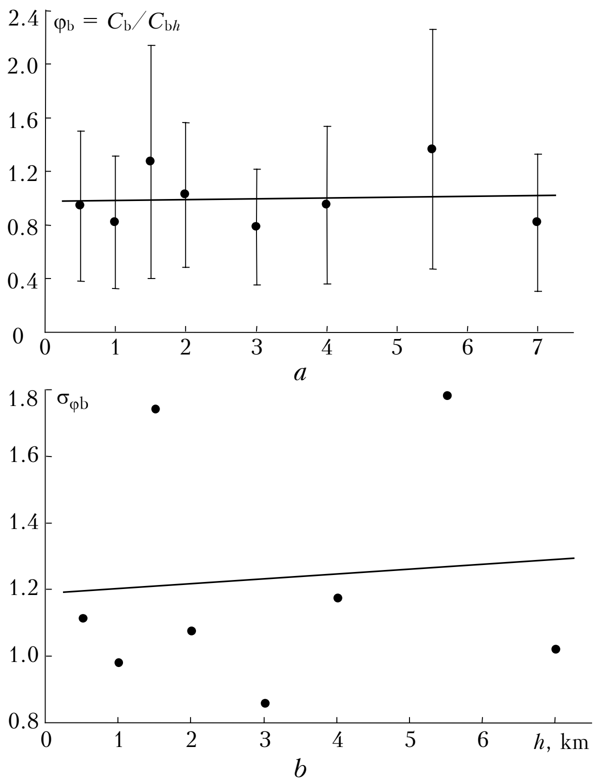

Fig. 3. Height dependence of φ_b and $\sigma_{\varphi b}$.

We can see the characteristic annual variation of the concentration of viable microorganisms. The abovesaid allows us to suggest the regression dependence of the concentration of viable microorganisms in the tropospheric aerosol of Southwestern Siberia on m and h, which is presented in Table 2. For completeness of the data presented, let us list the genera of microorganisms representing this component of tropospheric aerosol in the Southwestern Siberia. They are bacilli, cocci, nonsporiferous bacteria, fungi, actinomycetes, yeast, sarcines, coccobacilli.

Table 2. Regression dependences of the concentration of viable microorganisms in tropospheric aerosol of Southwestern Siberia on *m* and *h*

Dependence on m:
$\log_{10}C_{bm} = 1.984 + 0.868m - 0.110m^2 + 0.004m^3$

Dependence of φ_b on h (km):
$\varphi_b = C_b/C_{bh} = 0.98 + 5.77\cdot10^{-3}h$

Dependence of standard deviation of φ_b on h (km):
$\varphi_b = 1.19 + 1.42\cdot10^{-2}h$

h, km	0.5	1.0	1.5	2.0	3.0	4.0	5.5	7.0
$\log_{10}C_{bh}$	3.48	4.02	3.36	3.56	3.07	4.11	3.72	4.03

Consider now the generalized month and height dependences of the concentration of total protein and viable microorganisms, which were drawn based on the available ensemble of experimental data. The above discussion shows that it is sufficient to describe the concentration fields by polynomials of no higher than third order. The regression dependences of the total protein concentration C_p and the log concentration of viable microorganisms $\log_{10}C_{bm}$ on the month m and the height h are summarized in Table 3.

Table 3. Generalized regression dependence of the concentration of total protein and viable microorganisms in tropospheric aerosol in Southwestern Siberia on *m* and *h*

Dependence of C_p (μg/m^3) on m and h (km):
$C_p = 1.736 - 0.695m - 0.423h + 0.24m^2 + 0.088h^2 + 0.022mh - 0.011mh^2 + 4\cdot10^{-3}m^2h - 0.016m^3 - 3\cdot10^{-3}h^3$

Dependence of $\log_{10}C_b$ on m and h (km):
$\log_{10}C_b = 2.25 + 0.535m - 0.057h - 0.056m^2 - 0.016h^2 + 0.031mh - 10^{-3}mh^2 + 4\cdot10^{-3}m^2h - 10^{-3}m^3 - 2\cdot10^{-4}h^3$

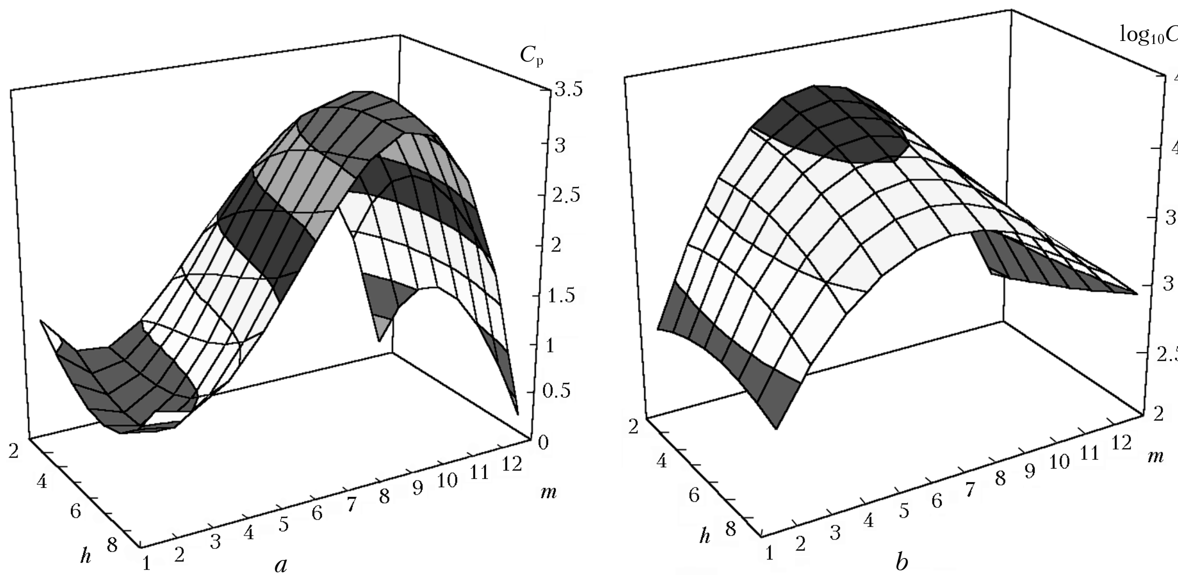

Fig. 4. Dependences of C_p and $\log_{10}C_b$ on m and h.

Table 4. Standard deviations of the total protein concentration and the log concentration of viable microorganisms from the regression dependence given in Table 3

Height h, km							
0.5	1.0	1.5	2.0	3.0	4.0	5.5	7.0
Standard deviation of the total protein concentration, μg/m^3							
0.74 ± 0.2	0.87±0.2	0.90±0.2	0.81±0.3	0.86±0.2	0.89±0.2	1.0±0.4	0.92±0.1
Standard deviation of the log concentration of viable microorganisms							
0.57 ± 0.2	0.64±0.3	0.57±0.1	0.61±0.1	0.48±0.2	0.63±0.2	0.51±0.1	0.59±0.1

Figures 4*a* and *b* present the plots giving an idea about the dependences of C_p and $\log_{10}C_b$ on the month m and height h. Table 4 presents the standard deviations of the concentration of total protein and viable microorganisms from the regression dependence given in Table 3; the deviations are averaged over the whole period of observations. These data demonstrate the domain of variability of the tropospheric biogenic aerosol concentration at a given height.

Thus, based on the experimental data, we have obtained simple regression dependences allowing one to estimate the concentrations of total protein and viable microorganisms depending on the month and height. Our investigations of the biogenic component of tropospheric aerosol are supplemented with ground-based measurements, which were largely conducted in Klyuchi village near Novosibirsk Akademgorodok and on the territory of SRC "Vector." With these data, we can try to estimate the contributions from local and remote sources to the biogenic component of atmospheric aerosol in our region. Such studies are of practical interest, since the concentrations of atmospheric admixtures have a rather complex structure when passing on from the surface atmosphere into the troposphere.[6] Comparison and analysis of ground-based and high-altitude measurements are of practical significance as well.

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