Seasonal changes in the spectrum of variation of the near-ground aerosol concentration

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Seasonal changes in the spectra of mesoscale and synoptic variations of the near-ground aerosol are studied by wavelet analysis. Three-year series of measurements by the network of automated stations of atmospheric monitoring was used. It was shown, that the intensity of synoptic variations for aerosol concentration is modulated by seasonal harmonics. The intensity of mesoscale variations is modulated by both synoptic and seasonal processes.

The urgency of the problem on selecting the characteristic scales of spatial and temporal variations of the atmospheric components and comparing them with variation of meteorological parameters is undoubted. Atmospheric processes of different scales interacting with each other affect the formation of the spatiotemporal characteristics of the fields of atmospheric admixtures. According to the classification,[1] one can divide them into the following temporal ranges:

- Micrometeorological range corresponds to the scale less than 5 minutes;
- Mesometeorological range is from 5 minutes to several hours;
- Planetary waves of synoptic scale with the period of several days contribute to the spectrum of atmospheric variations at lower frequencies;
- Seasonal variations include the period of a year and its harmonics;
- Inter-annual variations with the period of several years.

The purpose of this paper is to study the effect of seasonal and synoptic variations on the mesoscale ones.

The study was performed using the database obtained by means of the network of automated stations. Simultaneous measurements of the concentrations of aerosol, CO, NO, NO_2, H_2S, SO_2, and meteorological parameters such as temperature, relative humidity, and wind velocity were carried out at the height of 2.4 m every 30 minutes for aerosol and 1 min for the other parameters.

The instrumentation parameters[2] provide resolution of 1 $\mu g/m^3$ when measuring aerosol mass concentration. Measurement principle is absorption of β-radiation when it passes through a filter with deposited aerosol.

The long series of continuous observations since 1996 collected at the network of six stations in Zelenodol'sk (54°N, 49°E) and Al'met'evsk (53°N, 51°E) were used. The data on all parameters were averaged over 1 hour.

Preliminary analysis of long series of observations of aerosol and chemical admixtures obtained at the stations of atmospheric monitoring using the method of spectral and wavelet analyses has shown good possibilities of investigating the temporal and spatial variations of atmospheric admixtures.[3,4]

Wavelet analysis was applied for determining the characteristics of temporal variations. It allows obtaining the temporal variations of the spectral properties of the parameters under study.

The wavelet transform of a one-dimensional signal $f(t)$ lies in its expansion over the basis constructed from a function (wavelet) $\Psi(t)$ that has certain properties by means of the changes in scale a and shifts x:

$$Wf(x,a) = \frac{1}{a}\int_{-\infty}^{+\infty} \Psi\left(\frac{t-x}{a}\right) f(t)\mathrm{d}t.$$

Each of the functions of this basis characterizes both certain frequency (or the corresponding temporal scale of a variation) and its location in a physical space or time – x (Ref. 5).

Thus, in contrast to the Fourier transform, the wavelet transform provides two-dimensional scanning of the one-dimensional signal under study, here the temporal scale of variation and the coordinate are considered to be independent. As a result, the possibility appears of analyzing the properties of the signal in temporal and frequency spaces simultaneously.

The general rule in practice is that the form of the wavelet should be similar to the form of the data analyzed. The Morle wavelet was applied as a mother function:

$$\Psi(t) = \pi^{1/4}\, e^{i\omega_0 t}\, e^{-t^2/2}.$$

We have chosen it so that it is the harmonic function modulated by the Gaussian and it is well adjusted to the analysis of quasi-periodic processes.[6] As is accepted, we assumed that atmospheric variations, which are the proper oscillations of the atmosphere, are quasi-periodic, and the Morle wavelet makes it possible to clearly represent the results of analysis and to interpret them in terms of the Fourier analysis.

The absolute value of the wavelet transform in the case of complex wavelet characterizes temporal variations of the relative contributions of the components of different scale to the signal under study, i.e., at each moment in time, we can estimate the intensity of variations of all temporal scales under investigation.

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The initial three-year series of the aerosol concentration is shown in Fig. 1*a*, and its wavelet spectra of the scales of 2–52 days and 2–26 hours are shown in Figs. 1*b* and *c*, respectively. The painted parts of the section correspond to the variations of aerosol concentration exceeding the level of significance with the probability of 80%. The abscissa is time in months, and the ordinate is the period (temporal scale) of variations in days (Fig. 1*b*) and in hours (Fig. 1*c*). The isolines mark the equal levels of intensity of the aerosol concentration variations. The intensity scale is on the right, which shows the amplitude variations. Analysis made shows that significant modes of 4, 7, 14, 20, and 40 days are present in the spectrum of synoptic variations. The modes of 4, 6, and 12 hours are significant in the spectrum of mesoscale variations.

The Fourier spectra of the series of intensity of the aerosol concentration variations with the periods of 26 and 6 hours, 7 and 10 days were analyzed. The series of intensity were obtained by means of the wavelet transform of the initial series of aerosol concentration on the corresponding scales, and are the section of Fig. 1*c* in the range of scales numerically equal to 24 and 6 hours and the section of Fig. 1*b* in the scale range of 7 and 10 days. The Fourier analysis has shown that the intensity of synoptic variations of both near-ground aerosol concentration and atmospheric parameters and concentrations of gaseous admixtures are modulated by seasonal harmonics (year and half-year), and both synoptic and seasonal processes modulate the intensity of mesoscale variations. Calculations of the depth of modulation provide for the value exceeding the level of 90% significance by the χ^2-criterion.[7]

The period of the greatest intensity of variations of the aerosol concentration is winter. The period of the greatest intensity of both synoptic and mesoscale variations of temperature are winter and summer, and the period of the greatest intensity of diurnal variations is only summer. The calculations have shown that the concentrations of gaseous admixtures and wind velocity have the highest intensity of both synoptic and mesoscale variations since December until April. The intensity of synoptic and mesoscale variations of relative humidity modulates not only seasonal behavior, but also its higher harmonics. Diurnal variations of relative humidity have high intensity in spring and summer.

It is obtained from comparison of the wavelet representations of aerosol, relative humidity, and wind velocity that the structure of aerosol variations has common features with representations of other parameters. The correlation coefficient of the series of intensity of variations of different scales was calculated in order to reveal the measure of correlation of temporal variations of the parameters under investigation. The series were formed by means of selecting the corresponding row in the wavelet spectrum matrix.

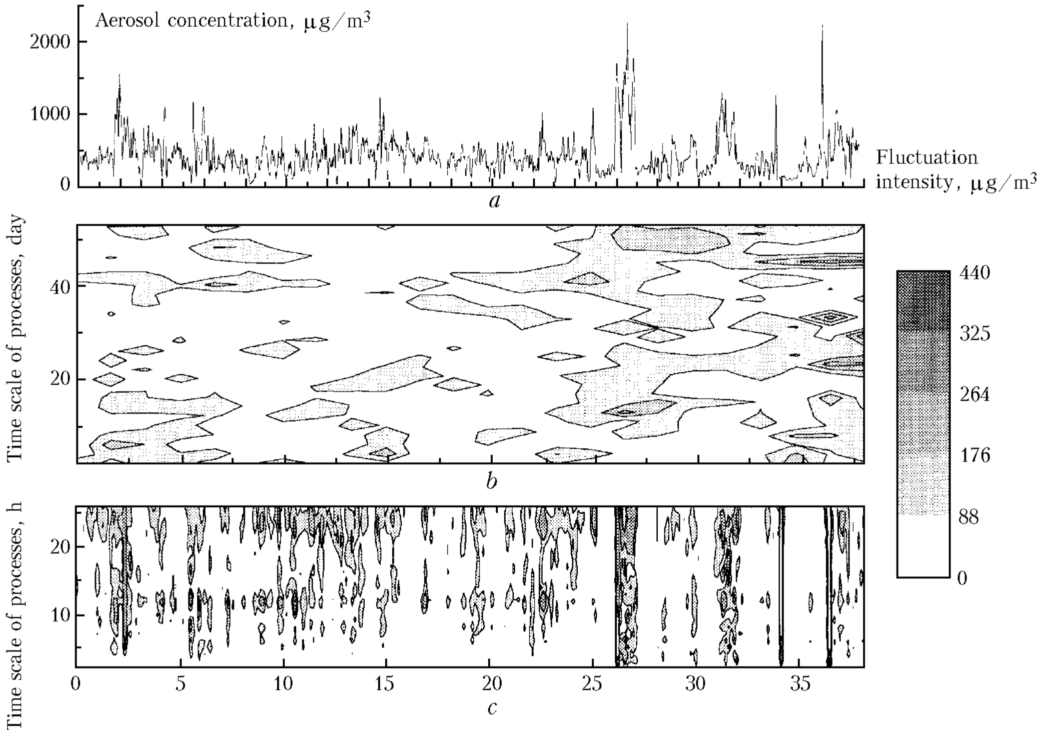

Fig. 1. The series of the near-ground aerosol concentration (*a*); wavelet transform of the aerosol concentration on temporal scales from 2 to 54 days (*b*); wavelet transform of the aerosol concentration on temporal scales from 2 to 24 hours (*c*).

The correlation coefficient of the wavelet spectra of intensity of synoptic variations of the aerosol concentration and relative humidity is significant and is equal to 0.2–0.5. The correlation coefficient of aerosol and wind velocity variations with periods of 7, 10, and 20 days is significant and positive, and that for periods from 20 to 40 days is significant and negative and is equal to –0.3 – –0.5. The correlation coefficient of aerosol and NO_2 concentration variations with periods up to 20 days is significant and positive and is equal to 0.3, and that for periods greater than 20 days is significant and negative and is equal to –0.2 – –0.5. These estimates show the correlation of synoptic variations of the near-ground aerosol concentration with meteorological parameters and concentration of trace gases. It is interesting that the correlation coefficient of wavelet spectra of the intensity of synoptic variations of the NO_2 concentration and the wind velocity is significant and is equal to 0.3–0.7 that is an evidence of the formation of NO_2 concentration field principally due to the wind velocity variations.

The mean values of the amplitudes of the aerosol concentration variations of different scales are estimated. Annual variations make principal contribution to the total variance at the mean value of the aerosol mass concentration equal to 410 $\mu g/m^3$. Its amplitude is equal to 119 $\mu g/m^3$. Diurnal variations are second in the contribution to the total variance, their mean amplitude is equal to 74 $\mu g/m^3$. Mean contribution of mesoscale variations to the total variability of trace gases and aerosol is 16–20%, their mean amplitude is 50 $\mu g/m^3$. Sometimes the amplitude of mesoscale variations can exceed the amplitude of annual behavior by several times.

The main results obtained are as follows:

1) intensity of synoptic variations of the near-ground aerosol concentration is modulated by the harmonics of annual behavior;

2) intensity of mesoscale and diurnal variations of the aerosol concentration is modulated by both synoptic and seasonal processes.

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