Estimating biogenic pollution of Novosibirsk suburbs by analyzing the snow cover

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The pollutants, coming to the environment of Novosibirsk suburbs from the biogenic component of atmospheric aerosols and accumulated in the snow cover of 1999–2000 have been studied. It has been found that the total protein concentration in snow was up to tens micrograms per square meter of the snow-covered surface. Living microorganisms were also found in the snow samples. A close agreement between the calculated and measured values of the total protein concentration in snow has been obtained. It was noticed that the total protein concentration in snow decreases with the distance from sources of both organic and inorganic aerosols.

Introduction

Snow is a good accumulator of atmospheric pollutants in winter. This fact has been confirmed in earlier studies of the contents of polyaromatic hydrocarbons (PAH), radionuclids, and heavy metals in snow for evaluation of the ecological situation in a region.[1–5] It is also well-known that biological particles and living microorganisms keep well at low temperatures in snow and ice deposits.[6–8]

In this paper, we undertake an attempt to evaluate the possibility of using the snow cover for a more thorough estimation of the biogenic component of atmospheric aerosol within the framework of complex ground-based and high-altitude measurements.[9–11]

Materials and methods

The sampling sites we used in our study are situated both close to and far from powerful anthropogenic sources. A snow sample with the area of 1 dm^2 and the length equal to the whole depth of the snow cover was taken from snow with a specialized sampler. Samples were melted under sterile conditions, and then each sample was divided into several parts for analysis on the presence of protein, living microorganisms, and, whenever necessary, other characteristics (such as the presence of inorganic coarse particles, etc.).

The total protein content in the samples was analyzed by the Bradford method.[12] The sensitivity of the method was 0.1 μg of protein per 1 ml of sample washout from the filter. The measurement error in concentration did not exceed 30%.

Analysis of living microorganisms was restricted to their identification to genus and determination of the concentration of viable bacteria and fungi in the samples by sequential sowing of the ten times diluted samples on the corresponding culture media with the following gram staining of bacteria:

– MPA, RPA, and LB full culture media;
– Chapek medium based on extracts of animal origin;
– mineral culture medium with known composition;
– media with soil extract.

Colonies nascent in the samples were studied visually with a microscope. Some additional tests were also performed.[13,14]

To estimate long-term (month, season, year) pollution from a local source from the observations, we have proposed and tested the following regression dependence[15,16]:

$$p(r, \varphi, \Theta) = \Theta_1 \, g(\varphi + 180°) \, r^{\Theta_2} \exp(-c/r), \quad (1)$$

where p is the specific content of the studied pollutant in snow (soil, air); r and φ are polar coordinates of a computational point with the origin at the place, where the source is situated; $g(\varphi)$ is the climatic occurrence of wind directions for the considered period; c is the parameter depending on the height of a source, temperature and volume of the emitted gas-air mixture, and wind velocity; $\Theta = (\Theta_1, \Theta_2)$ is the vector of unknown parameters.

The component Θ_1 is proportional to the emitted volume; it depends, in a complex way, on the climatic

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characteristics such as wind velocity, turbulent exchange coefficients, source height, and aerosol sedimentation rate, and

$$\Theta_2 = -2 - w/[k_1(n+1)], \qquad (2)$$

where w is the sedimentation rate of aerosol particles; k_1 is the coefficient of vertical turbulent diffusion at the altitude of 1 m; n is the exponent in the approximation of the horizontal component of the wind velocity by a power function.

At $\Theta_2 \to -2$ $w \to 0$ (the case of slowly depositing pollutant). If we have climatic information on the wind velocity and know the geometry and thermodynamic characteristics of the source, we can pre-calculate the parameter c with the allowance for the equation[17]

$$c = 2r_{\max},$$

or determine it from observations of the surface concentration field for a slowly depositing pollutant. In this equation, $r_{\max}$ is the point of maximum surface concentration for a weightless pollutant. Otherwise, the parameter c should be considered as an unknown parameter of the model (1).

Results and discussion

Snow samples were collected in Novosibirsk and its suburbs in February 1999 and February–March 2000. It was found that all samples contain a large total amount of protein, whose concentration achieves tens milligrams per 1 m^2 of snow cover, and living microorganisms.

In snow samples taken in 1999 near a boiler-house of the Novosibirsk Capacitor-Making Plant (NCMP), the correlation was found between the concentrations of microorganisms and the total amount of protein (Table 1).

Since the emissions from the object under study do not contain protein, we likely dealt with the adhesion of fine bioaerosol particles to the surface of emitted particles with their following transportation or washing-out of fine bioaerosol particles by coarse particles emitted from a smoke stack. Since, as was noted above, there were no powerful sources of bioaerosols near the sampling sites, it is natural to believe that the mean values of the concentration of living microorganisms and the protein content of aerosol particles are equal to the "background" values. However, in this case, particles washed out from the atmosphere must produce similarly varying amounts of living microorganisms and the protein content in the samples.

Based on the proposed hypothesis, we undertook an attempt to find the correlation between the amount of living microorganisms and the total protein content in the snow samples. We have calculated the Spearman's rank correlation.[18] The correlation r_S proved to be equal to 0.70. At the 5% significance level, this rejects the "zero" hypothesis by a two-sided criterion and serves a heavy argument in favor of the hypothesis that the biogenic component of atmospheric aerosol may be accumulated in the snow cover.

Table 1. Summary data on the protein content in snow per 1 dm^2 of a surface, the concentration of microorganisms and their species in the order of increasing abundance in the samples

Sample #	Protein content in the sample, mg/dm^2	Microorganism species in the order of increasing abundance	Content of microorganisms, CFU/dm^2***
1	1.8	Bacilli (Gr+)* Bacilli (Gr–)**	14
2	2.5	Bacilli (Gr+) Bacilli (Gr–)	41
3	< 0.4	Bacilli (Gr–) Bacilli (Gr+) Cocci (Gr–)	6
4	0.5	Bacilli (Gr+) Bacilli (Gr–)	4
5	1.8	Bacilli (Gr+) Bacilli (Gr–)	52
6	1.6	Bacilli (Gr+) Bacilli (Gr–)	124
7	2.7	Bacilli (Gr+) Bacilli (Gr–)	63
8	2.6	Bacilli (Gr+) Bacilli (Gr–)	100
9	< 0.4	Bacilli (Gr+) Bacilli (Gr–)	31
10	< 0.4	Bacilli Gr.+ Bacilli Gr.–	7

* Gram-positive microorganisms.
** Gram-negative organisms.
*** Colony-forming units.

In 2000, strip surveys of snow cover were conducted near the Berdsk Chemical Plant (BCP) and the NCMP. The local conditions and the state of the snow cover had allowed us to make the path in the northern direction from the sources of emission, and this provided rather rich information content of the experimental data.[16] Some sampling points (reference points) were used for estimating the regression function (1), and other points were used to check the accuracy of reconstruction. When selecting the reference points, we took into account their optimal arrangement.[19] Protein pollutants are emitted from the BCP at the altitude of about 30 m. In this case, $r_{\max}$ can be estimated roughly as 0.3–0.4 km. For the NCMP boiler-house, $r_{\max}$ equals 0.8 km. This value was estimated from the data on chemical composition of snow samples in 1998–1999 (Ref. 16).

The experimental data are given in Table 2. The obtained data allow their interpretation by means of mathematical simulation based on the above dependence (1).

Figures 1*b* and 2*b* show the results of reconstruction of the specific content of protein in the direction of the selected paths. The comparison of the calculated results with the measurement data at the control points demonstrate a good agreement, which confirms the adequacy of the chosen model to the processes of long-term protein pollution of the

environment. Table 3 gives the estimates of the vector Θ and the total content of protein in the snow cover.

Table 2. Protein pollution of snow near the BCP and NCMP

Distance, km	Concentration, μg/ml
BCP, northern direction	
0.25	7.1
0.3	2.3
0.35	5.1
0.4	2.4
0.45	2.8
0.6	1.2
0.65	1.5
NCMP, northern direction	
0.25	4
0.3	5.1
0.35	3.5
0.4	1.4
0.47	1.3
0.6	1.2

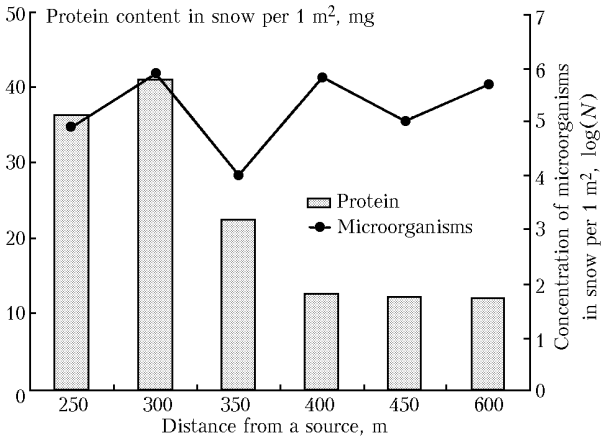

Fig. 1. Concentrations of protein and microorganisms vs. distance from the NCMP stack (*a*) and experimental and calculated content of protein in the snow cover vs. distance from the NCMP stack. Reference points used to estimate the regression function are shown on the calculated curve (*b*).

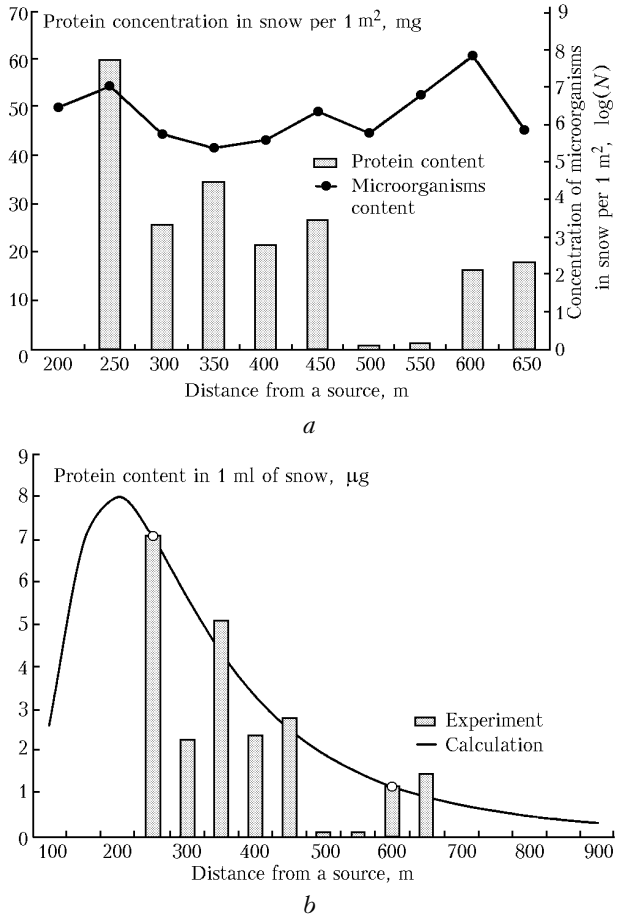

Fig. 2. Concentrations of protein and microorganisms vs. the distance to the BCP smoke stack. The concentration of the total protein at the point separated by 200 m from the source was not determined (*a*). Experimental and calculated content of protein in the snow cover vs. distance to the BCP stack. Reference points used to estimate the regression function are shown on the calculated curve (*b*).

Table 3. Estimated regression parameters and total protein emissions

Source	Estimated parameters		Total emission, kg
	Θ_1	Θ_2	
BCP	1.06	−3.68	24.7
NCMP	0.73	−5.84	15.4

Analysis of Table 3 with the allowance for Eq. (2) shows that the relative sedimentation rate of protein-containing particles for the NCMP is roughly twice as high as that for the BCP. In this case, this difference can be explained by peculiarities in the dust emissions from the NCMP boiler-house. From the results of previous studies of the chemical pollution of snow cover near the boiler house, $\Theta_1 \approx 8.1$ for the coarse (more than 2 μm) fraction of the dust. For the fine aerosol fraction, $\Theta_2 \approx 5.5$. These data, if compared with data from Table 3, show that the atmospheric protein was mostly captured by the fine fraction of dust. The similarity of the curves of distribution of the sediment

density over distance from the NCMP boiler-house for protein and the fine dust allows the practically important conclusion to be drawn that the distribution of protein over distance can be, in principle, reconstructed from the protein content measured at only one point or few points by estimating the parameter Θ_1. The parameter Θ_2 can be estimated from analysis of the fine fraction of dust.

As follows from the data shown in Figs. 1*a* and 2*a*, although the total protein concentration depends on the distance from possible source of pollution, such a dependence for the concentration of living microorganisms was not found. This fact indicates that the sources of living microorganisms and the total protein in our case are likely independent and have different nature.

Thus, we can draw the well-justified conclusion that the above results demonstrate the possibility of using snow samples for analysis of the biogenic component of atmospheric aerosol in our region.

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