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The Effect of Meteorology on Air Pollution in Moscow during the Summer Episodes of 2010

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Abstract—Relations between short-term variations in the concentrations of aerosol (PM_{10}) and carbon monoxide (CO) and meteorological characteristics are considered for the episodes of severe atmospheric pollution in the region of Moscow in the summer of 2010. The assumption is made and substantiated that the observed (in late June) severe aerosol pollution of the atmosphere over Moscow was caused by air masses arrived from soil-drought regions of southern Russia. In August, during the episodes of advection of forest-fire products, the maximum surface concentrations of pollutants were observed in Moscow mainly at 11:00–12:00 under a convective burst into the atmospheric boundary layer and at night in the presence of local wind-velocity maxima or low-level jet streams within the inversion layer. On the basis of results from an analysis of these air-pollution episodes before and after fires, it is concluded that the shearing instability of wind velocity favors the surface-air purification under ordinary conditions and an increase in the surface concentrations of pollutants during their advection (long-range transport, natural-fire plumes, etc.). It is shown that the pollution of the air basin over the megapolis with biomass-combustion products in 2010 led to an increase in the thermal stability of the atmospheric surface layer and in the duration of radiation inversions, as well as to an attenuation of the processes of purification in the urban heat island.

Keywords: atmosphere, boundary layer, temperature inversion, shearing instability, air pollution, aerosol advection.

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1. INTRODUCTION

The extreme characteristics of air pollution and meteorological parameters in the region of Moscow have been extensively considered in many scientific publications devoted to the effect of the natural fires of summer 2010 (for example, a special issue of the journal *Izvestiya Rossiiskoi akademii nauk, Fizika atmosfery i okeana* (Izvestiya, Atmospheric and Oceanic Physics), 2011, No. 6). We turned our mind to the significant interdiurnal and short-term variations in pollutant concentrations (rather than the extremely high air-pollution levels) according to observational data obtained at the Moscow Ecological Monitoring (Mosekomonitoring) network (http://www.mosecom.ru/).

Even before these forest fires, episodes of high surface air pollution levels [2, 3] were repeatedly observed in the region of Moscow due to an anomalous large-scale circulation [1]. One of these episodes (in the late June) is worthy of consideration as a rare case of severe and long aerosol pollution. On those days, the concentration of atmospheric aerosol with particles more than 0.01 μm in size (according to observational data obtained in a nearby suburb of Moscow [4]) proved to be comparable to that in early August within the forest-fire period, which also is considered in this work. For analysis, the concentrations of the most conservative pollutants—carbon monoxide and suspended particulate matter (PM_{10})—were used as the markers of air pollution [5, 6].

First of all, we compare the variations in the pollutant concentrations and in meteorological parameters in the surface air and, second, we attempt to reveal the effect that air pollutants may have on processes occurring in the atmospheric boundary layer (ABL).

2. DATA USED

Physical processes within the ABL with a characteristic time scale of up to a few hours are analyzed using high-resolution observational data in both time and space. We used data on atmospheric pollutants and meteorological characteristics (wind velocity and wind direction at heights of 85 to 500 m) obtained from simultaneous measurements from the Ostankino TV tower and data on the vertical air-temperature profile (for this layer) obtained from remote measurements with MTP-5 instruments at two separate stations in the center of Moscow (Krasnaya Presnya) and in a nearby northern suburb (the town of Dolgoprudnyi). Data obtained from an objective analysis of meteorological fields and from radiosounding were

Correlation coefficients (R) of instant concentrations of PM_{10} at the stations located in the region of Moscow according to Mosekomonitoring data for summer 2010

Name of station	Period	Mar'in-skii Park	Zelenograd*	Moscow State University	Kosino	Spiridonovka	Pavlovskii Posad*	Zvenigorod*
Zelenograd*	The whole summer	0.69						
	Before fires	0.38						
Moscow State University	The whole summer	0.75	0.91					
	Before fires	0.55	0.43					
Kosino	The whole summer	0.86	0.87	0.91				
	Before fires	0.63	0.26	0.48				
Spiridonovka	The whole summer	0.79	0.90	0.95	0.95			
	Before fires	0.56	0.46	0.70	0.50			
Pavlovskii Posad	The whole summer	0.24	0.38	0.40	0.31	0.37		
	Before fires	0.48	0.42	0.38	0.43	0.43		
Zvenigorod*	The whole summer	0.66	0.72	0.75	0.71	0.74	0.40	
	Before fires	0.42	0.63	0.22	0.20	0.38	0.35	
Kozhukhovo	The whole summer	0.84	0.87	0.91	0.98	0.95	0.31	0.71
	Before fires	0.45	0.30	0.52	0.55	0.41	0.58	0.14

Note: * Suburban station. All correlations are significant at a level of $p < 0.05$; the number of cases $N = 258$ (before fires) and $N = 439$ (over the whole summer).

used to describe the processes occurring in the free atmosphere. MODIS satellite data (http://rapidfire.sci.gsfc.nasa.gov/subsets/index.php) were used as an accessory material in analyzing the propagation of fire plumes and the degree of atmospheric turbidity. The variations in the concentrations of both gas and aerosol pollutants in the surface air were estimated from observational data obtained at the Mosekomonitoring automated network for Moscow and some towns in its region (http://www.mosecom.ru/).

3. RESULTS AND THEIR DISCUSSION

Because aerosol pollution is used as one of the basic markers of processes occurring in the ABL, before presenting the results obtained, we fix on some characteristics of aerosol (PM_{10}) in this region.

3.1. Spatial Variability of the PM_{10} Concentration in Summer 2010

In 2010, the observations of suspended particles (PM_{10})—a mixture of solid and liquid particles less than 10 μm in aerodynamic size, including fine particles less than 2.5 μm in size—in the atmosphere over the region of Moscow were carried out at nine stations (http://www.mosecom.ru/). Some characteristics of the PM_{10} variability for Moscow are described in [7–9]; however, the multiple components and emissions of PM_{10} imply significant short-term local and spatial variations in the mass concentrations of suspended matter [10], which are still not clearly understood.

The correlation indices of the PM_{10} concentration were calculated for different stations of the Moscow region according to observational data obtained in summer 2010 (see the table). Before the summer fires, the coefficients of correlation between the PM_{10}

instant concentrations measured (with a 10-min interval) at these stations varied mainly within the range $R = 0.4–0.6$. Due to the period of forest fires, these coefficients increased to 0.65–0.85 for these stations and up to 0.95 and more between the stations in the center of the city (Spiridonovka station) and in the east of Moscow (Kosino and Kozhukhovo stations).

Due to the period of forest fires, the correlations of variations in the PM_{10} concentrations between the Zvenigorod and Zelenograd suburban stations located 40–50 km west of Moscow increased, and, on the whole, over the summer period, $R = 0.72$ for the instant concentrations of PM_{10} and $R = 0.9$ for the daily mean concentrations of PM_{10}. The Pavlovskii Posad station located to the east of Moscow is worthy of special notice. This station was more frequently affected by fire plumes, and, for this station (unlike others), the coefficients of correlation of the PM_{10} concentrations with other stations, on the whole, over the summer period, proved to be mostly smaller than those before the propagation of smoke.

The estimates for relations between the daily mean concentrations of PM_{10} at individual stations did not show a significant difference in the correlation of this characteristic before the summer fires and over the whole summer period ($R = 0.7–0.9$ in general and $R = 0.6–0.7$ for the Zvenigorod background station).

These results confirm that the short-term local fluctuations caused by the effect of local emissions form a pronounced inhomogeneity of the field of the surface concentrations of PM_{10}, which is smoothed (over 24 h) into the field of its mean concentrations. According to estimates by foreign authors [11, 12], a significant portion of intradiurnal aerosol variations can be explained by the effect of atmospheric processes (up to 50% according to [10]). In situations when scale advection becomes a dominating factor, the fluctuations in the local concentrations of PM_{10} are significantly synchronized, which allows one to use its mean urban concentration in analyzing the effect of atmospheric processes.

3.2. Comparison of Thermal Stratification and Wind Shears in the ABL with Surface-Air Pollution under Unfavorable Meteorological Conditions

Unlike local short-term fluctuations in the concentrations of pollutants (which are determined by local sources), the total increase in the level of urban pollution is usually caused by the slowed processes of atmospheric self-purification under the so-called unfavorable meteorological conditions (UMCs). The set of UMCs for a region is determined from relations between weather patterns and pollutant concentrations; this allows one to forecast (of 2–3 days) the episodes of high-level pollution on the basis of only atmospheric circulation and meteorological parameters. In addition, the UMC parameter can be used in verifying numerical predictions of air pollution [13].

According to our estimates, in the region of Moscow, one of the consequences of the blocking anticyclone of summer 2010 was an almost twofold increase (compared to typical summer weather) in the frequency of episodes with UMCs. Four UMC episodes with pollutant concentrations 2–3 times exceeding the background level were observed before the invasion of the products of forest combustion. A high concentration of PM_{10} was a distinguishing feature of the episode in the late June: over four days (June 23–26) the daily mean concentration of PM_{10} exceeded the maximum permissible concentration (MPC_{dm}) 50 μg m^{-3}. This is very rare for Moscow; a similar situation was observed in August 2007, when air masses arrived from the regions of peatbog fires [9].

According to data given in [4], on June 23–25 (measurements were not taken on June 26), the atmospheric aerosol concentration proved to be comparable to that observed on some days of forest fires in summer 2010. This atypical episode started on June 23 with an increase in the PM_{10} concentration (in contrast to the normal daily cycle) at about noon at all monitoring stations (Fig. 1). However, relative to all meteorological parameters, the meteorological conditions unfavorable for air purification had emerged only by the evening of June 24. This gives grounds to suggest that the episode of high-level aerosol pollution under consideration was influenced by both local and external sources.

On June 24, the PM_{10} concentrations were high at all monitoring stations: 70 ± 20 μg m^{-3} (at a background level of 30–40 μg m^{-3}; see Fig. 1 for June 21). In this case, at night, a pronounced advective transport of pollutants with a velocity of 5 to 10 m s^{-1} was observed in the stably stratified ABL (Fig. 2), and, in the daytime, convective mixing was observed within a layer of more than 2 km in depth with a decrease in the velocity of southeasterly winds to 3–5 m s^{-1}.

The results of a trajectory analysis showed that the PM_{10} concentration increased in the air masses transported from the lower reaches of the Volga and the Caspian Sea, where a strong soil drought was observed early in this summer [14]. Radiosounding data showed that the relative humidity of arriving air masses was very low: for the most part, 20–30% for June 23–26 (10% for June 24) at a temperature typical for southern latitudes (for example, 22–26°C for an isobaric surface of 925 hPa). Moderate wind velocities in the lower troposphere (about 10 m s^{-1}) and mesojet streams at the periphery of the anticyclone in the absence of precipitation created most favorable conditions for the long-range transport of soil aerosol from southern to central Russia. In this case, aerosol could be transported at a distance of about 900 km per day.

Some anomalies in the air-temperature profiles according to MTP-5 measurement data indirectly imply that the arriving air masses contained a significant amount of aerosol. Note that, at night and in the morning, the temperature of the unpolluted air at

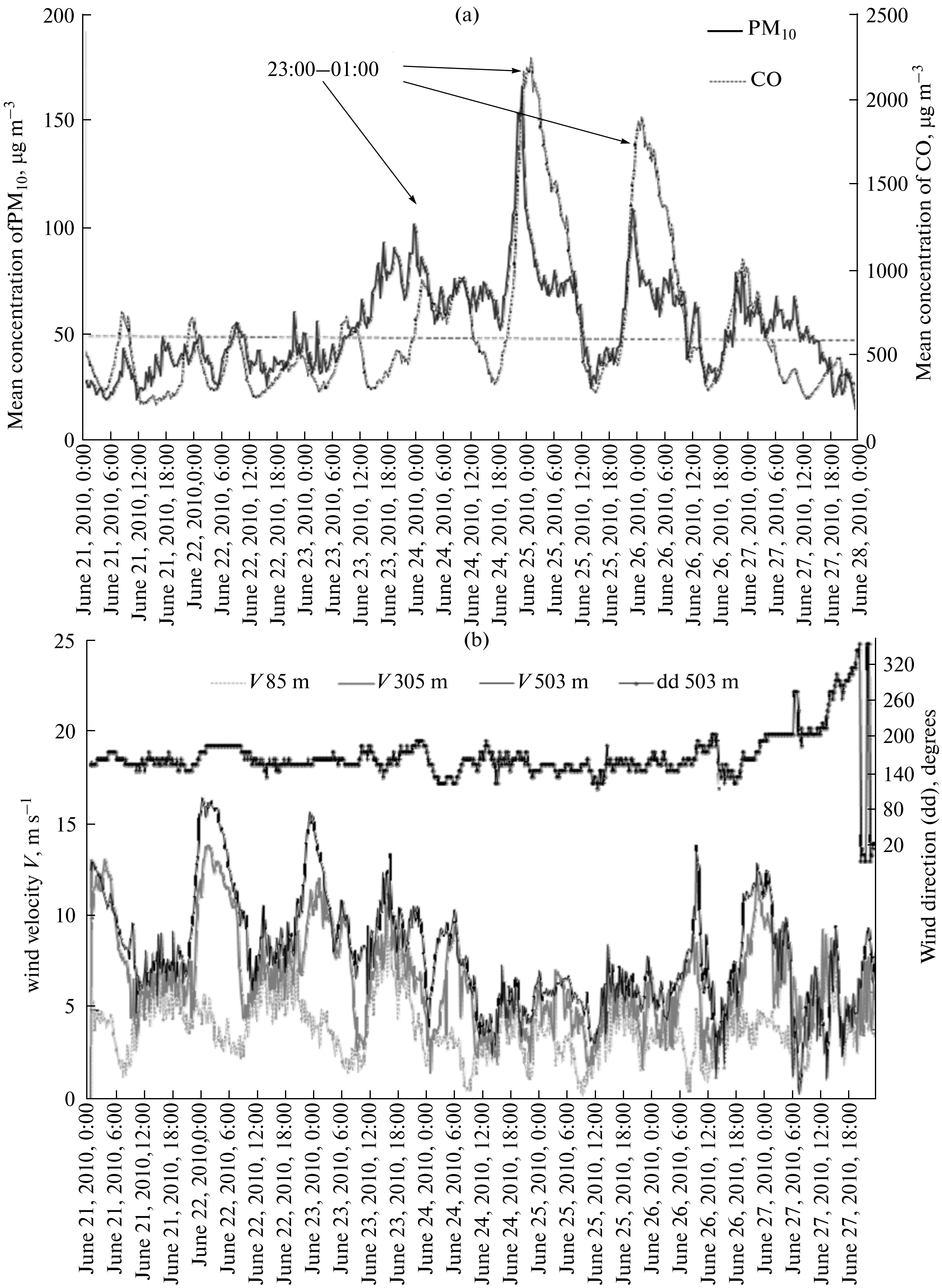

Fig. 1. (a) Urban mean concentrations of PM_{10} and CO and (b) wind velocity and direction in the lower 500-m air layer according to measurements taken from the Ostankino TV tower on June 21–27, 2010.

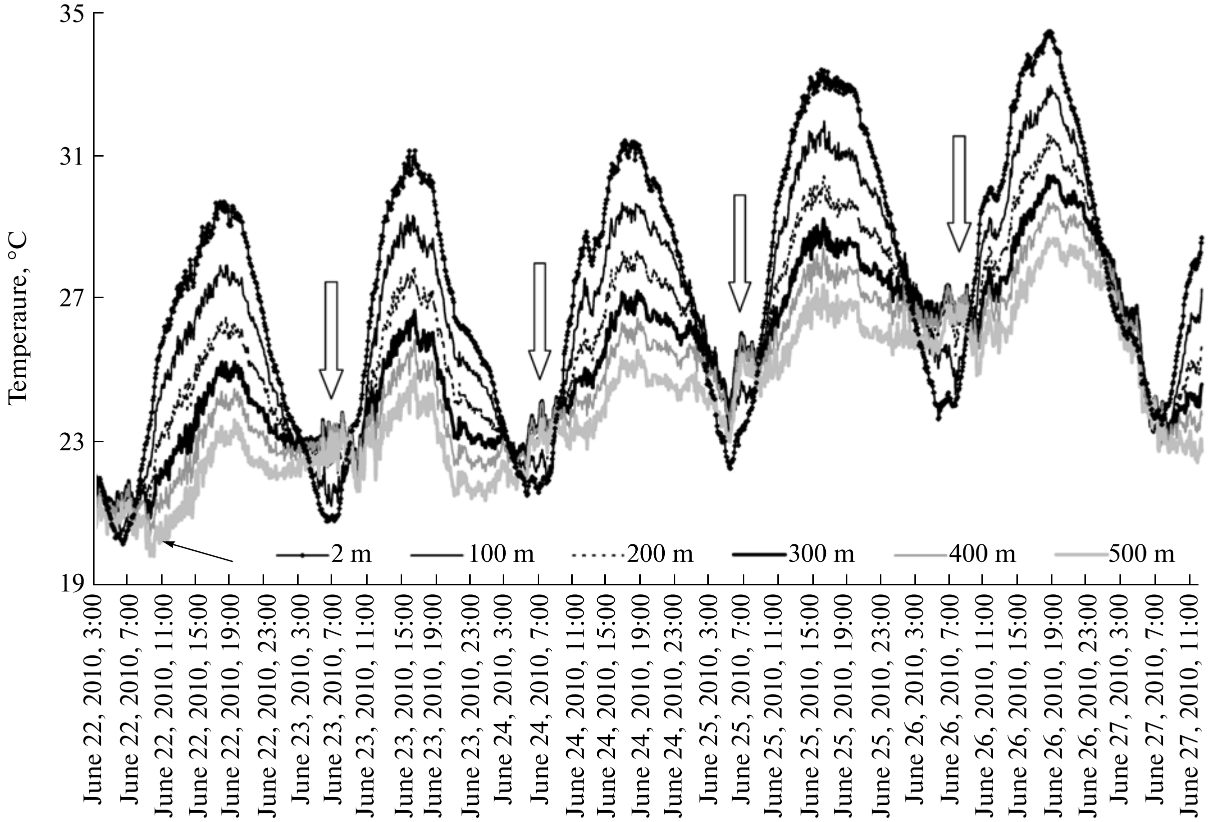

Fig. 2. Temperature at different heights within the air layer 0–500 m over the center of Moscow according to the MTP-5 data obtained on June 22–27, 2010 (the thin arrow shows a characteristic decrease in the temperature within an air layer of 300 to 500 m and the wide arrows show the air-temperature increase during the pollution of this layer).

heights of 400 to 600 m almost does not change and, at about 10:00 (in summer), it decreases almost by 1°C (thin arrow in Fig. 2 for June 22) due to its mixing with colder air masses at higher levels under a convective "burst" into the ABL [15, 16]. In the episode under consideration, an hour after the sunrise, the air layer of 250 to 600 m started to abnormally heat up and continued to heat until the adiabatic gradient was established in the lower ABL. The anomalous air-temperature increase is shown in Fig. 2 (wide arrows) in the form of "morning humps." It is seen that the heating was stronger by 1.5°–2°C at heights of 400 to 600 m than at the height of the upper boundary of radiation inversion (about 300 m). Similar phenomena at the sun's lower altitudes (20°) are described, for example, in [17], and they are associated with the shortwave-radiation absorption by soil aerosol transported from the southeast. The effects of heated air layers elevated over the land surface were observed earlier in Moscow at a high level of air pollution and during the transport of combustion products in the summer of 2002 [16, 18].

During the episode under consideration, the highest concentrations of PM_{10} were observed in the windward eastern sector of this region. The differences in the concentrations of PM_{10} between the stations were significantly smoothed at a transport velocity of 6 to 10 m s^{-1} in the ABL and increased at a velocity of 3 to 5 m s^{-1} (Fig. 1). In this case, the most significant differences in the concentrations of PM_{10} between the urban and suburban stations were observed from 21:00 to 24:00, when the temperature-inversion zone was transferred from suburbs to the city center. This process is reflected by the vertical gradients of the temperature of the surface air layer (2–100 m) on the days of UMCs with the highest concentrations of PM_{10} (June 25 and 26), which are shown in Fig. 3 (arrows indicate the time of formation/collapse of inversions).

On the night of June 24 to June 25, the peak of the PM_{10} concentration was observed at 23:00–24:00, when the temperature inversion was formed in the city center (Fig. 3) and, in the lower 300-m air layer, the southeasterly wind subsided to 1–3 m s^{-1} (Fig. 1). For various reasons, we can only make assumptions of the factors that determined the near-midnight peak of the PM_{10} concentration. On the one hand, there are no good reasons to state that this evening increase in the PM_{10} concentration was caused only by local emissions, because such a significant sudden increase in the PM_{10} concentration was not observed in other episodes with UMCs. Even the day before, on the night of

June 24, at a pronounced advective pollutant transport in the ABL, no similar peak was observed under temperature inversion. It is also impossible to estimate the contribution of nucleation or formation of secondary aerosols to this significant increase in the PM_{10} concentration, although the formation of condensation nuclei is pointed out in [4]. If we take into account that this increase in the concentration of PM_{10} changed into its decrease when shears occurred in the wind-velocity profile at about 1:00 a.m. (Fig. 3), the most probable cause of this increase in the surface concentrations of PM_{10} could be the sedimentation of aerosol accumulated in the inversion layer at a calm in the air. It should also be taken into account that, when the PM_{10} concentration started to decrease, the CO concentration determined by surface sources continued to increase (arrows at the top of Fig. 1) until the shearing instability of the wind velocity occurred, which, apparently, played a crucial role in the night variations in the concentrations of both aerosol and CO. On June 25, from 1:00 to 3:00 a.m., a wind shear was observed in the vicinity of the inversion boundary (downward arrow in Fig. 3). Evidently, under such conditions, the concentration of PM_{10} in the surface air decreased due to the entrainment of the above-inversion air, which is less polluted than the air within the inversion layer. When the wind shears vanished (at about 3:00 a.m.) under the stable stratification of the ABL, the concentration of PM_{10} almost did not change over the following 6–7 h and remained high and comparable to its daylight level of June 24. This implies that, the factor of the long-range transport of aerosol at that night dominated over both condensation and coagulation processes, resulting in a decrease in its concentration. The conditions for aerosol advection remained favorable: a wind velocity of 5–6 m s^{-1} dominated up to 6:00 a.m. in the air layer of 200 to 400 m and, later, due to a wind-velocity decrease at a height of 300 m, two local maxima were formed in the wind-velocity profile at heights of around 200 and 400 m (horizontal arrow in Fig. 3). Consequently, the absence of the night dynamics of the surface concentration of PM_{10} after its peak vanished could be due to the inflow of aerosol from above under the conditions of thermal stability and wind shears in the inversion layer. It is important to emphasize that such a state of the night ABL (turbulent mixing due to shearing instability) hindered the accumulation of CO: the morning maximum of carbon monoxide (which is characteristic of the city) was not formed because of dilution with clean air.

After night stabilization, the PM_{10} concentration started to rapidly decrease only after the dissipation of wind shears and the destruction of temperature inversion in the suburb when the mixing layer reached 500 m (at about 10:00 a.m.) in the center of the megapolis. Due to active convection in the daytime, the PM_{10} concentration decreased to a value that is characteristic of the megapolis.

The noted relation between the level of the PM_{10} concentration and wind shear in the night stable ABL was confirmed by an analysis of the processes that occurred on June 26. Due to aerosol advection, at wind shears up to 3–4 m s^{-1}, a high level of PM_{10} concentration (50–100 μg m^3) was observed at night within the layer of radiation inversion (Figs. 1–3). Like on the day before, the CO level only decreased at night and in the morning. One distinctive feature of June 26 was that, during the formation of radiation inversion, the wind was slightly stronger (no calm was observed) and this, apparently, did not allow the near-midnight peaks of the CO and PM_{10} concentrations to reach the levels of the previous night. The episode of high aerosol pollution ended with the southeasterly-to-southwesterly change due to an approaching atmospheric front.

The results of sodar measurements of the vertical structure of wind at spaced sites in the region of Moscow show that the megapolis affects the transport of air masses in the ABL [19]. There is no doubt that the high-altitude data obtained at one of the sites cannot reflect the full-scale pattern of the evolution of the wind-velocity field in the night urban ABL. However, even the results presented indicate that the little-studied mechanism of shearing instability seems to significantly affect the dynamics of atmospheric pollution in the megapolis; this mechanism can explain some situations when no significant increase is observed in the surface concentrations of pollutants emitted by quasi-regular urban sources in the presence of temperature inversion.

3.3. Pollution Extrema Caused by Meteorological Conditions during Fires

An extreme amount of air pollution was observed in the region of Moscow on August 2–10, 2010. This episode is of interest because significant intra- and interdiurnal variations in the surface concentrations of PM_{10} and CO—the markers of fire products—were observed under the conditions of scale smoke generation. The observed pronounced synchronization of variations in the mean urban levels of the concentrations of PM_{10} and CO indicates that the factors forming their surface concentrations are common; in this case, these factors are the advection of pollutants and thermodynamic processes in the lower atmosphere.

In Moscow, this extreme air pollution started with a slow increase in the concentrations of pollutants (Fig. 4) on the night of August 2 during the northeasterly-to-southeasterly change. A radiation inversion of 5–7°C (Fig. 5) did not hinder an increase in the concentrations of PM_{10} and CO in the surface air layer. Towards the morning of August 2, the upper inversion boundary was at heights of 600 to 700 m; below, a low-level jet stream (LLJS) with a velocity of 9–10 m s^{-1} was formed and became a transporter of pollutants from the region of fires. The temperature fluctuations

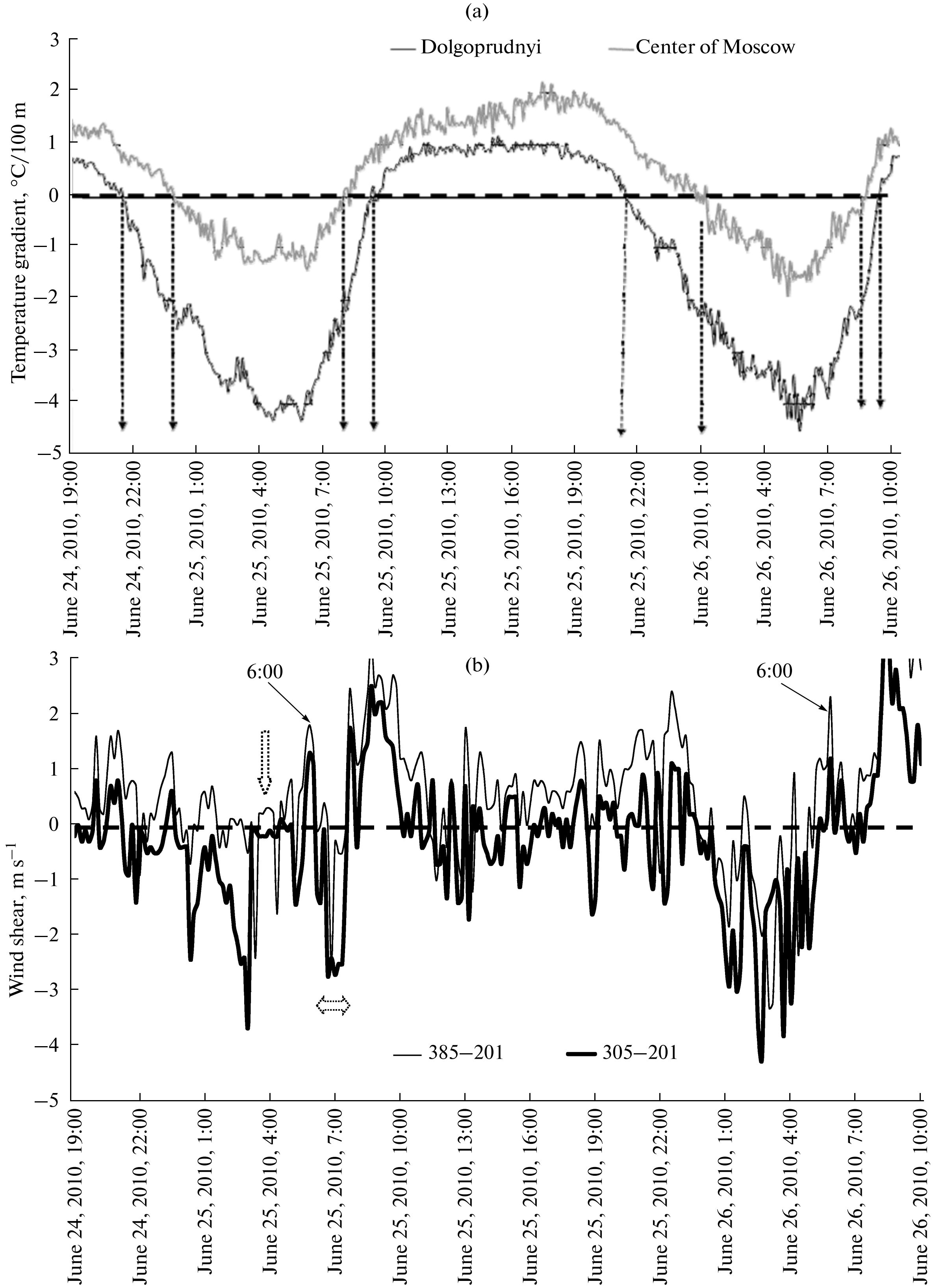

Fig. 3. (a) Temperature gradient within the air layer 0–100 m according to MTP-5 data for the center of Moscow and its northern suburbs and (b) wind shears according to measurements taken from the Ostankino TV tower at heights of 201, 305, and 385 m on the days with maximum pollution (June 24–26, 2010).

(measured with MTP-5 profilers) in the layer of 400 to 500 m (figured arrow in Fig. 5) suggest mixing within the LLJS.

At about 11:00 a.m., the level of air pollution reached peak values and proved to be 10 times higher than the day before; this occurred after a convective burst into the ABL (the thin arrow at the bottom of Fig. 5 indicates a vertical temperature gradient higher than 0.98°C/100 m). The following rapid decrease in air pollution was due to the fact that the direction of the air-mass transport changed to southwestern. In the evening, a soft atmospheric front with an increase in the wind velocity within the ABL up to 15–18 m s^{-1} passed over Moscow (Fig. 4). The southwesterly-to-northwesterly change caused an inflow of clean air, and the content of pollutants approached their normal level. On August 3, approximately at 6:00 a.m., the wind velocity within the ABL decreased to 1–2 m s^{-1}; 1 h earlier, a radiation inversion emerged, which, in the suburbs of the city, remained approximately up to 10:00 and reached 4°C. A weak (up to 1°C) raised inversion with the lower boundary at heights of 100 to 150 m was observed in the city. Evidently, when the air was calm, such a thermal structure proved to be favorable for the accumulation of urban pollutants within the subinversion layer. The PM_{10} and CO surface concentrations ceased to increase at about 11:00 after the destruction of inversion; however, in the daytime, the air was not significantly purified, apparently due to the occurrence of the southeasterly wind.

With an increase in the velocity of this wind, the air pollution rapidly increased in Moscow on the night of August 4. The air-pollution peak was observed during the existence of the LLJS with a maximum velocity of 10–12 m s^{-1} at a height of about 350 m in the stably stratified ABL. Significant air-temperature fluctuations according to MTP-5 data (figured arrow in Fig. 5) testify that there is shear turbulence within the LLJS zone. The air-pollution level continued to increase while vertical wind shears existed (up to 7:00 a.m.). That night, in addition to the LLJS, the local maxima of wind velocity were observed at heights of 1.2 km (10 m s^{-1}) and 1.9 km (13 m s^{-1}).

In the daytime, a mesojet stream with an axis velocity of 12 m s^{-1} remained only in the upper part (higher than 1.5 km) of the thermally unstable ABL. The surface-air pollution slightly decreased; however, in the air mass full of combustion products, the concentrations of pollutants were still high.

The following increase in the surface-air pollution (on August 5 at about midnight; see Fig. 4) was apparently due to the transport of pollutants from the upper ABL: this increase concurred with the local maxima of wind velocity up to 8–10 m s^{-1} in the inversion layer. However, later, when smoke-free air masses arrived from the southwestern sector (180–230°), at a wind velocity of 5–7 m s^{-1} in the lower ABL from 11:00 to 19:00, the contents of pollutants in the surface air were close to their background levels (Fig. 4).

On August 6 and 7, the extremely high air pollution in Moscow was undoubtedly due to the approaching sources of fires; however, the decrease in the wind velocity was the deciding factor: on August 6, the wind velocity decreased to 1–2 m s^{-1}, first, in the lower troposphere, and, on the night of August 7, there was a calm in the 10-km air layer. The power of anticyclone controlling the situation can be judged by the fact that, on these days, the tropopause rose to a height of 12 km. The record high concentrations of PM_{10} and CO were observed on August 7 under a more powerful (than usual) inversion (up to 7°C) which emerged the day before at 19:00 and remained almost up to the noon (oval contour in Fig. 5). The absolute maximum of surface-air pollution was observed at a full calm during the destruction of inversion (at about 12:00). Under the conditions of smog, the effect that pollutants have on processes occurring within the ABL was more clearly pronounced in increased thermal stability. In the daytime, the pollution level decreased 2–3 times, but it remained extremely high.

On the following days (August 8 and 9), like on August 7 the PM_{10} and CO peaks were observed at about noon (11:00–12:00) after the destruction of surface inversion and the anticipatory dissipation of shearing instability. At night, when the humidity increased in the surface air layer, the high pollution level was determined by the imbalance of the processes of aerosol removal (due to coagulation, condensation, sedimentation, etc.) and pollutant advection. The last significant rapid increase in the level of air pollution was observed on the night of August 10 with an increase in the velocity of air transport in the lower troposphere to 10–13 m s^{-1} (Fig. 4) before the passage of an atmospheric front in the evening of the same day. After its passage, the wind changed to southwestern and an air mass whose temperature was 5°C lower arrived in this region; the surface-air pollution level rapidly decreased.

3.4. Variations in the ABL Thermal Characteristics during Fires

The results of studying the radiation properties of the atmosphere during the fires of summer 2003 in Western Europe showed that, over the regions of forest fires at heights of 1 to 3 km, the air temperature noticeably increases and the atmospheric stability intensifies [17, 20]. One of the consequences of the effect that the severe air pollution of summer 2010 had on radiation processes in the ABL was the specific variation in the characteristics of temperature inversions: their duration (when compared to the ordinary one [15]) increased almost by a factor of 2 (up to 6–8 h in the center of Moscow and 10–14 h in its suburbs); in this case, no significant anomalies in their values were noted. Another indicator of the air-pollution effect is a decrease in the heat island over Moscow. In August 2010, the surface-temperature gradients between the

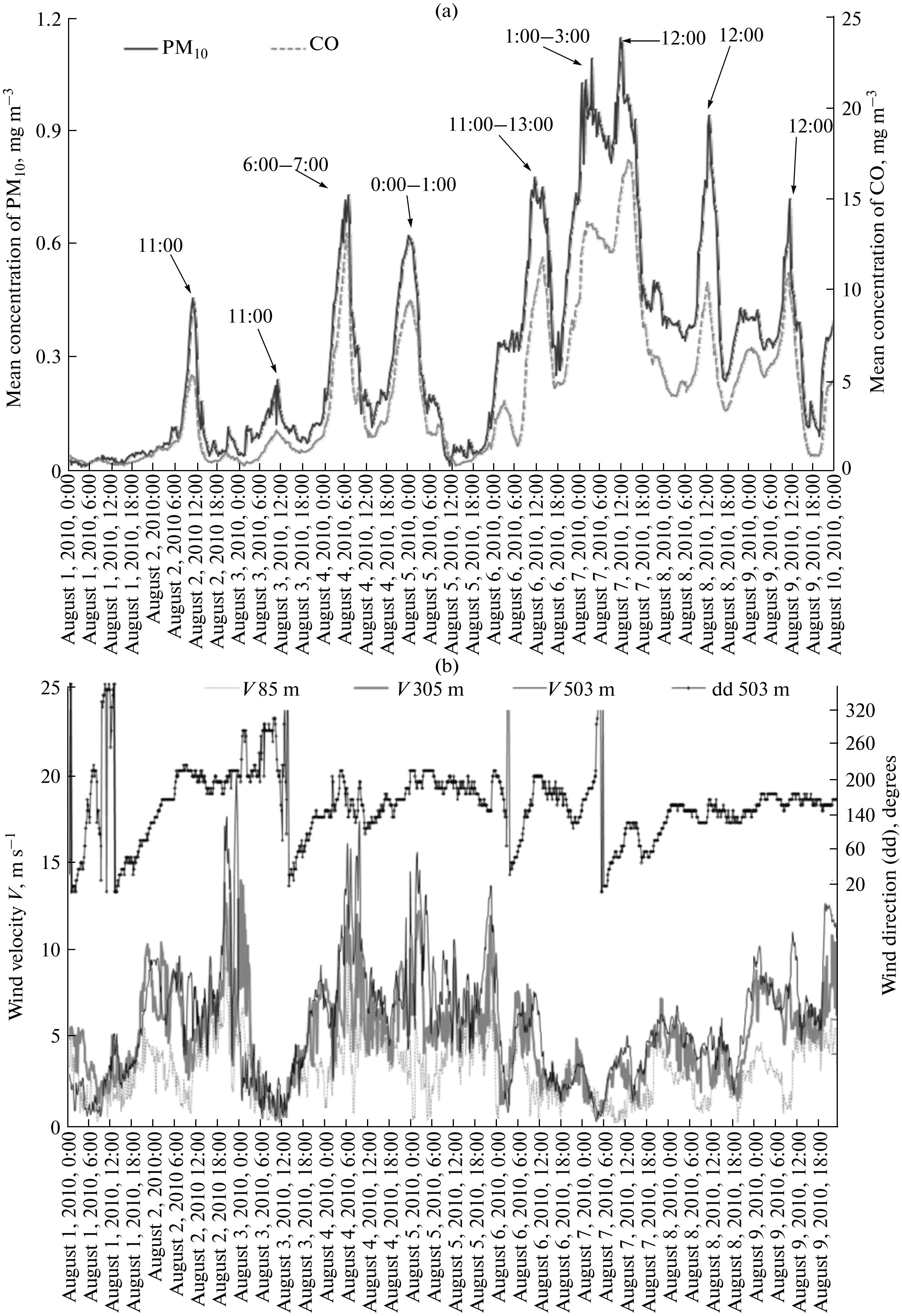

Fig. 4. (a) Urban mean concentrations of PM_{10} and CO and (b) wind velocity and wind direction in the lower 500-m air layer according to measurements taken from the Ostankino TV tower on August 1–10, 2010.

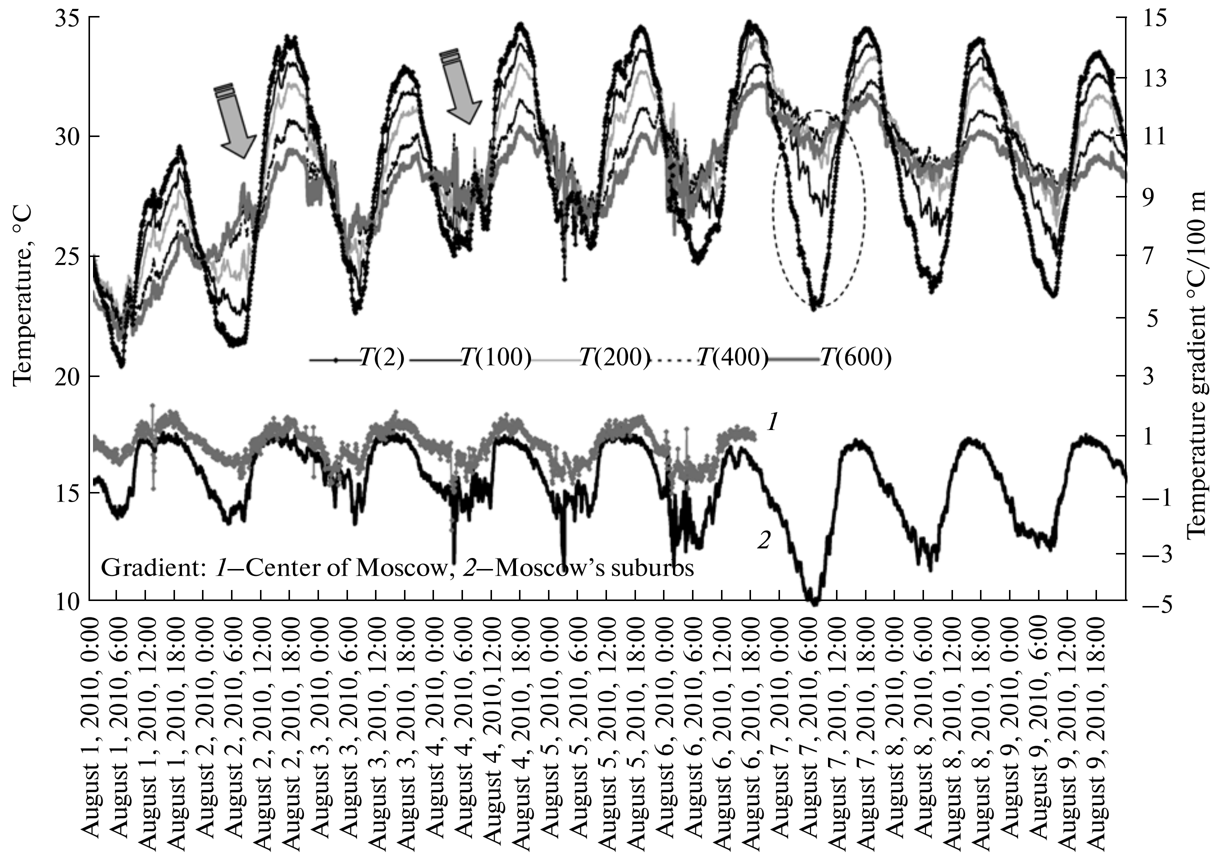

Fig. 5. Temperature within the air layer 0–600 m according to MTP-5 data for Moscow's northern suburbs at an extremely high level of air pollution in the region of Moscow (top). Temperature gradients in the air layer 0–100 m (bottom) for the suburbs of Moscow and for its center (data sequence discontinued because of instrument failure on the hottest day).

center of Moscow and its suburbs proved to be smaller than ordinary ones almost by a factor of 2, which, apparently, resulted in an attenuation of the positive (under ordinary conditions) heat-island function: to stimulate the processes of air purification from pollutants through the formation of local circulations and the activation of convective processes [16, 21].

An additional heating of the lower atmosphere due to the pollutant absorption of radiation caused a decrease in the vertical gradients of air temperature, i.e., an increase in the ABL thermal stability. One can suggest that, in August, in the suburbs of the megapolis, the increased thermal stability partially had a positive effect, because the attenuation of thermal vertical mixing to some extent decreased the inflow of pollutants from the upper ABL. Conversely, within the megapolis, the convection intensified due to the heat accumulated by the city only increased the inflow of pollutants from smoke plumes. Apparently, the inhabitants of Moscow were more exposed not only to hyperthermia (than those living in its suburbs), but also to atmospheric pollutants whose concentrations increased due to urban emissions and the products of photochemical reactions proceeding in the more polluted atmosphere.

4. CONCLUSIONS

For two summer episodes with high levels of air pollution in 2010, both interdiurnal and short-term variations in the surface concentrations of PM_{10} and CO were analyzed using the results of combined observations, including Mosekomonitoring data on the concentrations of pollutants and data from remote measurements of both temperature (with MTP-5) and wind profiles in the lower 500-m air layer (Ostankino).

It is assumed and substantiated that in the late June, the severe aerosol pollution of the atmosphere over Moscow was caused by a long-range aerosol transport. The maximum concentrations of PM_{10} were observed at about midnight with a weak wind and radiation inversion. Such a high level of the PM_{10} concentration in the night thermally stable ABL was apparently caused mainly by an aerosol inflow from the upper polluted air layer due to shear turbulence. In the daytime, the convective mixing caused an increase in the concentration of PM_{10} (June 23 and

24) at a moderate wind velocity in the ABL and a decrease in its concentration (to normal values) at a weak wind (June 25 and 26).

It is shown that, in August, with the advection of the biomass-combustion products during the natural fires, the maximum surface concentrations were observed mainly at 11:00–12:00 under a convective burst into the ABL and at night in the presence of local wind-velocity maxima or low-level jet streams within the inversion layer. The daylight convection due to the entrainment of less polluted air masses from the upper ABL caused almost a twofold decrease in the night level of pollution within the surface air layer (August 2–4 and 6–10). On August 6 and 7, an extremely high level of surface-air pollution was observed in Moscow when there was a calm in the thermally stable lower troposphere.

It follows from an analysis of these two episodes that, in the night thermally stable ABL, the shearing instability intensifies vertical mixing and, under ordinary conditions, favors surface-air purification. At night, in the presence of LLJSs, the morning pollution maximum caused by the peak of urban emissions significantly decreases or does not manifest itself. During the advection of pollutants (long-range transport and natural-fire plumes), the vertical wind shears (which accompany the night temperature inversion) can be an important mechanism of transporting pollutants from the upper ABL and an additional factor in increasing the concentrations of pollutants in the surface layer. In the episodes under consideration, the vertical wind shear was observed after the formation of radiation inversion and accompanied by an increase in the level of surface pollution; these wind shears dissipated more frequently before the destruction of temperature inversion.

During the forest fires, due to variations in the radiation balance under the influence of pollution, an increase in the ABL thermal stability and in the duration (but not the magnitude) of radiation inversions was observed, along with an attenuation of the urban heat island in Moscow.

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