Periodic structure of bioaerosol concentration fields in troposphere of the south of Western Siberia

A.I. Borodulin, A.S. Safatov, A.A. Yarygin, O.G. Khutorova, B.D. Belan, and M.V. Panchenko

State Scientific Center of Virology and Biotechnology "Vector," Koltsovo, Novosibirsk Region
Institute of Atmospheric Optics,
Siberian Branch of the Russian Academy of Sciences, Tomsk

Received November 30, 2004

The work presents the results of wavelet and harmonic analyses of an array of experimental data on aerosol concentrations of total protein and viable microorganism in troposphere of the south of Western Siberia obtained in 1999–2003. The applied wavelet analysis has shown that typical seasonal processes with the periods of 12, 6, 4, and 8–9 months mainly determine variations in bioaerosol concentration in the troposphere. Seasonal variations determine about 80% of the total dispersion of variations in total protein concentration, and the amplitudes of variations in viable microorganism concentration are too small as compared with the constant component for any altitude of observations.

State Scientific Center "Vector" together with several institutes of Siberian Branch of the Russian Academy of Sciences carry out systematic investigation of biogenic component (total protein and viable microorganisms) of atmospheric aerosol on the south of Western Siberia.[1–5] Generalization and analysis of the obtaining data have shown that the concentration of biogenic component in atmospheric aerosol in this region, apart from seasonal behavior, significantly varies, and its concentration fields are mainly determined by the presence of remote sources of atmospheric admixtures.[4] Oscillation processes occurring in atmosphere can also affect the properties of the bioaerosol concentration fields. Wavelet analysis of data on the near-ground aerosol concentration observed in the vicinity of Novosibirsk[5] allowed us to reveal some correlation between variations of the aerosol mass concentration and the total protein concentration in the atmospheric near-ground layer with its characteristic periodic synoptic processes.

In this paper, we present the results of wavelet and harmonic analyses of the array of experimental data on the aerosol concentration of the total protein and viable microorganisms in the troposphere of the south of Western Siberia obtained during 5-year observational period from 1999 to 2003.

The sampling has been conducted in the last decade of each month from the aircraft–laboratory at eight heights: 0.5, 1, 1.5, 2, 3, 4, 5.5, 7 km. Flights were carried out over Karakan forest situated at the right bank of the Ob' River (54°30′N, 82°20′E). The techniques of sampling and analysis are described in Ref. 4. The 2×8 temporal series of the concentration represented by 60 readings were considered.

Based on the aforementioned facts, we assume that variations in the tropospheric bioaerosol concentrations can be also caused by periodic atmospheric processes. The wavelet analysis makes it possible to select the periodic components and to estimate their temporal scales. Wavelet transformation provides for two-dimensional scanning of the one-dimensional signal under study, the scale and the coordinate in this case are treated as independent variables. This makes possible to analyze the signal properties simultaneously in temporal and frequency spaces.[6] We used the Morlet wavelet in the analysis. In general case, the choice of wavelet is ambiguous and depends on the specific problem. We chose the Morlet wavelet on the following counts:

• it is well adapted to analysis of quasi-periodic processes, because it has a good localization in the frequency space;

• its mother function is a periodic signal modulated by the Gauss function, so we can compare the wavelet spectrum and the atmospheric wave spectrum, which are the characteristic oscillations of the atmosphere commonly considered[7] as quasi-periodic ones;

• at a proper choice of its parameters we avoid complicated recalculations of the temporal scale during the process, that allows us to use the temporal scale as a preset value when carrying out the harmonic analysis;

• a presence of the complex component allows us to analyze not only the amplitude, but also the phase of the selected harmonics;

• and, finally, it was already successfully used in the analysis of the near-ground fields of the atmospheric aerosol concentration.[5]

The wavelet transformation module characterizes temporal change of the relative contribution of components of different scales into the signal under study, i.e., at each moment we can estimate the intensity of variations of all temporal scales under study. At such interpretation, it is possible to consider mathematical models of physical processes of different scales affecting atmospheric parameters.[8]

We also carried out harmonic analysis of temporal series in order to estimate the amplitudes and phases of their periodic components. In this case, the temporal

0235-6880/05/05–06 450-04 $02.00

series was approximated by a sum of harmonics with *a priori* known periods. Usually, at such analysis, the periods are set based on assumptions in the framework of the selected model of the atmospheric physics or are determined by other methods. In general case, we can carry out the wavelet analysis of the temporal series, to determine by this method the existence of stable oscillations and their temporal scales, and then to determine the amplitudes and phases of periodic variations by means of the harmonic analysis. The method of harmonic analysis was, for example, successfully used for determining parameters of flood processes and seasonal variations of the wind velocity field in the lower thermosphere.[9]

An example of the obtained wavelet spectra of concentrations of the total protein and viable microorganisms in 1999–2003 at a height of 7 km is shown in Fig. 1.

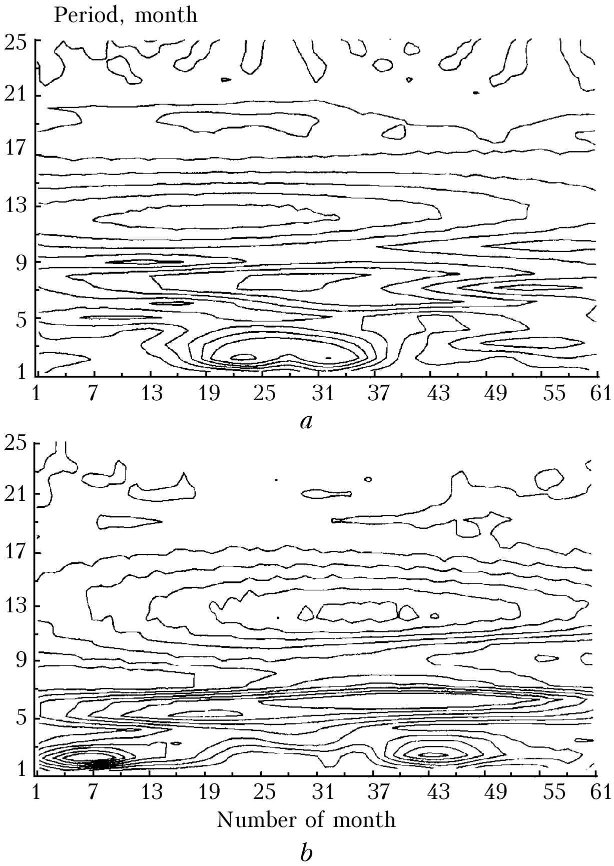

Fig. 1. Wavelet spectra of concentrations of the total protein (*a*) and viable microorganisms (*b*).

The wavelet spectrum for a series of the total protein concentration was constructed for the variability range 0.1–1.1 at a step of 0.15; for viable microorganisms – 0.05–0.35 at a step of 0.05.

Analysis of the obtained data shows that regular periodic processes of 12, 8–9, 6, and 4 months can be revealed for each time series by means of the wavelet analysis. The amplitude of these variations is not constant in time, but always is significant with a probability of more than 80%. In addition to regular oscillations, the processes with a period of about 24 months (inter-annual oscillations) are sometimes observed.

Approximate similarity of the obtained concentration wavelet spectra for the total protein and viable microorganisms attracts our attention. It allows us to assume that variations in the bioaerosol mass concentration are mainly determined by dynamical processes in troposphere, in particular, by its seasonal variations. In addition, the partial similarity of the wavelet spectra, probably, indicates different natures of sources and sinks of tropospheric bioaerosols.

When carrying out the harmonic analysis of the concentration series, the experimental data were approximated by the sum of seasonal harmonics with periods of 12, 8–9, 6, and 4 months, i.e., only those harmonics were taken, which were significant in the wavelet spectra of all time series.

An example of such approximation of time series of the total protein and viable microorganism concentrations by the sum of harmonics is shown in Fig. 2 for 2000 year at the height of 0.5 km. Gaps in curves mean the absence of data.

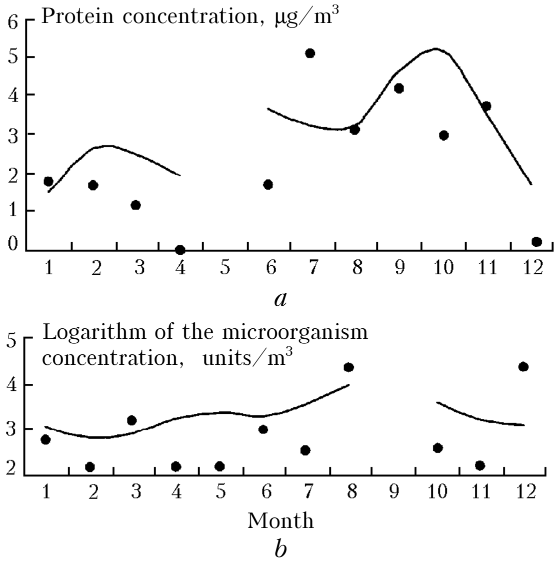

Fig. 2. Approximation of experimental series of the total protein (*a*) and viable microorganism (*b*) concentrations by a sum of harmonics with found seasonal periods.

Summary results of harmonic analysis are shown in Tables 1 and 2, where the following parameters are presented: A_0 is the constant component and the confidence interval; A_i and T_i are the amplitudes and times of the maximum and confidence intervals for the periods of 12, 8.5, 6, and 4 months, respectively (see upper and lower rows in Tables 1 and 2); the residual portion of the total variance, %, is presented without taking into account seasonal variations and the constant component. Analysis of the data has shown that seasonal variations determine about 80% of the total variance of the protein concentration. Amplitudes of variations of the microorganism concentrations are small in comparison with the constant component at all heights.

Table 1. Summary of harmonic analysis of the series of the total protein concentration

Parameter	Height, km							
	0.5	1	1.5	2	3	4	5.5	7
A_0	2.83	2.5	2.13	2.09	1.92	1.79	2.07	1.85
	$6.97\cdot10^{-10}$	$1.43\cdot10^{-10}$	$3.90\cdot10^{-10}$	$6.47\cdot10^{-10}$	$5.55\cdot10^{-10}$	$5.39\cdot10^{-10}$	$4.55\cdot10^{-10}$	$4.93\cdot10^{-10}$
A_1	1.43	1.47	1.14	1.27	1.53	1.3	1.28	0.93
	$1.58\cdot10^{-9}$	$1.20\cdot10^{-9}$	$8.52\cdot10^{-10}$	$5.63\cdot10^{-10}$	$7.60\cdot10^{-10}$	$1.24\cdot10^{-10}$	$6.30\cdot10^{-10}$	$3.18\cdot10^{-10}$
T_1	240.79	228.01	244.21	266.37	265.03	264.8	241.43	261.56
	$6.57\cdot10^{-8}$	$4.33\cdot10^{-8}$	$3.77\cdot10^{-8}$	$3.41\cdot10^{-8}$	$5.41\cdot10^{-8}$	$8.57\cdot10^{-9}$	$2.80\cdot10^{-8}$	$1.98\cdot10^{-8}$
A_2	0.57	0.57	0.36	0.73	0.79	0.67	0.9	0.52
	$8.46\cdot10^{-10}$	$4.06\cdot10^{-10}$	$1.22\cdot10^{-10}$	$7.36\cdot10^{-10}$	$8.73\cdot10^{-10}$	$6.30\cdot10^{-10}$	$7.59\cdot10^{-10}$	$3.96\cdot10^{-10}$
T_2	176.31	161.28	194.42	175.61	195.95	201.8	170.74	171.42
	$3.23\cdot10^{-8}$	$1.04\cdot10^{-8}$	$1.84\cdot10^{-8}$	$2.29\cdot10^{-8}$	$9.48\cdot10^{-8}$	$7.88\cdot10^{-8}$	$1.65\cdot10^{-8}$	$1.30\cdot10^{-8}$
A_3	0.39	0.26	0.37	0.43	0.42	0.42	0.47	0.31
	$9.26\cdot10^{-10}$	$9.63\cdot10^{-10}$	$8.16\cdot10^{-10}$	$7.83\cdot10^{-10}$	$6.77\cdot10^{-10}$	$6.18\cdot10^{-10}$	$8.07\cdot10^{-10}$	$5.49\cdot10^{-10}$
T_3	118.58	160.31	110.4	87.72	102.32	117.82	28.61	36.58
	$1.93\cdot10^{-8}$	$2.43\cdot10^{-8}$	$1.36\cdot10^{-8}$	$5.65\cdot10^{-9}$	$1.26\cdot10^{-8}$	$1.12\cdot10^{-8}$	$3.60\cdot10^{-9}$	$3.71\cdot10^{-9}$
A_4	0.81	0.72	0.61	0.62	0.46	0.36	0.16	0.3
	$3.84\cdot10^{-10}$	$9.45\cdot10^{-10}$	$3.23\cdot10^{-10}$	$7.54\cdot10^{-10}$	$5.36\cdot10^{-10}$	$2.47\cdot10^{-10}$	$4.16\cdot10^{-10}$	$5.58\cdot10^{-10}$
T_4	64.34	74.03	57.26	68.88	68.27	55.12	116.23	84.23
	$7.00\cdot10^{-9}$	$1.07\cdot10^{-9}$	$6.00\cdot10^{-9}$	$7.08\cdot10^{-9}$	$6.69\cdot10^{-9}$	$5.07\cdot10^{-9}$	$4.34\cdot10^{-9}$	$9.21\cdot10^{-9}$
Residual variance, %	15.86	21.81	17.6	23.35	34.64	28.16	15.56	18.48

Table 2. Summary of harmonic analysis of the series of the viable microorganism concentration

Parameter	Height, km							
	0.5	1	1.5	2	3	4	5.5	7
A_0	3.3	3.36	3.19	3.18	3.17	3.21	3.36	3.21
	$4.79\cdot10^{-10}$	$4.36\cdot10^{-10}$	$4.31\cdot10^{-10}$	$4.91\cdot10^{-10}$	$4.70\cdot10^{-10}$	$4.65\cdot10^{-10}$	$4.39\cdot10^{-10}$	$4.35\cdot10^{-10}$
A_1	0.4	0.4	0.32	0.48	0.28	0.11	0.52	0.45
	$3.88\cdot10^{-10}$	$3.60\cdot10^{-10}$	$3.76\cdot10^{-10}$	$4.11\cdot10^{-10}$	$1.4\cdot10^{-10}$	$3.28\cdot10^{-10}$	$4.06\cdot10^{-10}$	$2.89\cdot10^{-10}$
T_1	234.7	218.82	197.37	231.73	267.28	358.05	227.36	233.02
	$1.53\cdot10^{-8}$	$1.06\cdot10^{-8}$	$7.46\cdot10^{-8}$	$1.61\cdot10^{-8}$	$1.55\cdot10^{-8}$	$1.30\cdot10^{-8}$	$1.45\cdot10^{-8}$	$1.18\cdot10^{-8}$
A_2	0.18	0.15	0.24	$9.69\cdot10^{-3}$	0.2	0.18	0.14	0.23
	$3.60\cdot10^{-10}$	$5.45\cdot10^{-10}$	$3.70\cdot10^{-10}$	$3.90\cdot10^{-10}$	$4.57\cdot10^{-10}$	$4.61\cdot10^{-10}$	$3.67\cdot10^{-10}$	$2.57\cdot10^{-10}$
T_2	126.1	32.5	131.23	142.28	167.41	113.67	225.88	136.35
	$3.78\cdot10^{-9}$	$2.82\cdot10^{-9}$	$6.97\cdot10^{-9}$	$8.94\cdot10^{-9}$	$1.22\cdot10^{-8}$	$7.80\cdot10^{-9}$	$1.32\cdot10^{-8}$	$4.98\cdot10^{-9}$
A_3	0.12	0.16	0.08	0.17	0.16	0.11	0.05	0.5
	$3.00\cdot10^{-10}$	$2.76\cdot10^{-10}$	$1.14\cdot10^{-10}$	$2.35\cdot10^{-10}$	$2.95\cdot10^{-10}$	$1.17\cdot10^{-10}$	$2.53\cdot10^{-10}$	$3.79\cdot10^{-10}$
T_3	123.03	121.23	175.1	9.23	121.39	121.42	156.82	86.6
	$7.43\cdot10^{-9}$	$6.31\cdot10^{-9}$	$5.63\cdot10^{-9}$	$3.97\cdot10^{-9}$	$5.71\cdot10^{-9}$	$3.20\cdot10^{-9}$	$6.35\cdot10^{-9}$	$4.41\cdot10^{-9}$
A_4	0.17	0.11	0.04	0.08	0.16	0.03	0.25	0.15
	$4.43\cdot10^{-10}$	$2.49\cdot10^{-10}$	$3.34\cdot10^{-10}$	$2.45\cdot10^{-10}$	$1.47\cdot10^{-10}$	$3.01\cdot10^{-10}$	$2.62\cdot10^{-10}$	$3.22\cdot10^{-10}$
T_4	16.8	89.52	41.74	117.9	34.67	115.07	108.94	112.56
	$1.19\cdot10^{-9}$	$2.31\cdot10^{-9}$	$2.47\cdot10^{-9}$	$2.00\cdot10^{-9}$	$1.27\cdot10^{-9}$	$6.16\cdot10^{-9}$	$4.17\cdot10^{-9}$	$6.32\cdot10^{-9}$
Residual variance, %	17.19	9.05	12.59	14.76	11.43	4.08	17.7	29.12

Wavelet analysis shows that not all amplitudes of seasonal variations are constant during the period of observations. It means that the results of harmonic analysis give time-mean values of the amplitudes. Estimates of the phases of variations show that all harmonics excepting four-month ones are related to special heights, i.e., variations at the indicated heights are in phase. It was revealed that the four-month periodicity is inner and caused by the descending wave propagation with the vertical speed of the order of 4 km per month.

Thus, wavelet and harmonic analyses of the five-year temporal series of the tropospheric bioaerosol concentrations, as in Ref. 5, have shown that variations in concentration of the total protein and viable microorganisms on the south of Western Siberia are mainly determined by the revealed periodic processes related with seasonal variations of the atmosphere.

References

1. I.S. Andreeva, B.D. Belan, A.I. Borodulin, G.A. Buryak, Yu.V. Marchenko, S.E. Ol'kin, M.V. Panchenko, V.A. Petrishchenko, O.V. P'yankov, I.K. Reznikova, A.S. Safatov, A.N. Sergeev, and E.V. Stepanova, Atmos. Oceanic Opt. **13**, Nos. 6–7, 592–596 (2000).

2. A.N. Ankilov, A.M. Baklanov, B.D. Belan, A.I. Borodulin, G.A. Buryak, A.L. Vlasenko, Yu.V. Marchenko, S.E. Ol'kin, M.V. Panchenko, V.V. Penenko, O.V. P'yankov, I.K. Reznikova, A.S. Safatov, A.N. Sergeev, and

E.A. Tsvetova, Atmos. Oceanic Opt. **14**, Nos. 6–7, 473–477 (2001).
3. I.S. Andreeva, A.I. Borodulin, G.A. Buryak, S.E. Ol'kin, V.A. Petrishchenko, V.F. Raputa, I.K. Reznikova, and A.S. Safatov, Atmos. Oceanic Opt. **15**, Nos. 5–6, 425–428 (2002).
4. I.S. Andreeva, A.I. Borodulin, G.A. Buryak, V.A. Zhukov, S.V. Zykov, Yu.V. Marchenko, S.E. Ol'kin, V.A. Petrishchenko, O.V. P'yankov, I.K. Reznikova, V.E. Repin, A.S. Safatov, A.N. Sergeev, V.F. Raputa, V.V. Penenko, E.A. Tsvetova, M.Yu. Arshinov, B.D. Belan, M.V. Panchenko, A.N. Ankilov, A.M. Baklanov, A.L. Vlasenko, K.P. Koutsenogii, V.I. Makarov, and T.V. Churkina, Khimiya v Interesakh Ustoichivogo Razvitiya **10**, No. 5, 547–561 (2002).
5. A.I. Borodulin, A.S. Safatov, O.G. Khutorova, K.P. Kutsenogii, and V.I. Makarov, Dokl. Ros. Akad. Nauk **392**, No. 2, 280–282 (2003).
6. G. Torrence and G.P. Compo, Bull. Amer. Meteorol. Soc. **79**, No. 1, 61–78 (1998).
7. A.S. Monin, *Weather Forecast as a Physical Problem* (Nauka, Moscow, 1969), 184 pp.
8. O.G. Khutorova and G.M. Teptin, Izv. Ros. Akad. Nauk, Fiz. Atmos. Okeana **37**, No. 6, 853–856 (2001).
9. O.G. Khutorova and G.E. Karachaganak, Atmos. Oceanic Opt. **14**, Nos. 6–7, 577–579 (2001).