Study of the spatial structure of mesoscale variations of near-ground aerosol by different methods

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Mesoscale variations of near-ground aerosol are studied by different methods using data from automated network stations. According to three years of near-ground aerosol observations in Tatarstan, these processes contribute 16% to the total variance of near-ground aerosol fluctuations. Horizontal transport rates and spatial scales of mesoscale variations of near-ground aerosol are estimated.

The near-ground aerosol concentration varies over different spatial and time scales.[1–3] The investigation of mesoscale processes is of great concern, and an analysis of convectively driven coherent structures in particular[4] has aroused significant interest.

Since 1996 Kazan State University, under the support of the Tatarstan Ministry of Nature, has performed continuous observations of near-ground aerosol concentration from automated stations of an ecological monitoring network. The measurements are made at a height of 2.4 m by the filtering method with an accuracy of 1 μg/m^3 (Ref. 5). In addition to aerosol characteristics, the stations also measure meteorological parameters (wind speed and direction, temperature, and relative humidity) and concentrations of gaseous admixtures (CO, NO, NO_2, SO_2, and H_2S).

In 1996–1999 measurements were made at five automated network stations located at 53°N, 51°E. Geographically, the interstation distance ranges from 0.9 to 6.3 km (Fig. 1), allowing a study of the mesoscale spatial structure of near-ground aerosol variations.

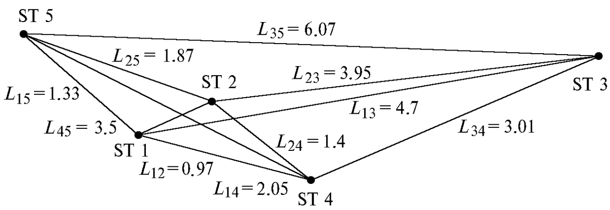

Fig. 1. Locations of measurement sites.

Based on four-year series of aerosol measurements, the contribution of variations on different timescales to the total variance of the aerosol concentration was estimated. The variance was estimated on synoptic and seasonal timescales using time series of daily and monthly mean concentrations, respectively. The variance contributed by mesoscale processes was estimated from 30-min resolution time series. For this, the large-scale variations were removed by applying a running mean (24-h for the mesoscale and 30-day for the synoptic scale). The calculations show that mesoscale variations contribute 16%, whereas processes on other timescales contribute more to the total variance (Table).

Table. Variance of fluctuations of the near-ground aerosol concentration

Variance	Contribution, %
Total	100
Seasonal	22
Synoptic	24
Mesoscale	16
Turbulent	38

The fluctuations on characteristic timescales from 2 to 16 h were identified using wavelet analysis of 30-min resolution series of measured aerosol concentrations. As is well known, the wavelet representation projects the one-dimensional signal-function of time onto the time–frequency plane, thus visualizing time variations of signal spectral properties. The wavelet transform $Wf(x, a)$ of the one-dimensional signal $f(t)$ expands the signal over a basis constructed using a soliton-like function (wavelet) $\psi(t)$ subjected to scalings a and translations x:

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

Thus, in contrast to the Fourier transform, the wavelet transform provides a two-dimensional sweep of the investigated one-dimensional signal, in which the frequency and the spatial coordinate are treated as independent variables. In this way, it is possible to analyze signal properties simultaneously in the physical (time, spatial coordinate) and frequency domains. To analyze quasi-periodic variations, we used the Morlet wavelet,[9,10] representing a plane wave modulated by a Gaussian:

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

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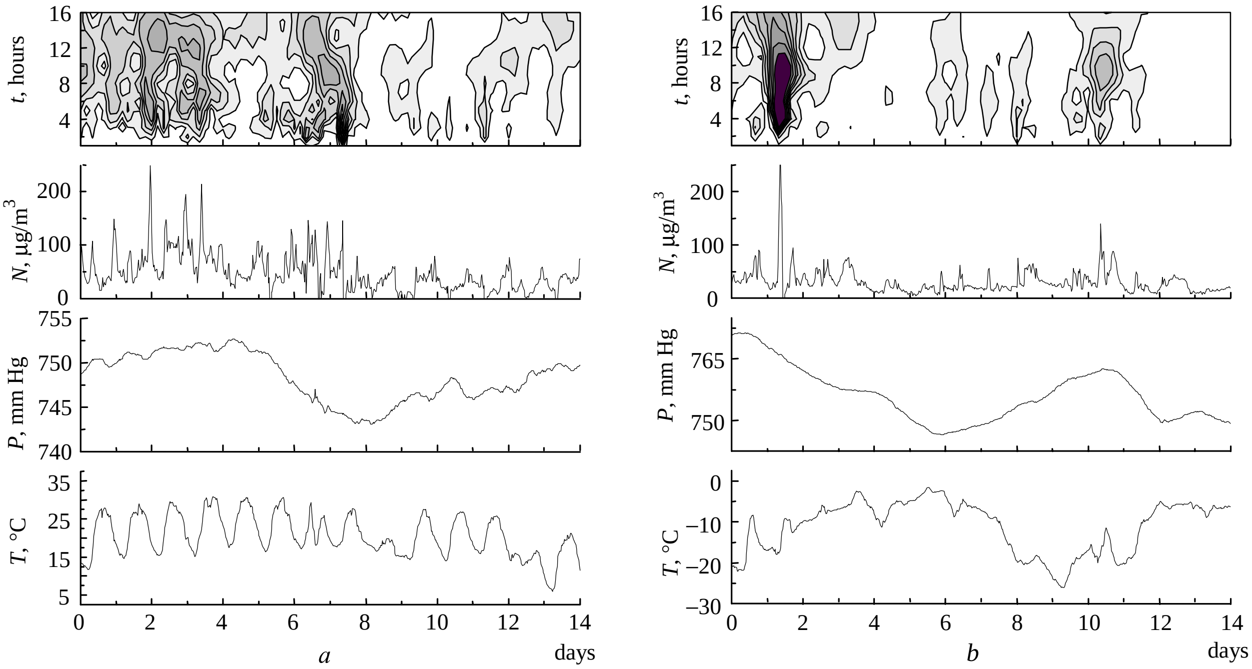

Fig. 2. Intensity of mesoscale variations of aerosol concentration, pressure, and temperature, as inferred from June (*a*) and November (*b*) 1997 measurements.

Figure 2 presents examples of wavelet representation for two-week time series of aerosol concentration measured in June and November 1997. The horizontal axis represents time covering a two-week observation period while the vertical axis gives time scales of the identified fluctuations. Shades of gray represent steps in intensity of the fluctuations. Also shown are the measurements themselves, together with pressure and temperature time series for the same time period. As can be seen, the mesoscale aerosol fluctuations reach a maximum in periods preceding the passage of fronts of low- and high-pressure systems. As a rule, the concentration of near-ground aerosol also increases during these periods. Comparison of wavelet transforms for aerosol and other meteorological parameters shows that the perturbation modes of the aerosol concentration coincide with those of the wind velocity.

Using long time series of aerosol concentration measured at each station between October 1 and 14, 1996, we performed a dynamical spectral analysis inside a 24-h wide sliding time window to identify periodic mesoscale variations with periods between 1 and 16 h. The sliding time window was applied simultaneously to five time series.

In the five spectra thus obtained, all pertaining to the same time period, we selected statistically significant (to 0.9 level according to the χ^2 test) peaks, identified simultaneously at all stations. This suggests the presence of wave processes propagating in space. The observations of spectra at spatially separated points can be used to estimate the horizontal phase speeds of movement of wave perturbations C_x, as well as the periods T_x of these wave processes and their spatial extents (wavelengths λ_x).

The spatial scales were estimated using linear regression over phase spectra at different sites:

$$\Delta\varphi_k = \frac{2\pi}{\lambda_x} x_k, \quad k = 1, \ldots, 9.$$

Knowing the periods of the waves, we can then determine their phase speeds:

$$C_x = \lambda_x / T.$$

Histograms of these variables are presented in Fig. 3 for periods from 2 to 16 h; the most probable values are λ_x = 2–15 km and C_x = 10–50 m/s.

The periods and phase speeds of mesoscale waves coincide with those of internal gravity waves (IGW) observed in the middle atmosphere.[3] This suggests that the wave variations in the near-ground layer have the same nature as their mesospheric counterparts, and that the fluctuations of aerosol concentrations may be due to dynamic processes caused by IGW's in the troposphere.[4] Maximum aerosol inhomogeneities, with periods of 2–16 h, are observed in January–February and July–August; precisely in which period an increase in the aerosol concentration is also observed.[2,5]

The main results of this paper are:

1. The contribution of mesoscale wave processes to the total variance of fluctuations of near-ground aerosol is found to be 16%, based on three-year series of observations of aerosol concentration in Tatarstan.

2. It is shown that the intensity of mesoscale fluctuations of aerosol concentration increases in

periods preceding passage of fronts of high- or low-pressure systems.

3. The periodic mesoscale variations of near-ground aerosol have phase speeds between 10 and 50 m/s and spatial scales of up to 15 km.

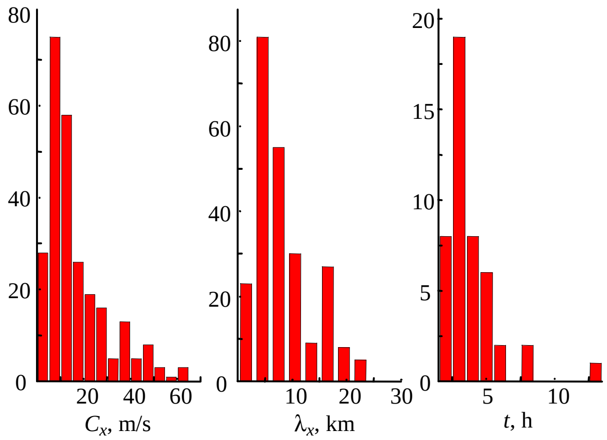

Fig. 3. Histograms of parameters of mesoscale wave variations of near-ground aerosol (C_x is phase speed, T_x is period, and λ_x is wavelength).

Acknowledgments

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