ATMOSPHERIC RADIATION, OPTICAL WEATHER, AND CLIMATE

Effect of Meteorological Conditions and Long-Range Air Mass Transport on Surface Aerosol Composition in Winter Moscow

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Abstract—We discuss the results from the complex experiment aimed at studying the composition and time variations in urban aerosol in the surface air at the center of Moscow based on daily data on PM_{10} and $PM_{2.5}$ concentrations. In addition to these continuous observations every season (for 35–40 days), the total aerosol mass concentration (by gravimetric method) and 65 chemical elements in aerosol composition were measured daily. Winters 2019/2020 and 2020/2021 are considered. The aerosol composition is juxtaposed to the meteorological parameters in the surface atmosphere in Moscow, the direction of long-range air mass transport toward the Moscow region, and the distribution of dust in air over the European Russia (using the MERRA-2 reanalysis data). The detailed analysis of the aerosol elemental composition in Moscow made it possible to identify the elements of global/local spread, as well as of natural/anthropogenic genesis. Concentrations of all aerosol constituents in Moscow during winter did not exceed the corresponding daily average MPC values for the air of residential territories. It is shown that the accumulation of PM_{10} and $PM_{2.5}$ in urban air was favored by calm weather conditions. The maximal levels of aerosol pollution were observed in December 2020 during southeasterly winds, when long-range atmospheric transport of admixtures to Moscow occurred from sources located in the southern regions of European Russia, the Caspian Depression, and western Kazakhstan.

INTRODUCTION

Aerosol is a highly variable atmospheric constituent influencing both the environmental state and the climate in different natural zones and territories [1—3]. Sources (remote and local, natural and anthropogenic) supply to the atmosphere the primary aerosol, the composition of which differs in both particle sizes and chemical components. Moreover, the atmosphere contains not only aerosol, but also gas constituents, thus favoring the formation of secondary aerosol particles, as well as different physical and chemical conversions of aerosol leading to changes in its chemical composition and particle size distribution. The presence and the efficiency of these processes depend on the intensity of solar radiation, the meteorological parameters of the atmosphere, the variations in the emissions from local sources and in sinks of admixtures, the conditions of their long-range transport by air masses on specific days and in different seasons. Thus, the aerosol study in a big city is a very intricate problem, involving an analysis of many variables that describe the atmospheric properties and, if possible, the composition of emitted substance and locations of natural and anthropogenic sources of diverse atmospheric constituents.

There are still not too many scientific publications devoted to studying urban aerosols [4]. Aerosol research has been most active in recent years, both worldwide [5] and in Moscow [6], under the conditions of the COVID-19 pandemic constraints that can, and should, influence the composition of urban air. However, the natural conditions in many countries are very diverse, so that general or, at least, similar tendencies of variations in aerosol parameters can still not be reliably identified against the background of their conventional "background" oscillations, characteristic for specific location and season [7].

Very important information for studying the atmospheric aerosol can be derived from its elemental composition that indirectly indicates the local/remote sources of atmospheric pollution, simplifying the determination of pathways of aerosol supply to an observation site [8]. The sources of atmospheric pollution are determined using certain tracers (concentrations of a number of chemical elements and their ratios), which are characteristic of the composition of

a substance emitted into the atmosphere as a result of human activities or natural processes, such as different industries, motor vehicles, volcanoes, fires, dust storms, etc. [9−11]. In recent years, a growing number of works are devoted to studying the elemental composition of aerosols in different regions of Russia (such as, on desertified territories [10−13], remote regions of the Arctic [14, 15], Siberian cities [16, 17], etc. [18]). As regards the atmosphere of the Moscow region, the aerosol elemental composition was studied only episodically here, and the publications on the topic are few [7, 19−25]. In recent years, the staff of Moscow State University has carried out work on comparing the elemental composition of solid particles of soils and roadway dusts to that of the atmospheric aerosol in Moscow and the Moscow region [26−28].

In this work, we analyze the data on aerosol composition in the urban air of Moscow obtained at the Obukhov Institute of Atmospheric Physics, Russian Academy of Sciences (IAP RAS) (certain results from the analysis of these data were presented in [7, 25, 29, 30]). We consider winters 2019/2020 and 2020/2021, which are the seasons with the weakest aerosol pollution of the atmosphere over the two-year observation period. The emphasis is on the analysis of how the distribution of aerosol mass over particle sizes (mass composition) and elemental composition of aerosol vary when juxtaposed to the meteorological conditions and the direction of long-range air mass transport to the Moscow region.

INITIAL DATA ACQUISITION AND ANALYSIS

During the last two years (from October 2019 to October 2021), IAP RAS has conducted a complex experiment on studying the physicochemical characteristics of the surface aerosol. The observation site (approximate coordinates: 55.74° N; 37.62° E) is located in the IAP RAS yard in the central part of Moscow in a zone of dense urban development not far from moderately busy traffic arteries. Aerosol samples were taken daily at an altitude of ∼2 m above the ground; filters were replaced at 09:00 Moscow time.

During the experiment, continuous time series of daily data on the aerosol particle size distribution function and number concentration (in the size range 0.25−10 μm) in the surface air layer were obtained for two years of observations. The well-known formula [1, section 8.1.1. P. 356, formula 8.8] was used to determine the particle mass distribution over sizes. Assuming that the dust and soot particles are the main components of urban aerosol [31], the particle density was assumed to be 1.8 g/cm^3 in the calculations. The wetted particle density was assumed to be 1 g/cm^3 under the conditions of high humidity. In addition, an intensive complex experiment was carried out for 35−40 days in each season; specifically, the daily samples collected by the aspiration method were used to determine the mass concentration of all filter-trapped aerosol particles (usually not exceeding 40 μm in size) and aerosol elemental composition. In the winter seasons considered here, these experiments were conducted from January 10 to February 14, 2020 and 2021.

The aerosol sampling instrumentation comprises:

— The aspiration aerosol samplers with analytical AFA-type filters made from Petryanov filtering sheet for a subsequent gravimetric and chemical analysis (for particles with sizes (diameters) $D = 0.1$ μm, the AFA filter skip factor is 0.1% [32]).

— Six-stage impactors with hydrophobic filters for determining the aerosol mass and elemental composition in particle size ranges: < 0.5; 0.5−1.5; 1.5−2.5; 2.5−4.0; 4.0−6.5; and > 6.5 μm.

— Laser aerosol spectrometers LAS-P for determining the number of aerosol particles with $D = 0.15−2.0$ μm every 5 min in 10 channels.

— Optoelectronic aerosol spectrometers OEAS-05 for determining the number of aerosol particles with $D = 0.2−10.0$ μm every 5 min in 10 channels.

Different aerosol parameters were determined and analyzed using the following methods and instruments:

— Aerosol particle microphysical characteristics, by the methods of laser and electronic spectroscopy.

— Aerosol mass concentration, by the gravimetry method or/and through numerical calculation applying data on the particle size distribution [1].

— Elemental composition, by the method of inductively coupled plasma atomic emission spectroscopy (ICP-AES), inductively coupled plasma mass spectrometry (ICP-MS), and through X-ray fluorescence (XRF) analysis [9−11, 33].

— Data statistics obtained by means of standard statistical software for automatic numerical processing and graphical display of information.

Internet resources and databases used for analysis and interpretation of results included:

— Meteorological parameters of the Balchug weather station closest to IAP RAS available at websites [34−36].

— Back trajectories of air mass transport to the observation site calculated using the HYSPLIT model available at the ARL NOAA website [37].

— Spatial distribution of dust in the surface air from MERRA-2 (version 2) reanalysis data obtained using satellite observations and real monitoring [38].

— Data from State Nature Organization Mosecomonitoring (MEM) network stations [39].

RESULTS AND DISCUSSION

Snow cover isolates the underlying surface (soil and partially roads) from the atmosphere in Eurasian midlatitude winter in most continental regions. This
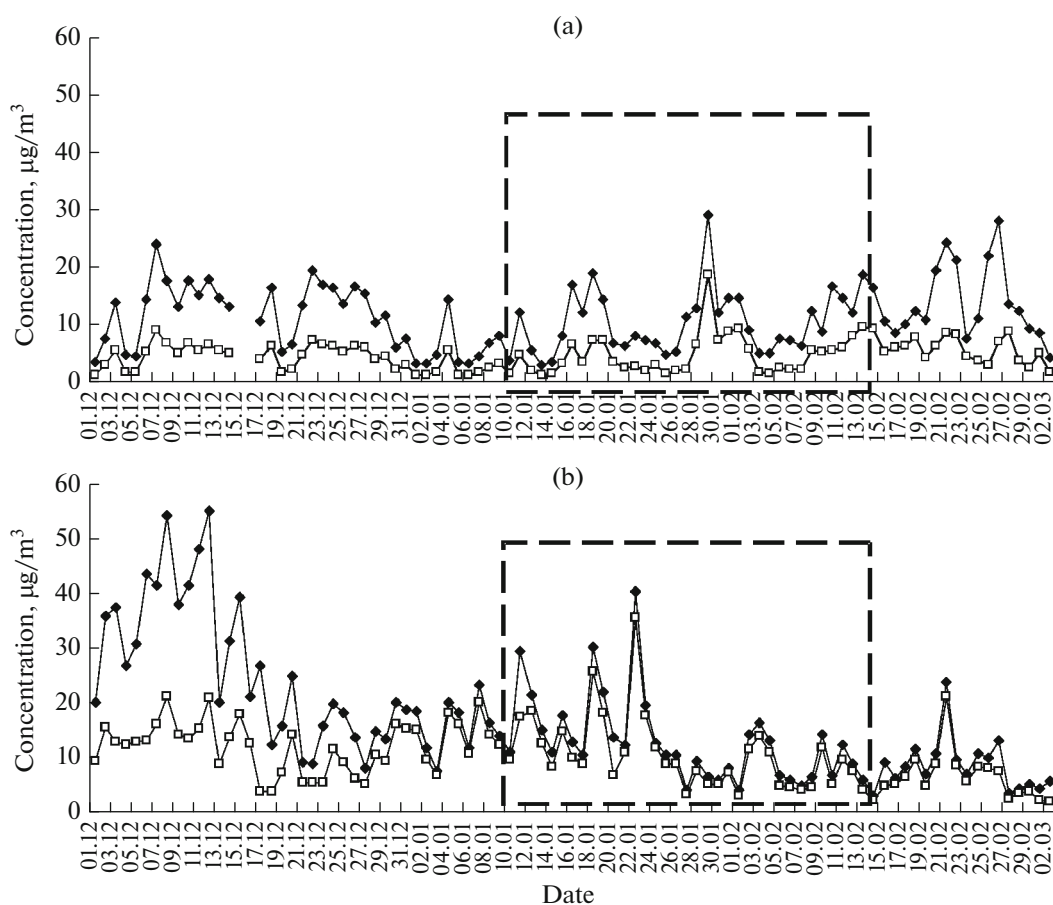
Fig. 1. Concentration of PM_{10} (black squares) and $PM_{2.5}$ (open squares) in the surface air in Moscow during winter (December–February) seasons: (a) 2019/2020; (b) 2020/2021; dashed line boxes show the intensive monitoring periods.

strongly mitigates the effect of local natural sources of soil and dust aerosols on the composition of the surface atmosphere. Moreover, low temperatures slow down the formation of secondary aerosol particles from precursor gases, and also nearly block out the emissions of bioaerosols by vegetation. Thus, the surface urban aerosol during winter should predominantly be composed of anthropogenic components of local origin and natural/anthropogenic admixtures of global spread. Our data from the two-year continuous monitoring indicate that winter seasons are the periods when all aerosol components in the surface air of Moscow show minimal concentrations. It is noteworthy that winters may strongly differ in how strongly the weather conditions and long-range atmospheric transport of air masses influence the air composition.

General Information on the Composition of Winter Aerosol

Figure 1 shows the daily average mass concentrations of PM_{10} and $PM_{2.5}$ and their variations in surface air at the center of Moscow in winters 2019/2020 and 2020/2021. The concentrations did not exceed the daily average maximum permissible concentration (MPC) (60 and 35 μg/m³ for PM_{10} and $PM_{2.5}$, respectively) throughout the observation period. As can be seen from Fig. 1, the daily average mass concentrations of PM_{10} and $PM_{2.5}$ synchronously vary for three months (the correlation coefficients are 0.84 and 0.75 in 2019−2020 and 2020−2021, indicating that the particles in these fractions have the same sources, or that these sources are nearly synchronously activated/deactivated).

Comparison of daily mass concentrations of PM_{10} and $PM_{2.5}$ obtained at the IAP RAS and at the nearest MEM network station (Spiridonovka) at the center of the city showed a good convergence of absolute values and variations in these characteristics. The correlation coefficients between the data from the IAP and Spiridonovka in each of these seasons are ∼0.8 for PM_{10} and >0.9 for $PM_{2.5}$.

The average mass concentrations of aerosol particles in different fractions and the total aerosol mass concentration M (D < 40 μm) are presented in Table 1. The most distinct differences between winters

Table 1. Average mass concentrations ($\mu g/m^3$) $\pm$ SD of aerosol particles with different sizes in diverse time intervals during the winters under study

Time interval	D, μm				M
	<2.5	2.5−10	<10	>10	
Jan. 10−Feb. 14, 2020	4.7 ± 3.7	5.7 ± 2.7	10.4 ± 5.6	10.4 ± 6.7	20.6 ± 9.0
Jan. 10−Feb. 14, 2021	10.7 ± 6.8	**2.5 ± 2.1**	13.1 ± 8.0	18.4 ± 10.2	32.0 ± 12.6
3 months of 2019/2020	4.7 ± 2.8	6.7 ± 3.9	11.4 ± 5.9		
3 months of 2020/2021	10.3 ± 5.9	6.5 ± 8.5	16.9 ± 11.9		
Dec. 1−15, 2020	**14.4 ± 3.5**	**23.1 ± 7.7**	**37.5 ± 10.6**		
Dec. 16, 2020−Mar. 3, 2021	9.5 ± 5.9	3.4 ± 3.4	12.9 ± 7.6		

2020/2021 and 2019/2020 are that the aerosol concentrations in air were much larger in the first half of December 2020; as well as that the mass concentrations of aerosols with sizes from 2.5 to 10 μm (the difference between the PM_{10} and $PM_{2.5}$ fractions) were small in January−February 2021 (see Fig. 1). Anomalous values are bolded in Table 1.

Meteorological Features of These Winters in Moscow and Associated Differences in Aerosol Particle Size Distribution

Winters 2019/2020 and 2020/2021 in Moscow stood out in values of the main meteorological parameters: temperature T, relative air humidity U, and atmospheric pressure p. That was manifested primarily in anomalously high (positive) air temperatures (Table 2) during all three months of winter 2019/2020. The pressure and humidity in that period of time were slightly lower than in the next year, when all three indices were close to normal. The snow-covered period in winter 2019/2020 was just two months (December and January), given that the average (over 2005−2021) snow-covered period is longer than four months in Moscow. As a result, the snow-free soil was unfrozen and sufficiently dry to be a source of aerosol particles already in February. This latter could be why the concentration of aerosol particles with sizes from 2.5 to 10 μm was much larger in February 2020 than 2021 (see Table 1 and Fig. 1). Therefore, the size distribution of PM_{10} from December 16, 2020, to early March 2021 should be more typical for winter aerosol in Moscow than the distribution in the preceding anomalous winter season.

The wind conditions in Moscow during these winters were characterized by quiet, weak winds; calm conditions were more frequent during winter 2020/2021 than during the preceding winter. However, wind roses in these seasons drastically differed (Figs. 2a and 2b): predominantly westerly winds in 2019/2020 versus a larger percentage of southeasterly winds in 2020/2021.

These differences influenced the size distribution of aerosol mass for different wind directions. In particular, the data in Figs. 2c and 2d show that the mass concentrations of the PM_{10} and $PM_{2.5}$ in the surface air in Moscow during winter are larger under southerly and easterly winds. Interestingly, precisely winds from southern, eastern, and southeastern rumbs were permanently recorded in Moscow from December 1 to 15, 2020, in the period of maximal aerosol concentrations (see Fig. 1b and Table 1). It is on these 15 days that the calm conditions were recorded in 40% of cases, which could also favor the increase in aerosol concentration in the surface layer when the outflow of pollutants from the city with air masses was weak. On the whole, the statistics for two winter seasons (without accounting for episode with increased aerosol concentration in the first half of December 2020) shows that, when calm conditions occur at a frequency of 12−18%, the mass concentrations of PM_{10} and $PM_{2.5}$ increase by 4−11 and 7−13%, respectively.

Long-Range Atmospheric Transport of Air Masses and Aerosol to Moscow during Winter

During winter, the underlying surface is partially covered by snow, plants are defoliated, and air temperatures are often negative; therefore, the processes of removal of admixtures from the atmosphere and deposition onto the underlying surface are slowed down as compared to the warmer season, and aerosol is transported large distances away [40−42]. Air masses passing southward of Moscow, where the snow cover is either absent or very thin at this time, should contain natural (dust, soil) aerosols from the surface of these territories. Moreover, particles, having been

Table 2. Monthly average meteorological indices of surface air in Moscow during the seasons under study

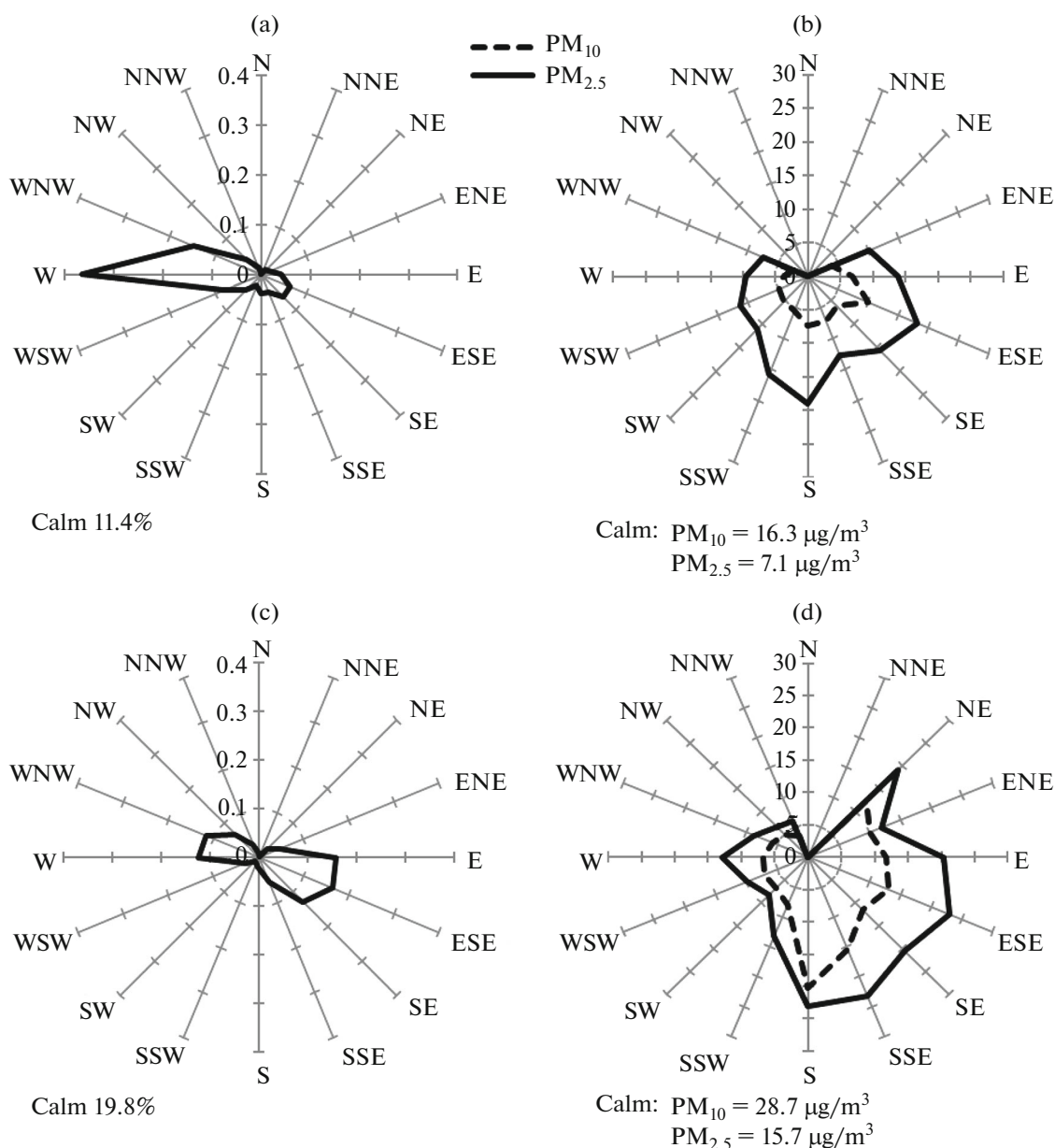| Season	Month	T, °C	p, mmHg	U, %
2019/2020	December	1.3	747	82
	January	0.7	748	79
	February	0.5	744	75
2020/2021	December	−3.9	760	81
	January	−5.0	749	83
	February	−8.3	751	75

Fig. 2. (a, c) Wind roses and (b, d) mass concentration roses of PM_{10} and $PM_{2.5}$ particles in Moscow over three winter months: (a, b) in 2019/2020; and (c, d) in 2020/2021 along with the indices of calm conditions: (a, c) frequency, % and (b, d) average concentrations under calm conditions, $\mu g/m^3$.

formed on other territories and keeping the properties of the initial aerosol, can be carried to the atmosphere of these regions and then entrained into the flow travelling toward Moscow. These formation processes of aerosol composition in Moscow are quite probable considering the long lifetime of submicron and micron admixtures in winter air.

Analysis of long-range air mass transport for each winter day in these seasons showed that air masses and aerosol arrive at Moscow from the south of European Russia, the Caspian Depression, and western Kaza-

khstan when winds blow from the southeast. This is important for identifying such days because standard meteorological data include data on wind direction.

Figure 3 presents the distributions of the trajectories of air mass transport toward Moscow and dust trajectories in the surface atmosphere of Moscow (using MERRA-2 reanalysis data [38]) for two days typical for the interval from December 1 to 15, 2020, when aerosol content in the city was increased. The back trajectories of air mass motion to the IAP RAS observation site were calculated at the NOAA's Air Resources Labora-
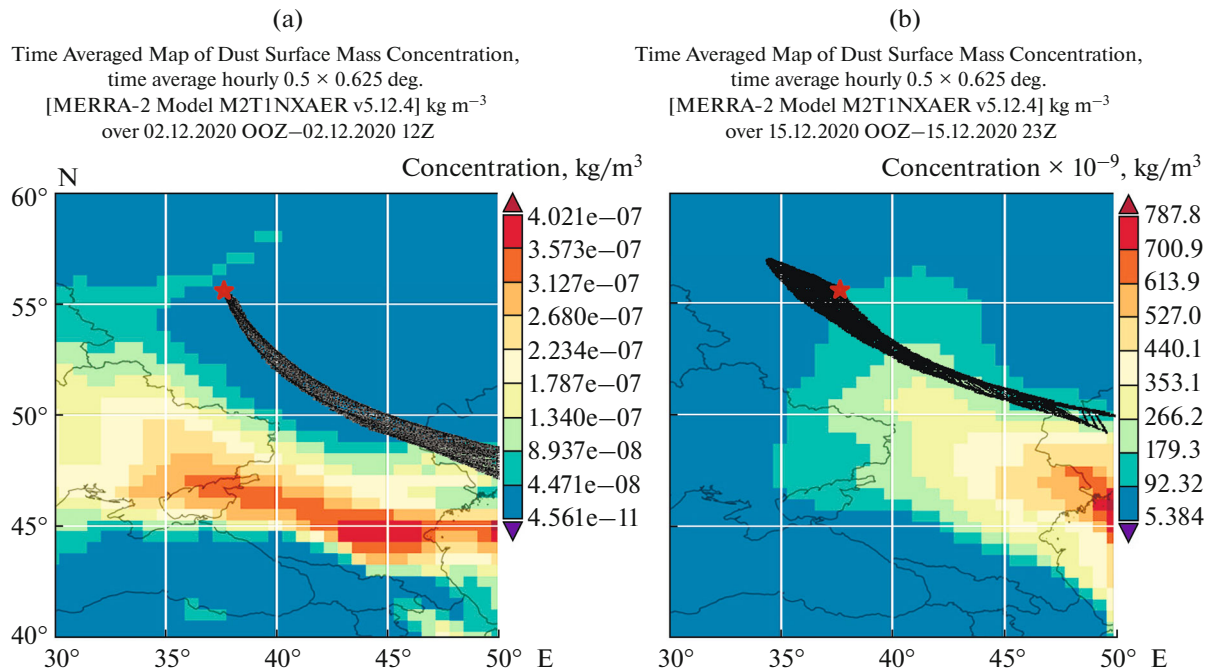
Fig. 3. Maps of the dust distributions in the surface air and trajectories of air mass transport (black dots) toward Moscow (red star) on December (a) 2 and (b) 15, 2020.

tory (ARL) website [37] (eight 72-hour trajectories per day at an interval of 3 h at an altitude of 100 m above the surface).

Winds in the city were from the southeastern rhombs in all 15 days. From Fig. 3 it can be seen that, for a three-day (duration of trajectories) period, air masses carrying sand and dust from the southeast of European Russia, Kalmykia, as well as from the Ryn-Peski Desert [43], situated in the Caspian Depression and in the west of Kazakhstan, could arrive to Moscow. On these territories, where rainfall is ~230 mm per year, at negative wintertime air temperatures, the snow cover is very thin and dust storms occur quite often. It can be seen that, in early December 2020, the air masses could carry dust and sand from Kalmykia (northwestern Caspian coast), where dust storms developed on those days (Fig. 3a). We observed and recorded a similar situation (though with heavier aerosol pollution) in Moscow during fall 2020 [30]. By December 15, the trajectories of air mass transport to Moscow slightly shifted, and aerosols were transported from Caspian Depression and from more eastern territories of the Ryn-Peski Desert. On the other hand, the probability of air transport from those areas to the Moscow region in the winter season is estimated to be, on the whole, within 5% [44]. Thus, we recorded quite a Moscow-atypical event of a wintertime supply of arid aerosol from the southeastern regions of European Russia and western Kazakhstan.

During those two winters, there were also other days, when aerosol transport to the region was from about the same areas as in the first half of December 2020. However, those were short-term episodes and, as such, could not significantly influence the aerosol concentration in Moscow. As was already noted above, the aerosol pollution in the city from December 16–17, 2020, to the end of the winter 2021 was about the same (see Table 1) as regards the average mass concentrations of the PM_{10} and $PM_{2.5}$ particles and their variations. Seemingly, these parameters can be considered a conventional "background" level for winter air in Moscow.

Aerosol Elemental Composition in Surface Air in Moscow during Winter

During the experiment in Moscow, the aerosol elemental composition in each season was determined only during intensive monitoring, i.e., in the periods indicated in Fig. 1. From the figure it can be seen that the general aerosol indices in the periods from January 10 to February 14 little differed between 2020 and 2021. Out of all 65 chemical elements measured, for a more detailed analysis we chose 33 elements (Fig. 4), which are not only terrigenous and/or non-terrigenous elements, but also of global and/or local origin.

Figure 4 shows the geochemical profiles of the average concentrations (C) and enrichment factors (EF) of chemical elements in the composition of surface aerosol in Moscow during winter 2020/2021. Evidently, these dependences are similar in different
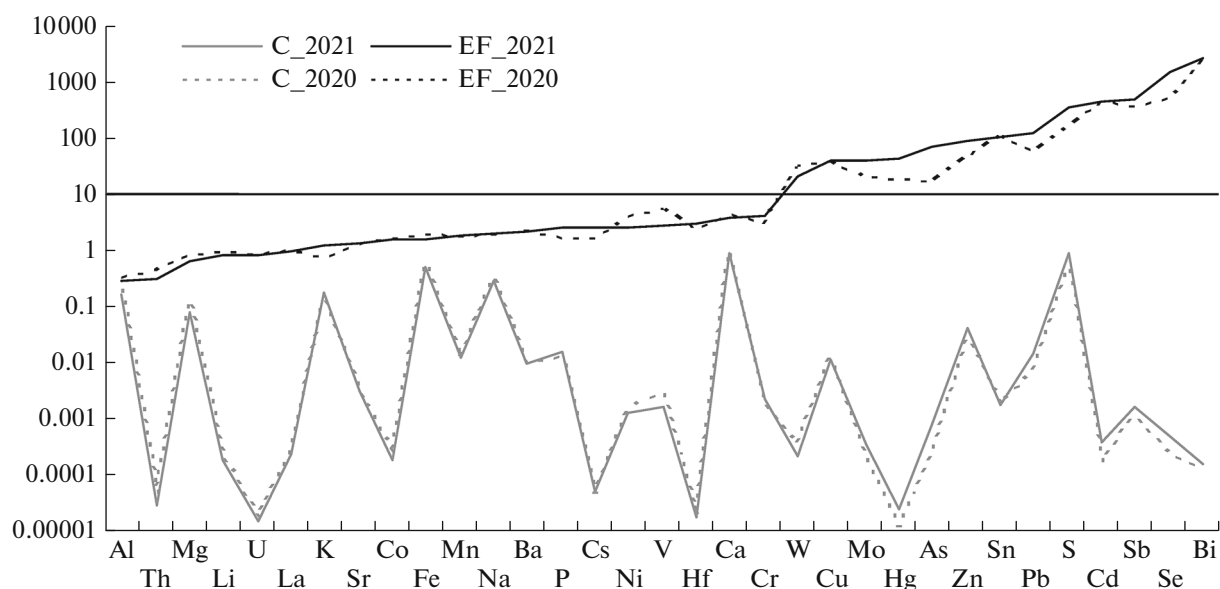
Fig. 4. Average mass concentrations (μg/m³) and enrichment factors of chemical elements in surface aerosol in Moscow in January−February 2020 and 2021. Logarithmic scale; elements along horizontal scale line up in EF_2021 increasing order.

years. The enrichment factor was calculated using comparison to the average composition of the Earth's crust (data were taken from [45]) according to the formula $EF = (C_X/C_{La})^{aer}/(C_X/C_{La})^{cr}$, where C_X and C_{La} are the concentrations of the element X and lanthanum La (a reference elements of predominantly terrigenous origin); and superscripts stand for aerosol (aer) or the Earth's crust (cr). All elements considered are divided into predominantly terrigenous (EF < 10) and non-terrigenous (EF > 10). Based on this index, W, Cu, Mo, Hg, As, Zn, Sn, Pb, S, Cd, Sb, Se, and Bi in the surface aerosol in Moscow can be classified as non-terrigenous elements; this group is the same for both winters and has the same non-terrigenous elements as in the group identified in spring 2020 [7]. Elements with 1 < EF < 10 are frequently, and especially in the city, of mixed origin and associated with agricultural activities or with the soil components used in production (construction sites, motor vehicles, production of building materials, etc.).

Analysis of variations in the concentrations of different elements made it possible to identify few groups, in which the concentrations of elements varied almost synchronously during winter months considered here. The pairwise correlation coefficients between elements of predominantly terrigenous origin (Mg, Al, P, Ca, Fe, Ba, Sr, Mn, Co, Hf, La, Th, U) were >0.8 in both winter seasons. The adjacent group (with the correlation coefficients from 0.7 to 0.8) contains elements of mixed or local origin: Cr, Cu, Mo, W, Sn, and Sb. In addition, we can single out the high correlations between variations in daily average concentrations for few groups of elements that we conventionally call the groups of sulfur (S, K, Cs, Se, Bi), iron (Fe, Mn,

Cr, Co, Zn, Sn), and lead (Pb, Cd, Sn, Sb). Elements of global spread entered to the sulfur group; metals and metalloids of local or anthropogenic origin, to the iron group; and elements mainly associated with motor engine exhausts to the atmosphere, to the lead group [46]. On the whole, these regularities are valid for both winter seasons.

The differences in elemental composition of surface aerosol between these winters in Moscow are manifested in changes in the concentrations of elements as functions of the wind direction (and, hence, the direction of long-range transport of air and pollutants to the Moscow region). Unfortunately, because of the vorticity of air flows, wind direction quite rarely indicates the possible remote territories from which air masses come. For instance, as can be seen from Fig. 3b, on December 15, 2020, the long-range transport of air masses was from southeastern regions for westerly winds in the city (these are possible, though rare, situations). The winds in the periods of intensive monitoring were distributed over directions in almost the same pattern as over the three months of the corresponding season (see Figs. 2a and 2b). The wind roses in these winters complemented each other with respect to directions; therefore, we considered two seasons together and plotted the so-called "concentration roses" of certain elements for an "undisturbed" average winter season in Moscow (the episode of long-range dust transport from southeastern regions in early December 2020 was not included in the intensive monitoring periods). These diagrams, averaged for two undisturbed winter periods (Figs. 5a−5d), show how the daily average concentration of each element in the surface air at the observation site changes with
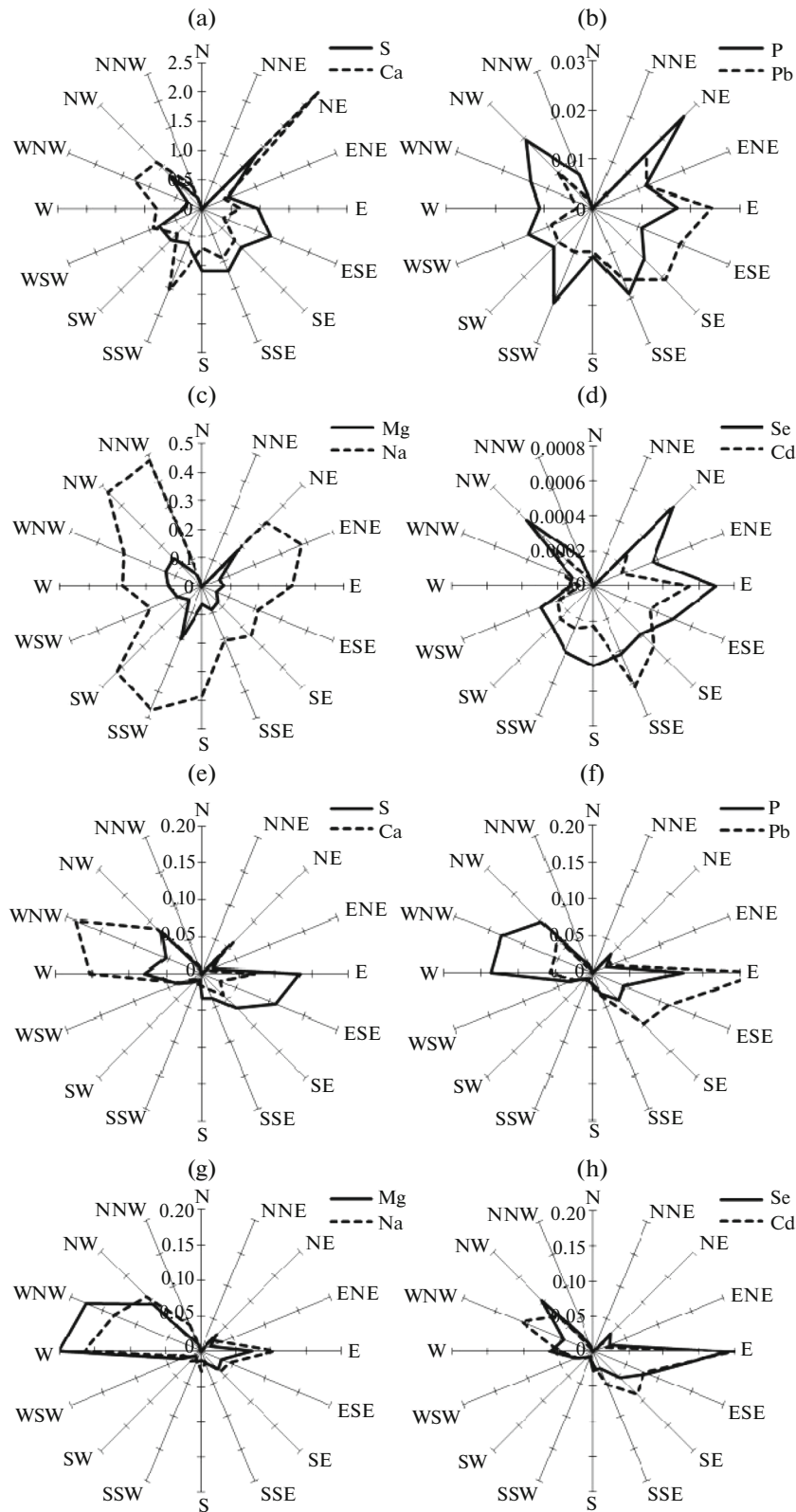
(a)

(b)

(c)

(d)

(e)

(f)

(g)

(h)

Fig. 5. Distribution over wind directions for certain elements in surface air in Moscow during winter 2020/2021: (a−d) concentrations, μg/m³; (e−h) contributions to the average concentration.

the wind direction in winter. It can be seen that the concentrations of such elements as S, Ca, Na, Mg, and P, on the whole, weakly depend on the wind direction in winter at the center of Moscow. On the contrary, the Pb, Cd, and Se concentrations in air at the center of Moscow during winter are higher under southerly and southeasterly winds. Of course, no distinction is made between effects from local and remote sources in such a consideration.

After taking into account the frequencies of winds from specific directions (wind rose) for the time interval under study (weighting coefficients of the wind direction), we can calculate the contributions to the average (over the winters considered) concentration of an element on those days when the wind blew in a corresponding direction. These "contribution roses" are shown in Figs. 5e–5h. It can be seen that more Ca, P, Mg, and Na is carried to the atmosphere of Moscow during winter with westerly winds, and more S, Pb, Cd, and Se, with easterly and southeasterly winds.

CONCLUSIONS

Winter is a season with minimal aerosol pollution in Moscow. The average total aerosol mass concentrations was 20.8 and 32.0 μg/m^3 in winter seasons of 2019/2020 and 2020/2021, respectively. For comparison: the average (over 2020 and 2021) total aerosol mass concentrations were ~57, 75, and 46 μm/m^3 during spring, summer, and fall. The winter concentrations of all measured constituents in the surface air did not exceed the daily average MPC for residential areas during both winters. Winter 2019/2020 was anomalously warm, with the shortest-lasting snow cover in all years of observations, which possibly resulted in a higher concentration of micron-sized particles (as compared to the preceding winter). On the contrary, winter 2020/2021 was closer to normal in terms of the main meteorological parameters, although the wind rose was characterized by more frequent southeasterly winds.

In the second half of December 2020 when winds were from the east and southeast, the concentration of aerosol (and especially of PM$_{10}$) was higher than average. The trajectory analysis of air mass transport toward Moscow, as well as the MERRA-2 reanalysis data on the spatial distribution of dust in the surface atmosphere showed that the aerosol sources in both cases were in the southern regions of European Russia, in Kalmykia, the northeastern Caspian region, and western Kazakhstan.

It is shown that calm conditions favor the accumulation of the mass concentration of PM$_{10}$ and PM$_{2.5}$ up to maximal levels in urban air. In the absence of anomalous atmospheric pollutant transport, the frequency of calm conditions in Moscow during winter is 12–18%, and the mass concentrations of PM$_{10}$ and PM$_{2.5}$ increase by 4–11 and 7–13%, respectively.

Study of variations in the enrichment factor (relative to the composition of the Earth's crust) revealed the elements, similar for both winter seasons, of predominantly non-terrigenous origin: W, Cu, Mo, Hg, As, Zn, Sn, Pb, S, Cd, Sb, Se, and Bi. Correlation analysis of concentrations of different elements makes it possible to single out few more groups. These are terrigenous elements (Mg, Al, P, Ca, Fe, Ba, Sr, Mn, Co, Hf, La, Th, and U), elements of global spread (S, K, Cs, Se, and Bi), as well as two groups of elements of local anthropogenic origin (Fe, Mn, Cr, Co, Zn, and Sn) and (Pb, Cd, Sn, and Sb), seemingly associated with aerosol emissions from industrial plants and with motor engine exhausts.

A joint analysis of wind direction and elemental composition of aerosol showed that westerly winds during winter carry to the Moscow atmosphere more Ca, P, Mg, and Na and other elements whose concentrations vary synchronously with the former. Easterly and southeasterly winds carry more S, Pb, Cd, and Se and, hence, more elements the concentrations of which vary synchronously with them.

Thus, the study of the formation of aerosol pollution of the atmosphere of Moscow during winter, despite the low level of this pollution, makes it possible to identify important relationships between the absolute content and variations in different aerosol constituents and natural meteorological and synoptic conditions in specific winters.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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