Periodic structure of surface concentration fields of aerosols, containing atmospheric protein, in the vicinity of Novosibirsk

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An attempt to apply the wavelet and harmonic analysis to the array of experimental data on the atmospheric aerosol mass concentration and the total protein concentration in surface air in the vicinity of Novosibirsk in 2001–2002 has been undertaken. The wavelet analysis of the data has shown that surface air concentration variations are mainly determined by characteristic synoptic processes with the periods of 4, 7, 10, and 15 days. The results of harmonic analysis have shown that the synoptic variations average from 40 to 70% of the concentration variations and reach 90% in spring.

Introduction

The distribution of the concentration of atmospheric admixtures is regularly considered and discussed in the scientific literature and still remains urgent because of its great fundamental and applied importance. The State Scientific Center of Virology and Biotechnology "Vektor" and some institutes of the Siberian Branch of the Russian Academy of Sciences have performed a systematic investigation of the biogenic component of the atmospheric aerosol in Southwestern Siberia within the framework of the "Siberian Aerosol" Integration Project.[1–4] The total atmospheric protein is the most representative part of the atmospheric aerosol of the biogenic origin.

First results of investigation into variations of the protein component in the tropospheric aerosol above forests of Southwestern Siberia were published in Ref. 1, and a more detailed analysis was carried out in Ref. 4. In parallel with the high-altitude investigations, we also conducted the ground-based studies of the concentration fields of the biogenic component of atmospheric aerosol. In this paper, we analyze the experimental data on the mass concentration of atmospheric aerosols and the total protein concentration in the surface atmospheric layer obtained in the vicinity of Novosibirsk in 2001–2002.

The surface air was sampled in the village Klyuchi located 12 km from Novosibirsk Akademgorodok. The samples have been taken every day onto AFA-KhA analytical filters for four monthly sessions (each of 30 days) in spring, summer, fall, and winter seasons. The diurnal volume of the sampled air was about 300 m^3.

The total protein content in the samples was analyzed under the laboratory conditions by the Bradford method, as well as by the fluorescent method.[4] The sensitivity of the analyses was 0.1 μg/ml for the sample washed out from the filter. The error of the concentration measurements did not exceed 30%. Before and after sampling, the filters were weighted with an analytical balance to determine the mass aerosol concentration.

Thus, the yearly data of the total atmospheric protein concentration and the mass concentration were represented by two arrays of four time series each including 30 readings.

Technique for analysis of time series

We assumed that the variations in the concentration series of the aerosol and its biogenic component could be caused by periodic atmospheric processes. The wavelet analysis permits separation of the periodic components and estimation of their time scales. Wavelet transformation gives a 2D scan of the studied one-dimensional signal, and the scale and the coordinate in this case are considered as independent variables. Thus, it becomes possible to analyze the signal properties simultaneously in the time and frequency spaces.[5] For analysis of the concentration variations, we used the Morlet wavelet.

In the general case, a choice of the analyzing wavelet is ambiguous and depends on the particular problem. The Morlet wavelet was chosen by the following reasons:

– it is well suited for analysis of quasiperiodic processes, because it is well localized in the frequency space;

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– the parent function is a periodic signal modulated by the Gauss function, so we can juxtapose the wavelet spectrum and the spectrum of atmospheric waves, being free oscillations of the atmosphere,[6] which are usually considered as quasiperiodic;

– at a proper choice of the wavelet parameters, we avoid the complicated conversion of the time scale into the period of the process, which allows us to use the time scale as a given parameter in the harmonic analysis.

The module of the wavelet transformation characterizes the time variations of the relative contribution of different-scale components to the studied signal, that is, at every time we can estimate the intensity of variations of all studied time scales a. With this interpretation, it is possible to consider mathematical models of different-scale physical processes affecting the atmospheric parameters.[6]

In Refs. 7 and 8, the wavelet analysis of the long measurement series of aerosol and chemical admixtures by the data of atmospheric monitoring stations has shown its high potentiality in studying the time variations of atmospheric admixtures. The wavelet analysis allows estimating the changes in the mode structure of variations in the time series under study.

We also applied the harmonic analysis of the time series to assessment of the amplitudes and phases of their periodic components. In this case, the time series was approximated by a sum of harmonics with pre-known periods P_i

$$S(t) = A_0 + \sum_i A_i \cos\left[(t - T_i)\, 2\pi / P_i\right],$$

where A_0 is the constant component of the signal; A_i and T_i are the amplitudes and phases of harmonics, which can be found using the least-squares method. Usually, the periods are specified based on some chosen model of atmospheric physics or determined by other methods. In the general case, we can perform the wavelet analysis of a time series, determine, in this way, the existence of stable oscillations and their time scales P_i, and then find the amplitudes and phases of periodic variations using the harmonic analysis. The method of harmonic analysis was successfully used in Ref. 9 to find the parameters of tidal processes and seasonal variations of the wind field in the lower troposphere.

Results and discussion

In the wavelet analysis, the seasonal data were combined in an array of 635 days long. The gaps between the experimental sessions were filled with values obtained through the linear interpolation of the series-averaged values. This procedure is needed to exclude the false results caused by the edge effects (finiteness of the series). As a result, the determined wavelet spectra are purely qualitative and allow us to evaluate only the presence or absence of quasiperiodic processes of some or other scale. Figure 1 depicts the obtained wavelet spectra of the mass protein and aerosol concentration.

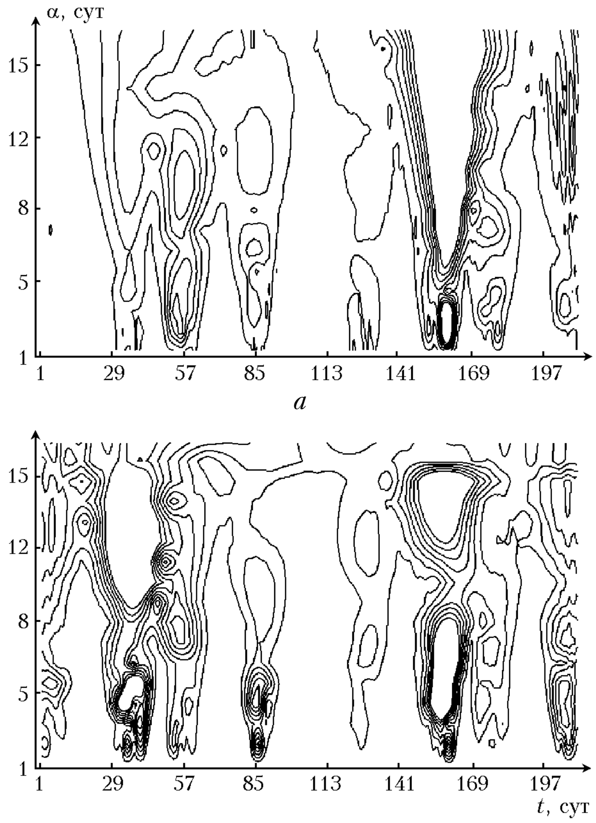

Fig. 1. Isolines of wavelet spectra of the series of atmospheric protein concentration (with the step of 0.01) (a) and the mass concentration (with the step of 1.0) (b).

It can be seen from Fig. 1 that, in spite of the seasonal concentration variations, there are also variations of characteristic synoptic scales: 4, 7, 10, and 15 days. To be noticed is the approximate similarity of the obtained wavelet spectra of the mass protein and aerosol concentrations. This allows us to suppose that the variations of the mass aerosol concentration and the protein concentration are largely determined by the dynamic processes in the atmosphere: advective transport and turbulent diffusion. At the same time, incomplete similarity of the wavelet spectra likely indicates a different nature of the sources and sinks both of the atmospheric aerosol in general and its protein component.

For estimation of the contribution of the concentration variation amplitudes, we have performed the harmonic analysis of the time series. Every series was approximated by a sum of harmonics with the synoptic periods of 30, 15, 10, 7, and 4 days. The period of 30 days should be considered as the main period of the series coinciding with its length. Besides, this period is close to the well-known solar activity cycle of 27 days. Figure 2 exemplifies the approximation of the experimental time series for the summer session of 2001. The initial data are shown by dots, and the results of fitting by the sum of harmonics are shown by lines.

The Table presents the amplitudes A_i ($\mu g/m^3$) and the maximum times T_i (days) obtained for the *a*

b

Fig. 2. Results of harmonic analysis of the data of the summer session of 2001.

sessions of 2001 and 2002. The columns corresponding to the mass concentration of the atmospheric aerosol and the atmospheric protein concentration are marked by C_m and C_p. The concentration is given in μg/m^3. The constant component is presented in the top part of the A_0 row. The rows marked by A_i ($i = \overline{1,\ 5}$) correspond to the amplitudes of the harmonics with the periods of 30, 15, 10, 7, and 4 days. The rows marked by T_i give the times of the maxima for these harmonics. Every value in the table cells is given along with its 90% confidence interval presented below in the same cell. Thus, for example, if for the mass protein concentration in winter of 2001 the time of the maximum T_4 is 3.1 days, then this value is significant, because its 90% confidence interval is $5 \cdot 10^{-5}$. The data evidence that the harmonic with the period of 7 days reaches its maximum in 3.1 days after the beginning of the time series. Then this maximum repeats every 7 days, namely, 10.1, 17.1, and 24.1 days after the beginning of the time series. The last row presents the fraction of the synoptic variations γ in the total variance of the process. The results obtained confirm that the synoptic variations amount to, on the average, 40–70% of the total variance of the concentration variations and achieve 90% in spring. The observed similarity of the curves approximating the time series for the mass aerosol concentration and the protein concentration supports the above assumption that the concentration variations are mostly determined by the dynamic processes in the atmosphere. In case that the similarity is absent, the effect of the possible aerosol sources and sinks should be included in the analysis. Unfortunately, the available data are still insufficient for analysis of these mechanisms.

Summary results of harmonic analysis of time series

Parameter	2001								2002							
	Winter		Spring		Summer		Fall		Winter		Spring		Summer		Fall	
	C_m	C_p	C_m	C_p	C_m	C_p	C_m	C_p	C_m	C_p	C_m	C_p	C_m	C_p	C_m	C_p
A_0	26.97	$7\cdot10^{-3}$	61.91	0.10	33.63	0.24	31.00	0.09	21.79	0.08	52.10	0.55	26.05	0.31	37.37	0.28
	0.28	10^{-4}	1.34	10^{-3}	0.35	$4\cdot10^{-3}$	0.31	$2\cdot10^{-3}$	0.23	$9\cdot10^{-4}$	0.89	$5\cdot10^{-3}$	0.49	$3\cdot10^{-3}$	0.67	$4\cdot10^{-3}$
A_1	2.59	$3\cdot10^{-3}$	33.25	0.09	6.37	0.03	16.25	0.08	0.57	0.02	35.36	0.63	4.28	0.02	9.90	0.15
	0.55	10^{-4}	1.22	10^{-3}	0.50	$2\cdot10^{-3}$	0.26	$9\cdot10^{-4}$	0.88	10^{-3}	1.06	$4\cdot10^{-3}$	0.38	10^{-3}	0.72	$2\cdot10^{-3}$
T_1	14.29	26.98	18.19	15.60	10.59	1.34	9.15	6.39	11.93	3.49	19.60	21.24	2.42	3.94	8.81	6.02
	0.39	$6\cdot10^{-4}$	4.02	$4\cdot10^{-3}$	0.83	$4\cdot10^{-4}$	0.66	$2\cdot10^{-3}$	0.75	$6\cdot10^{-4}$	3.80	0.03	0.14	$2\cdot10^{-3}$	1.46	$6\cdot10^{-3}$
A_2	9.03	10^{-3}	23.22	0.07	4.71	0.05	3.35	0.05	3.06	0.03	17.75	0.39	5.85	0.05	13.57	0.08
	0.15	$3\cdot10^{-4}$	2.31	$2\cdot10^{-3}$	0.35	$3\cdot10^{-3}$	0.58	10^{-3}	0.18	10^{-3}	0.49	$8\cdot10^{-3}$	0.93	$5\cdot10^{-3}$	0.81	$3\cdot10^{-3}$
T_2	3.64	5.07	14.74	1.25	1.55	3.49	6.95	3.99	12.91	8.95	3.49	6.47	4.99	7.67	1.00	3.79
	0.23	10^{-4}	4.87	$4\cdot10^{-4}$	0.10	$3\cdot10^{-3}$	0.31	$2\cdot10^{-3}$	0.57	$2\cdot10^{-3}$	0.73	$5\cdot10^{-3}$	0.76	$2\cdot10^{-3}$	0.10	$4\cdot10^{-3}$
A_3	6.45	$9\cdot10^{-4}$	21.91	0.07	9.42	0.09	4.49	0.02	2.36	0.02	6.26	0.19	4.34	0.01	6.37	$7\cdot10^{-3}$
	0.47	$8\cdot10^{-5}$	1.22	$2\cdot10^{-3}$	0.60	$6\cdot10^{-3}$	0.54	10^{-3}	0.49	$2\cdot10^{-3}$	1.40	$4\cdot10^{-3}$	0.63	$9\cdot10^{-3}$	1.39	0.01
T_3	6.05	0.06	6.05	5.97	5.22	6.61	6.04	7.73	4.91	5.84	7.18	2.20	2.53	5.43	3.62	8.76
	0.38	$6\cdot10^{-7}$	1.17	$2\cdot10^{-3}$	0.26	$7\cdot10^{-3}$	0.43	$3\cdot10^{-3}$	0.20	10^{-3}	1.74	$3\cdot10^{-3}$	0.32	$4\cdot10^{-3}$	0.73	$9\cdot10^{-3}$
A_4	0.79	10^{-3}	10.71	0.04	10.07	0.08	3.12	0.03	3.14	$9\cdot10^{-3}$	13.28	0.15	5.41	0.07	8.32	0.02
	0.75	$9\cdot10^{-5}$	0.70	10^{-3}	0.51	$5\cdot10^{-3}$	0.35	$3\cdot10^{-3}$	0.32	10^{-3}	0.97	$8\cdot10^{-3}$	0.86	$4\cdot10^{-3}$	1.07	$7\cdot10^{-3}$
T_4	5.15	3.10	2.61	1.73	0.39	2.35	2.98	4.16	4.97	3.45	2.10	1.24	0.56	5.39	0.81	1.10
	0.61	$5\cdot10^{-5}$	0.29	$4\cdot10^{-4}$	0.03	$2\cdot10^{-3}$	0.17	$2\cdot10^{-3}$	0.25	$5\cdot10^{-4}$	0.32	$2\cdot10^{-3}$	0.05	$4\cdot10^{-3}$	0.14	10^{-3}
A_5	1.87	$2\cdot10^{-3}$	7.94	0.02	1.30	0.06	5.07	0.02	0.71	$9\cdot10^{-3}$	15.06	0.02	3.50	0.03	4.14	0.02
	0.65	$2\cdot10^{-4}$	1.12	10^{-3}	0.58	$8\cdot10^{-3}$	0.55	$3\cdot10^{-3}$	0.75	$2\cdot10^{-3}$	1.21	$4\cdot10^{-3}$	0.69	$4\cdot10^{-3}$	0.48	0.01
T_5	3.78	1.62	3.50	3.62	1.42	3.52	3.98	0.83	1.00	3.65	1.68	1.56	1.53	1.07	1.69	0.77
	0.23	$5\cdot10^{-5}$	0.94	$7\cdot10^{-4}$	0.16	$4\cdot10^{-3}$	0.17	$4\cdot10^{-4}$	0.12	$8\cdot10^{-4}$	0.30	$2\cdot10^{-3}$	0.18	10^{-3}	0.19	10^{-3}
γ	58.85	36.29	68.44	92.40	66.00	47.00	62.91	69.14	41.79	55.94	64.90	86.70	49.21	52.80	43.15	65.50

Conclusions

The wavelet and harmonic analysis of the time series of the mass concentration of atmospheric aerosols and their protein component has shown at the qualitative level that variations of the mass concentration in the surface atmospheric layer are mostly determined by the characteristic synoptic processes. This inference corresponds to the earlier assumption that the biogenic component of the atmospheric aerosol in Southwestern Siberia is largely formed by independent and far remote sources.[1,4] At the same time, the contribution of the local sources is, likely, most significant in the spring period, corresponding to awakening of the plant community in this region. In the future, it is worth continuing the studies in this field in order to obtain the reliable quantitative characteristics and refine contributions of the local and remote aerosol sources and sinks to the concentration variations.

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