Statistical analysis of mass concentration variations of the coarse aerosol in Moscow

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Mass concentration variations of the coarse aerosol in Moscow have been analyzed. Basic statistical parameters of the concentration variations were calculated. The data on diurnal and seasonal variations of the mass concentration of coarse aerosol are presented.

Introduction

Aerosol pollution of atmospheric air in megapolises[1,2] is considered now as one of the most important ecological factors.[3–5] More and more attention is paid to climatic aerosol effects, including radiation ones. One of the main parameters in atmospheric ecology, which characterizes the aerosol pollution of the atmospheric air, is the mass concentration of aerosol particles[3] of the size no more than 10 μm (PM_{10}).

This paper presents the analysis of systematic measurements in 2004 of the mass concentration M or PM_{10}, of the coarse aerosol in Moscow at the network of automated stations of monitoring the quality of atmospheric air of the State Nature-Preservation Institution "Mosecomonitoring". Temporal mass concentration variations of the coarse aerosol are considered. The results of statistical analysis of the gaseous component concentration variations in pollution of the Moscow atmosphere are presented in Ref. 6.

Instrumentation

Mass concentration of aerosol particles of the size less than 10 μm was measured by radioisotopic method[7] from the extinction of β-radiation by aerosol samples collected on the periodically moved tape of fiber filter by the device DAST ("Monitoring" Co., Saint-Petersburg), intended for measurements of the dust (coarse) aerosol mass concentration. The source of β-radiation in the DAST dust-meter is the radionuclid ${}^{147}_{61}Pm$.

The upper limit of DAST measurements can vary from 10 to 30 μg/m^3 depending on the level of aerosol pollution and the given sampling time. In monitoring of aerosol in Moscow, the time of averaging was 20 minutes. The rate of airflowing through the device was 20 l/min. According to specifications, the instrumental error of the device did not exceed 20%. However, at the mass concentration of coarse aerosol particles less than 10–20 μg/m^3, it was necessary to increase the time of averaging.

Note that impactors and cyclones do not efficiently separate the fractions of particles with sizes greater and less than 10 μm, therefore, only aerosol particles up to 30 μm fall into the device.[3] Besides, it should be kept in mind that the dust-meter DAST is not intended for measurements of the mass concentration of the submicron aerosol fraction.

Statistical characteristics of the coarse aerosol concentration variation

The measurements of the mass concentration of the coarse aerosol M (or PM_{10}) obtained in 2004 at 6 automated stations, monitoring the quality of atmospheric air in Moscow (Veshnyaki, Lyublino, MSU, Novokosino, Narodnogo opolcheniya str., and Chayanova str.) were taken for statistical analysis. An example of temporal variability of daily mean concentrations of the coarse aerosol in January–September, 2004 (Lyublino) is shown in Fig. 1.

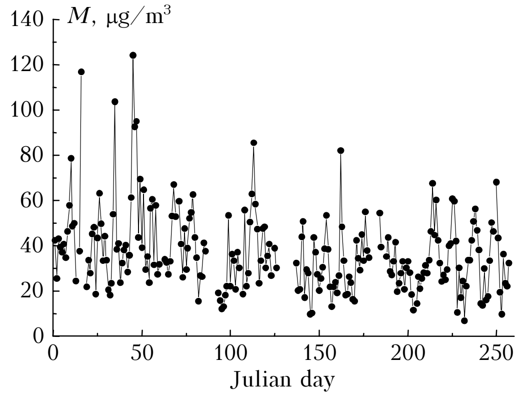

Fig. 1. Temporal variability of daily mean mass concentration of particles with the size less than 10 μm (PM_{10}) assessed from the measurements in Moscow (Lyublino) in 2004.

The characteristic peculiarity of the temporal behavior of daily mean concentrations is their well pronounced synoptic variability. Figure 2 presents the probability distribution of individual aerosol mass concentrations.

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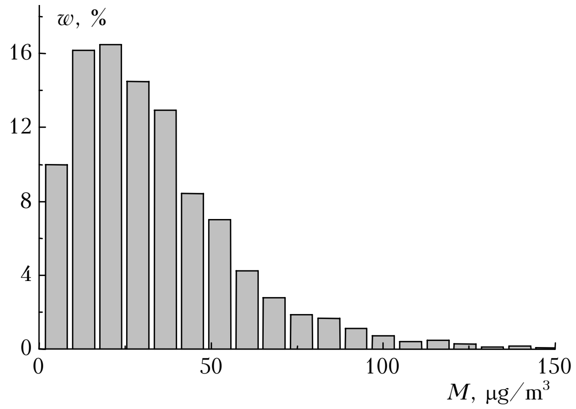

Fig. 2. Empirical distribution function of the aerosol mass concentration (PM_{10}) assessed from measurements at the station Veshnyaki (Moscow, 2004).

It is seen that individual concentrations in Moscow rarely exceed 120–130 μg/m^3. Data in more detail on empirical distribution functions M can be obtained from calculations of the principal statistical characetristics[8] of the parameter variations.

Along with annual mean concentration $\overline{M}$ and corresponding standard deviation σ, the values of asymmetry $A = n^{-1}\sigma^{-3}\sum_k m_k^{-3}$ (k is the number of realization) and excess $E = -3 + n^{-1}\sigma^{-4}\sum_k m_k^4$ of the empirical distributions of M have been calculated, where n is the number of measurements, $m_k = M_k - \overline{M}$ are the values of deviations of the mass concentrations from the corresponding means.

The results of calculations of the annual mean aerosol concentrations $\overline{M}$, variation coefficients[8] $\gamma = \sigma/\overline{M}$, parameters of asymmetry A, and excess E from measurements in 2004 are presented in the Table, as well as the seasonal mean mass concentrations $\overline{M_1}$ (winter), $\overline{M_2}$ (spring), $\overline{M_3}$ (summer), and $\overline{M_4}$ (autumn).

It is seen that the annual mean concentrations $\overline{M}$ vary within comparably narrow limits (32–36 μg/m^3), excepting the station situated on the territory of MSU Meteorological Observatory ($\overline{M}$ = 24 μg/m^3). Variation coefficients for the above stations (see the Table) lie between 0.71 and 0.98, the asymmetry parameters are between 2.6 and 4.0, and the excess is between 14 and 44. Statistical analysis has shown that variations of the coarse aerosol concentration are described by lognormal distributions with a satisfactory accuracy.

Statistical regularities of the aerosol mass concentration variability are very interesting in the context of the problem of statistical forecast of aerosol pollution of some urban atmosphere. For statistical forecast of inter-day M variability, it is necessary to know the probability distribution of the increase of daily mean aerosol concentrations. Figure 3 demonstrates this distribution for Moscow. It shows the empirical function of distributions of the difference ΔM of the daily mean concentration for neighbor days (yesterday – today) constructed from the measurements at Chayanova str. in 2004. It is easily to see that the absolute value of this difference exceeds 30 μg/m^3.

Table. Statistical characteristics of the coarse aerosol concentration in 2004

Station	$\overline{M}$, μg/m^3	γ	A	E	$\overline{M}_1$	$\overline{M}_2$	$\overline{M}_3$	$\overline{M}_4$
					μg/m^3			
Veshnyaki	35	0.81	2.6	14	31	33	44	33
Lyublino	36	0.76	3.8	29	46	36	32	30
MSU	24	0.77	4.0	44	22	27	27	24
Narodnogo opolcheniya str.	36	0.98	3.0	15	34	34	45	31
Novokosino	32	0.82	3.6	28	35	36	31	26
Chayanova str.	33	0.71	2.7	23	43	33	29	26
Mean	33	–	–	–	35	33	35	28

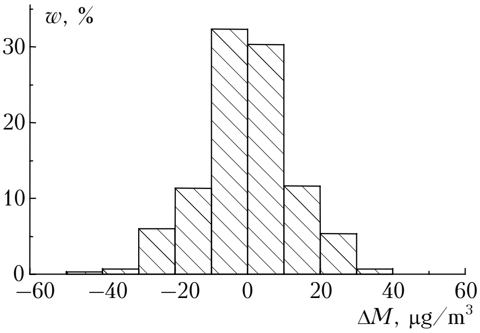

Fig. 3. Empirical distribution function of the difference between "neighbor" (yesterday – today) daily mean aerosol concentrations.

Time variability of the coarse aerosol mass concentration

The data on seasonal variability of M is shown in the Table. According to the measurements in 2004, the city-mean seasonal maximum (35 μg/m^3) is reached in winter and summer, with minimum (28 mg/m^3) in autumn. Seasonal M behavior at different stations is strongly different. The greatest mean concentrations are observed at the stations located at Veshnyaki and Narodnogo opolcheniya str. (44–45 μg/m^3) and the maximal winter concentrations are at the stations at Chayanova str. and Lyublino (43–46 μg/m^3). Mean level of aerosol pollution at MSU is low in all seasons, but at Novokosino it is close to the city-mean value.

Minimal values of the variation coefficient are observed in summer (0.56–0.62) at all stations excepting Narodnogo opolcheniya str., where this fact was observed in winter (0.76), and the maximal values are observed in autumn (0.82–1.02) and in winter in Lyublino (0.8) and Novokosino (1.14). The asymmetry parameter also reaches its minimum in summer (1.10–1.82) at four stations, in Narodnogo opolcheniya str. in winter (1.36) and in Chayanova str. in spring (0.90). The maximum values of the asymmetry parameter in 2004 are recorded in autumn (3.36–7.72), and only in Novokosino in winter (3.92).

The peculiarities of the annual behavior of the coarse aerosol concentration are shown in more detail in Fig. 4. The greatest amplitude of monthly mean aerosol concentrations is observed in Narodnogo opolcheniya str. (curve *1*). Weak variability of the monthly mean concentrations, excepting positive anomalies in January and February, is observed in Chayanova str. (curve *3*).

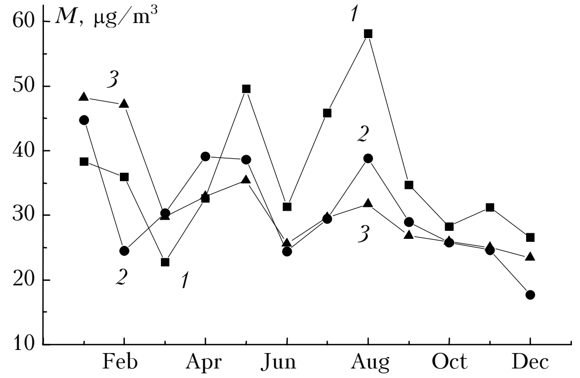

Fig. 4. Annual behavior of the aerosol mass concentration (PM_{10}) in Moscow (2004) assessed from the measurements in Narodnogo opolcheniya str. (*1*), in Novokosino (*2*), and in Chayanova str. (*3*).

One can judge about diurnal variability of M for the coarse aerosol from the mean diurnal behavior of this parameter. Diurnal M behavior in four seasons was averaged over all six stations. The results of calculation are shown in Fig. 5.

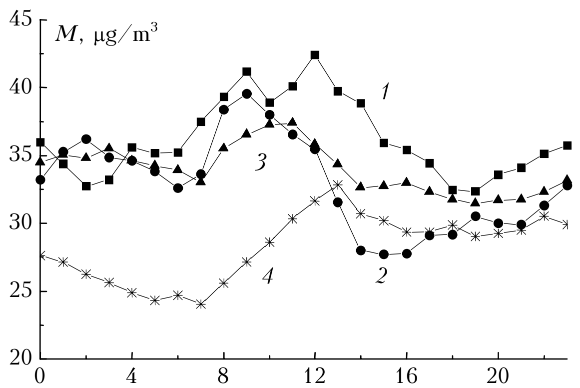

Fig. 5. Mean diurnal behavior of the aerosol mass concentration (PM_{10}) in Moscow in winter (*1*), spring (*2*), summer (*3*), and autumn (*4*).

Two maxima are observed in the diurnal behavior of M for the coarse aerosol in winter: in the morning and in the daytime. As the depth of the minimum between them is comparatively small, these maxima can be combined. Besides, the evening minimum of the aerosol concentration is observed in winter. The wide morning maximum is observed in spring and the daytime maximum is seen in summer. In spring, aside with the morning maximum, the daytime minimum is well pronounced. Autumn diurnal behavior of M is strongly different from other seasons, first of all, by wide nighttime minimum. It is important to estimate further the scale of interannual variability of the mean diurnal behavior of M in different seasons.

The mean diurnal behavior of M can be used as one of the predictors for forecasting the hourly mean concentrations of the coarse aerosol. However, significant contribution of irregular component into the total variance of hourly mean M values decreases the efficiency of the statistical forecast of the coarse aerosol diurnal variability. So, the "four-period" forecast of M diurnal behavior should be more successful. It can be reduced to statistical estimation of mean morning, daytime, evening, and nighttime concentrations from the known values of daily mean aerosol concentrations. The correlation diagram M_1–M constructed from the measurements in Chayanova str. in 2004 is shown in Fig. 6 as an example of realization of the four-period statistical forecast. Here M_1 are the mean nighttime concentrations (time period from 10 p.m. to 4 a.m.), M are the corresponding daily mean concentrations.

The regression line $M_1 = 1.1M$ (curve *1* in Fig. 6) enables one to determine the most probable M_1 values, and the line $M_1 = 1.1M + b$, where $b = 20$ μg/m^3 (curve *2* in Fig. 6) makes it possible to estimate maximal nighttime concentrations of the coarse aerosol.

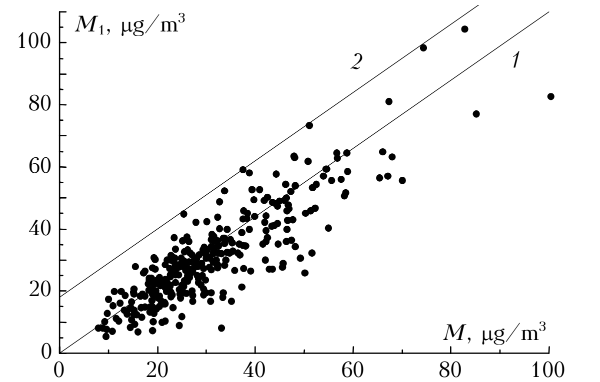

Fig. 6. Correlation diagram between M_1 in nighttime and daily mean M assessed from the measurements in Moscow (2004) in Chayanova str. (*1* is the regression line, *2* is the boundary of maximal "nighttime" concentrations).

Moscow is comparable with other European cities by the level of aerosol pollution of near-ground air. For example, according to measurements in London (1986–1989), the annual mean mass concentration of aerosol (PM_{10}) in the city center near roads reaches 60–100 μg/m^3, and that in other districts of the city is no more than 40 μg/m³ [Ref. 9]. Excesses over 100 μg/m³ level (1992) in London, Birmingham, Cardiff, and New Castle make no more than 1% of events.[9]

In the center of Prague,[3] in January, 1997 the daily mean concentrations of coarse aerosol (PM_{10}) reached 150–230 μg/m³, in districts with high traffic they were 130–200 μg/m³, and in dwelling zone they were 90–130 μg/m³.

In Germany,[10] according to the measurements in urban agglomerations, the mean concentration of coarse aerosol decreased from approximately 200 μg/m³ in 1969 to 80 μg/m³ in 80s of the last century.

According to data of selected measurements in London,[9] the hourly mean aerosol concentrations (PM_{10}) in May–June, 1992 varied from 29 to 49 μg/m³. Maximal hourly mean values of the aerosol concentration were observed at 9 a.m. (44 μg/m³) and at 2 p.m. (49 μg/m³); minimal values were at 11 a.m. (36 μg/m³) and at 3 a.m. (28.5 μg/m³).

About spatial distribution of coarse aerosol in Moscow

It was shown above that significant variations of spatial distribution of the coarse aerosol in the city are observed on the scale of seasonal variability. Additional differences of spatial distributions of M are observed when passing to smaller temporal scales.

In the context of forecasting the aerosol pollution of the urban atmosphere, correlations between variations of daily mean aerosol concentrations in different districts of the city are of interest. The correlation diagram $M_V - M_L$ of daily mean concentrations of the coarse aerosol at stations Veshnyaki and Lyublino is shown in Fig. 7 as an example.

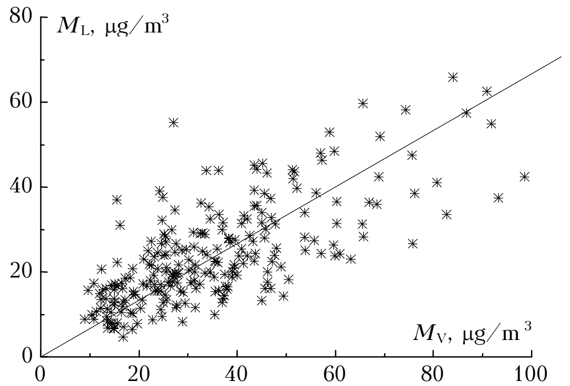

Fig. 7. Correlation diagram between daily mean aerosol concentrations (PM_{10}) assessed from the measurements in Moscow (2004) at stations Veshnyaki (M_V) and Lyublino (M_L).

The correlation coefficient $\rho(M_V, M_L)$ is equal to 0.48. Similar correlation diagrams and close values of the correlation coefficients were obtained for other pairs of stations. The error in statistical forecast of M_V from the known values M_L can be comparatively high. In particular, underestimation of the pollution level from measurements of M at another stations can reach 20 μg/m³ and more.

Conclusion

Thus, formulate the main results of the work.

1. Statistical characteristics of the coarse aerosol concentration variations are calculated from measurements in Moscow.
2. Diurnal and annual behaviors of the mass concentration of coarse aerosol have been analyzed.
3. Possibilities of the four-period diurnal forecast of the mass concentration of coarse aerosol are demonstrated.
4. The estimates of correlation of daily mean concentrations of coarse aerosol at different stations in the city are obtained.

The measurements in Moscow at the network of automated stations of monitoring the quality of atmospheric air of State Nature-Preservation Institution "Mosecomonitoring" were used in this paper.

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