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ATMOSPHERIC RADIATION, OPTICAL WEATHER, AND CLIMATE

Ground-Level Ozone as a Factor of Increase in Community-Acquired Pneumonia Rate in Moscow in Warm Seasons

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Abstract—Community-acquired pneumonia is among the most common acute infectious diseases. According to official statistics, pneumonia accounted for up to 50% of respiratory-disease mortality in the Russian Federation in 2005–2017. Ground-level ozone, being a key component of urban smog, is one of little-studied risks of community-acquired pneumonia. This work studies the effect of ground-level ozone on the rate of community-acquired pneumonia among Moscow residents in the warm season over a five-year period (2006–2009 and 2011). The study results have enabled us to conclude that ground-level ozone contributes to an increase in the community-acquired pneumonia rate among Moscow residents in summer. Daily average concentrations of ground-level ozone of 60–80 μg/m^3 can increase the community-acquired pneumonia rate by 30% compared to low-ozone periods, especially in combination with unfavorable weather conditions, such as high air temperature and low humidity. The results will help human ecologists and health care professionals to make the urban air safer.

Keywords: O_3, ground-level ozone, air pollution, health, morbidity, community-acquired pneumonia

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INTRODUCTION

Air pollution is one of leading global risk drivers of premature mortality [1]. Tropospheric ozone is a key component of urban smog; it is a secondary photochemical pollutant, and a strong oxidant. Ozone as a gaseous pollutant affects mainly human lungs. According to World Health Organization recommendations [2], the standard daily maximum 8-hr average (MDA8) ozone is 100 μg/m^3. Until March 2021, daily average maximum permissible (MPC_{da}) concentration of 30 μg/m^3 and maximum permissible one-time concentration of 160 μg/m^3 were accepted as ground-level ozone concentration (GOC) standards in the Russian Federation [3]. In March 2021, a new GOC standard was added to the existing ones according to WHO recommendations [4].

Compliance with MPC of harmful substances in the atmosphere ensures the necessary health protection. A number of studies have shown that even slightly increased ozone concentrations can result in disorder and injure of the respiratory system, for example, decreased lung function [5], epithelial lesion [6], airway hyperreactivity [6, 7], and inflammatory reactions [8]. Moreover, people with asthma [9, 10] and chronic obstructive pulmonary disease [11] usually experience disease exacerbation. Thus, stable positive correlations between GOC and bronchial asthma exacerbation were observed in all seasons in Simferopol [12]. It has been found that ozone can damage tissues and oxidative modify proteins, which can decrease the protective function of lungs and increase the susceptibility to respiratory infections [13]. Work [14] showed a significant correlation between GOC and the SARS-CoV-2 rate and mortality. Work [15] proved the positive effect of ozone on the dynamics of the COVID-19 pandemic, before a person is infected with SARS-CoV-2, since ozone is a disinfectant against airborne viruses, and an increase in its concentration is accompanied by a decrease in the amount of viruses in the surface air layer. An increase in ozone concentration negatively affects infected people, ultimately increasing morbidity and mortality. Taken together, these observations suggest that some people are particularly susceptible to this oxidizing gas.

Pneumonia is a group of acute infectious (mainly bacterial) diseases of different etiology, pathogenesis, and morphology, which are characterized by focal lesions of the respiratory system of lungs with obligatory intra-alveolar exudation [16]. Community-acquired pneumonia (CAP) is diagnosed if the disease develops outside a hospital or within the first 48 hours of hospitalization. It is one of the most common acute infectious diseases. According to official statistics, the average overall incidence of CAP was 433.8 cases per

100 thousand people in Russia in 2005–2017 [17]. The rate of pneumonia is small as compared to all respiratory diseases; however, the share of pneumonia in the mortality from respiratory diseases in the Russian Federation was up to 50% in the above period [18]. The causative agents of viral infections are different microorganisms: bacteria, viruses, fungi, and protozoa.

The literature describes many risk drivers for the development of CAP, including HIV, smoking, alcohol abuse, underweight, regular contact with children, poor oral hygiene, drugs, sedentary lifestyle, etc. [19–22]. However, the number of studies of the impact of air pollution, particularly with ozone, on the incidence of CAP is very few. Thus, the authors of work [23] estimated the short-term impact of air pollution on hospitalization of residents of Qingdao (China) with pneumonia and identified vulnerable groups. The results of the study showed that short-term increases in GOC were associated with increases in the cases of hospitalizations of urban residents for CAP compared with rural population. Work [24] showed the impact of air pollutants on acute respiratory diseases in outpatients. High O_3 concentrations positively correlated with outpatient visits due to asthma exacerbations and negatively correlated with visits due to acute respiratory viral infections, pneumonia, and bronchiectasis exacerbations was negative associated. Experiments with mice [25] showed hat ozone inhalation increased the degree of oxidation of surfactant protein A in the bronchoalveolar fluid of lungs, which deteriorated the immune protection and increased the susceptibility of the mice to experimental pneumonia.

The aim of this work is to estimate the effect of ground-level ozone on the rate of community-acquired pneumonia in a metropolis over a long time.

1. MATERIALS AND METHODS

The study was performed for Moscow and the Moscow region over a five-year period (2006–2009 and 2011); 2010 was excluded due to unprecedented air pollution in Moscow with smoke from forest and peat fires caused by very high air temperatures. The relationship between ozone air pollution and the CAP rate was studied in detail in [26] for summer 2010. GOC was measured out every 20 min at four Mosecomonitoring stations [27]: Mar'ino, Zelenograd 16, Spiridonovka, and Zvenigorod. Based on the data from each station, the daily average ($O_{3\_day\_av}$) and the daily maximal ($O_{3\_20\ min/max}$) ground-level ozone concentrations were calculated and averaged over four stations, thus providing the daily average and maximal one-time GOCs for the Moscow territory.

The number of cases of CAP was determined based on data from A.S. Puchkov Emergency and Urgent Medical Care Station of the Moscow Department of Health [28]. The network consists of 60 substations and 42 posts uniformly distributed over the city (including 20 posts on major highways and the Moscow Ring Road). In this work, we examine all cases of CAP in the adults (over 15 years old) without division by gender and age.

Meteorological data were provided by weather station no. 27612, VDNKh, Moscow [29]. The daily values of the following meteorological variables were analyzed: minimal (t_{min}), mean (t_{mean}), and maximal (t_{max}) air temperature, difference between the maximal and minimal air temperatures (dt), relative air humidity (Rh), dew point (Td), air pressure (P), wind speed (V), and total cloud amount (N).

2. RESULTS AND DISCUSSION

2.1. General Characterization of the Period Under Study

Figure 1 shows the annual variation in GOC and the total number of cases of CAP in Moscow residents averaged over the period under study. It is impossible to study the correlation between GOC and CAP over a long period of time, such as a year or even an individual season, because their annual courses are almost opposite, and a false positive or false negative correlation can be found. The only season when this study is justified is summer, when the rate of CAP is minimal, a seasonal trend does not show a clear increase or decrease, and GOC is maximal. In other seasons, the effect of air pollution on CAP rate is not so significant, although a short-term increase in CAP rate with along with the ozone concentration is pronounced even in average data series. In this work, we focus on summer months.

Table 1 includes average values of meteorological variables and GOC over June–August of each year. The average over the period $O_{3\_day\_av}$ was slightly above $1MPC_{da}$. High temperatures and maximal air pollution were observed in 2011. In summers 2006, 2008, and 2009, air temperatures and GOCs were lower than the averages over the period under study. The values in summer 2007 were close to the average over the selected period.

2.2. Effect of Ozone on the Incidence of Community-Acquired Pneumonia in Moscow

The peaks of air pollution and rate of CAP in population are spaced in time. Therefore, we averaged the variations in the parameters by the moving average method over 11 days. Here, we consider the variations in CAP rate and maximal GOC in summer 2007 as a typical summer for Moscow in terms of all the parameters under study (Fig. 2). One can see that both parameters were stable, without sharp changes, from June 1 to August 9. After August 10, they started sharply growing, with a 5-day delay between the $O_{3\_20\ min/max}$ and CAP rate peaks. The peak CAP rate was

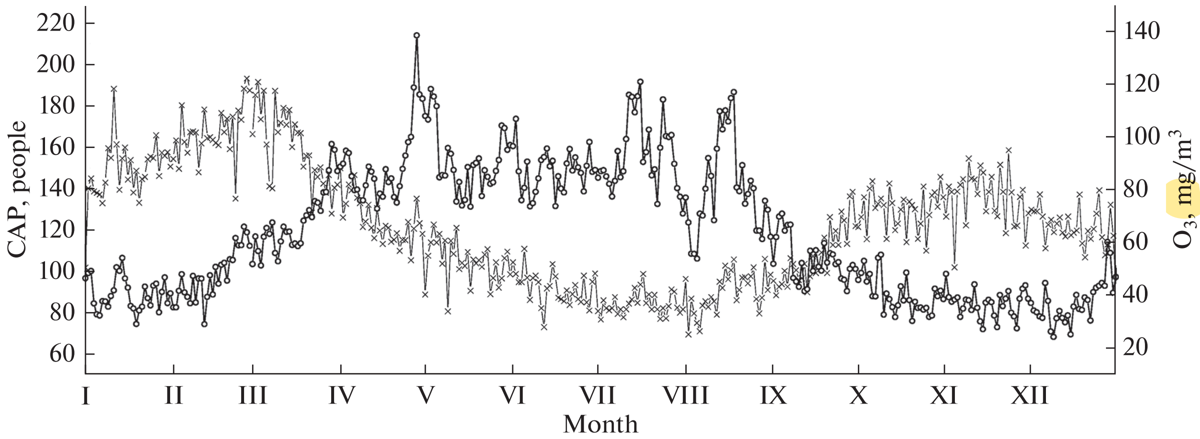

Fig. 1. Annual variations in the daily maximum ground-level ozone concentration (black curve) and the number of CAP cases (gray curve) among Moscow residents averaged over the period under study.

30% higher than the average over the first half of summer. The decrease in the parameters was also synchronous.

Figure 3 shows the dependence of CAP cases on the daily average and daily maximal GOCs throughout the period under study. A nonlinear relationship between these parameters is seen in Fig. 3a, where we can conventionally mark out three regions: 1) $O_{3\_day\_av}$ < 30–40 μg/m^3, which corresponds to MPC_{da} (standard until 2021), with a Pearson correlation coefficient of 0.15; 2) 40–60 μg/m^3 (up to $2MPC_{da}$), where the dependence becomes linear, but points are strongly scattered and the number of CAP cases moderately increases, by 10% on average compared to the first region; 3) $O_{3\_day\_av}$ > 60 μg/m^3, where points group around the trend line and the number of CAP cases significantly increases, by 30% on average compared to the first region. The Pearson correlation coefficient between the number of CAP cases and the daily average GOC was 0.44 at a significance level of 0.001 for regions 2 and 3.

In Fig. 3b, the relationship between the parameters under study is near linear. We can conventionally mark out two regions: 1) $O_{3\_20\,min/max}$ < 105 μg/m^3 (the num-

Table 1. Summer average values of used parameters

Parameter	Year					
	all	2006	2007	2008	2009	2011
O_{3_da}, μg/m^3	**44.04**	33.11	45.58	39.87	35.10	53.93
$O_{3\_20\,min/max}$, μg/m^3	**92.05**	73.74	97.69	81.92	69.48	112.02
t_{min}, °C	**13.96**	13.15	13.62	12.97	12.70	14.92
t_{mean}, °C	**19.01**	17.90	18.86	17.43	17.26	20.40
t_{max}, °C	**24.18**	22.90	24.05	22.26	22.05	25.94
dt, °	**10.21**	9.75	10.44	9.28	9.35	11.02
Td, °C	**13.64**	13.19	13.05	13.22	12.99	14.13
Rh, %	**73.66**	75.92	71.34	78.18	77.76	70.57
P, hPa	**994.80**	996.08	993.25	992.65	995.97	994.94
V, m/s	**1.03**	0.98	1.09	1.10	1.02	1.11
N	**6.07**	6.61	5.39	6.75	6.76	5.39
CAP, people	**102.38**	78.08	81.09	90.39	92.23	103.65

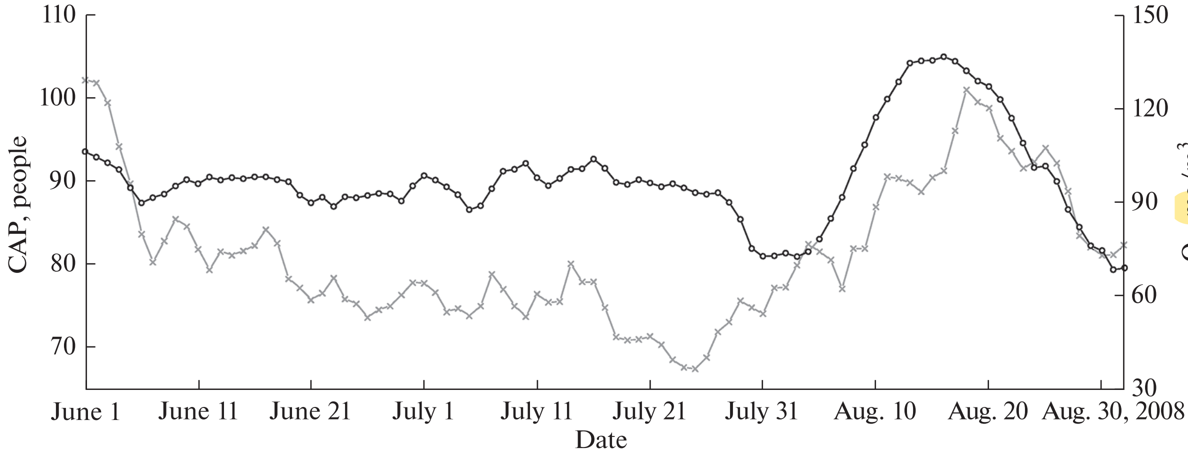

Fig. 2. Daily maximum GOC (black curve) and CAP cases (grey curve) in summer 2007.

ber of CAP cases slight increases with ozone concentration); 2) > 105 μg/m^3 (the number of CAP cases is higher by 20% than that in the first region). The Pearson correlation coefficient between the number of CAP cases and $O_{3\_20\ min/max}$ amounted to 0.48 at a significance level of 0.001. The results witness that the MPC of ground-level ozone should not be increased in regulatory documents.

Our results well agree with other studies. In work [30], one of causative agents of CAP *K. Pneumoniae*

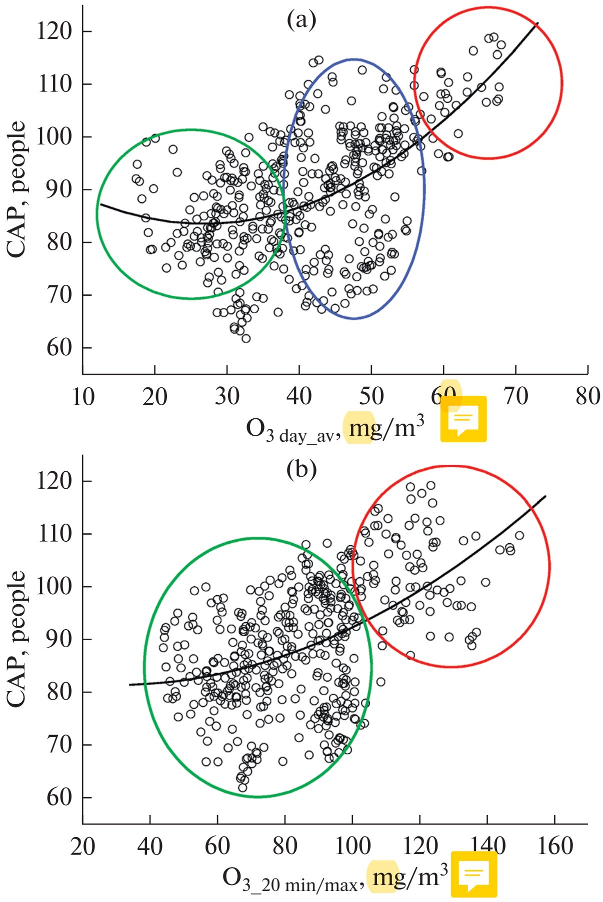

Fig. 3. CAP cases versus (a) daily average and (b) daily maximal ground-level ozone concentrations.

was detected in a control group of patients mainly due to their exposure to ozone with an 8-hour average concentration of >80 μg/m^3, especially within past six days. The authors of [31] showed a strong correlation between ozone and the number of ambulance calls at the daily average GOC above 60 μg/m^3 in Vyatskiye Polyany town in Kirov Oblast. In [32], upon GOC attained 80 μg/m^3, average increase of 0.5% in respiratory disease incidence with every 20 μg/m^3 of increase in O_3 was found in Almaty and Nur-Sultan cities.

2.3. Dependence of Ground-level Ozone Concentration on Meteorological Variables

Ground-level ozone positively or negatively correlate with certain meteorological variables [33–35]. The strongest positive correlation is between ozone and air temperature. High air temperatures lead to a sharp increase in the amount of volatile organic compounds, which participate in intense photochemical generation of ozone, in air [36]. Let us analyze the dependence of GOC on some available meteorological variables (Fig. 4), particular, air temperature (Figs. 4a–4c), relative humidity (Fig. 4d), dew point (Fig. 4e), and the total cloud amount (Fig. 4f). Other meteorological variables do not affect the ground-level ozone concentration in Moscow in summer.

The total cloud amount indirectly affects the ozone concentration. The photochemical factor is the main one in generation of tropospheric ozone [36], and the incoming total solar radiation increases at a low cloud amount.

2.4. Effect of Meteorological Variables on the Incidence of Community-Acquired Pneumonia in Moscow

All processes in the atmosphere jointly affect the human body, and some of them enhance the effects of others. The question of estimation of the effect of each individual component is of high scientific interest. To differentiate the effects of different meteorological factors and air pollution on the incidence of CAP in city residents, an additional study was conducted.

Figure 5 shows the dependence of the number of CAP cases on meteorological factors. The points are strongly spread and, despite the presence of a trend, it is difficult to talk about a reliable dependence, though the points convergence of to the trend line at extreme values of air temperature (Figs. 5a–5c), relative humidity (Fig. 5e), and dew point (Fig. 5f).

In view of the strong correlations between these meteorological variables and GOS, we can conclude that adverse weather conditions in combination with high air pollution can increase CAP incidence. Groups of points corresponding to low air temperatures and dew point, but a high number of sick citizens

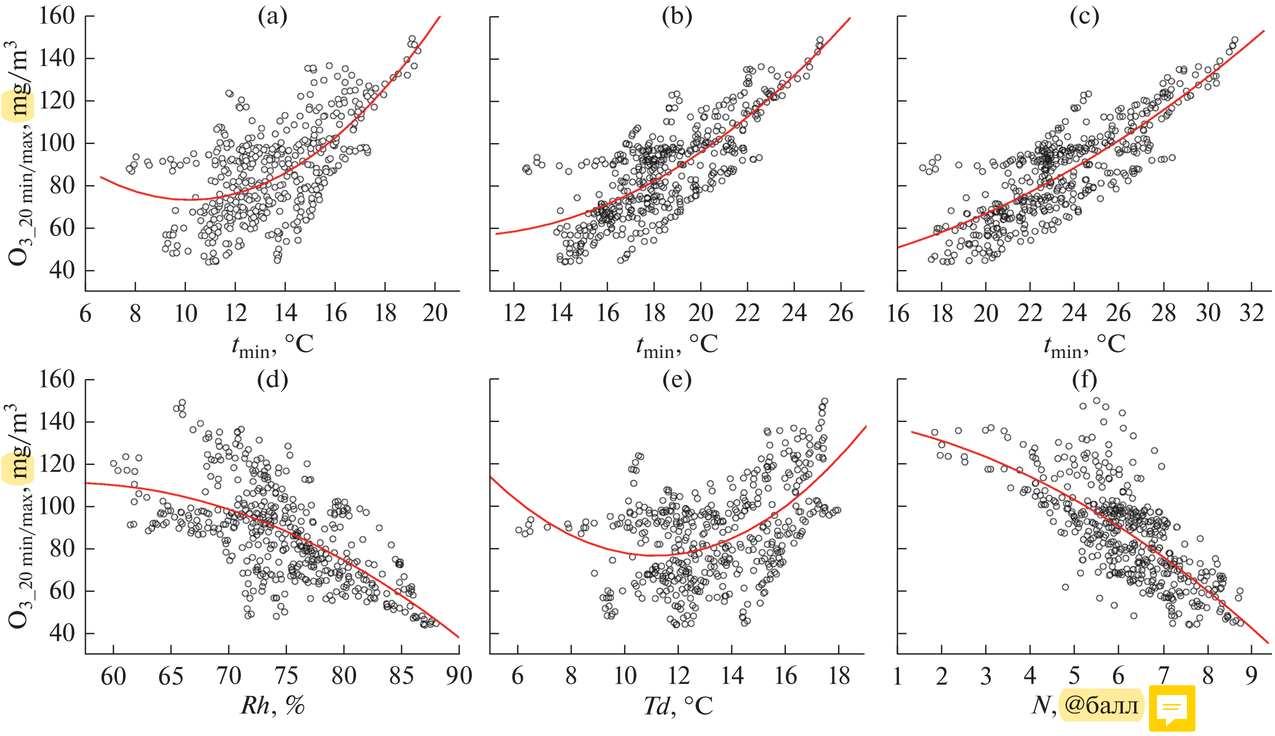

Fig. 4. Dependence of ground-level ozone concentration on (a) daily minimal, (b) daily mean, and (c) daily maximal air temperature, (d) relative air humidity, (e) dew point, and (f) total cloud amount.

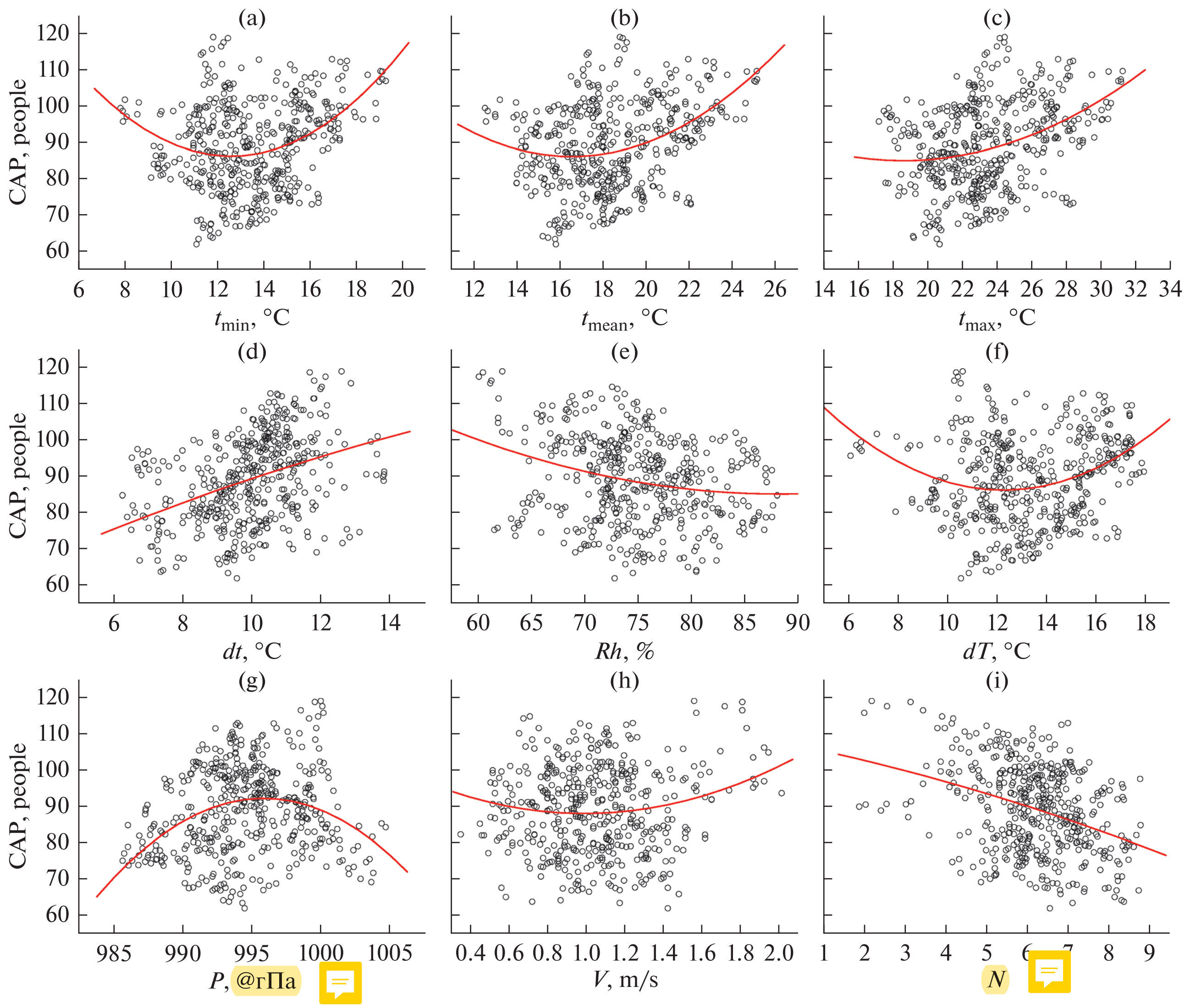

Fig. 5. Ground-level ozone concentration versus (a) daily minimal, (b) daily mean, and (c) daily maximal air temperature, (d) daily difference between maximal and minimal air temperature, (e) relative air humidity, (f) dew point, (g) air pressure, (h) wind speed, and (i) total cloud amount.

are seen in Figs. 5a, 5b, and 5f. Low values of these meteorological variables in Figs. 4a, 4b, and 4e correspond to high values of air pollution with ozone. Thus, we can conclude that the main reason for the CAP incidence among Moscow residents in the summer was air pollution.

The comparison of our data with the results of similar studies presented in the literature is a difficult task, since other authors usually analyzed an annual period neglecting account seasonal trends. For example, work [37] studied the effect of weather factors on the number of ambulance calls for respiratory diseases in the city of Petrozavodsk. A significant negative correlation between CAP and low cloud amount was found for warm months. No correlation was found between other meteorological factors and ambulance calls. This can be due to the fact that the work examined only monthly average values of the variables.

CONCLUSIONS

Our results have shown that an increase in ground-level ozone concentrations (especially in combination with unfavorable weather conditions, such as high air temperatures and low humidity) contributes to an increase in the rate of community-acquired pneumonia among Moscow residents in summer. Daily average GOC of 60–80 μg/m^3 are capable of increasing the Cap rate by 30% compared to periods with low GOC values. We can conclude that an increase in the

MPC of ground-level ozone in regulatory documents is unacceptable. Once again, we emphasize a need in creating a network for ground-level ozone monitoring and controlling concentrations throughout the territory of Russia.

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CONFLICT OF INTEREST

The authors of this work declare that they have no conflicts of interest.

REFERENCES

1. www.stateofglobalair.org/resources/report/state-global-air-report-2024. Cited September 3, 2024.
2. https://iris.who.int/bitstream/handle/10665/345334/9789240035409-rus.pdf. Cited September 3, 2024.
3. Resolution of the Chief State Sanitary Doctor of the Russian Federation dated December 22, 2017, No. 165 on Approval of Hygienic Standards GN 2.1.6.3492-17 "Maximum Permissible Concentrations (MPC) of Pollutants in the Atmospheric Air of Urban and Rural Settlements." https://docs.cntd.ru/document/556185926. Cited September 3, 2024.
4. Resolution of the Chief State Sanitary Doctor of the Russian Federation dated January 28, 2021, No. 2 on Approval of Sanitary Rules and Regulations SanPiN 1.2.3685-21 "Hygienic Standards and Requirements for Ensuring the Safety and (or) Harmlessness of Environmental Factors for Humans." https://docs.cntd.ru/document/573500115#6540IN. Cited September 3, 2024.
5. Y. Niu, T. Yang, X. Gu, R. Chen, X. Meng, J. Xu, L. Yang, J. Zhao, X. Zhang, C. Bai, J. Kang, P. Ran, H. Shen, F. Wen, K. Huang, Y. Chen, T. Sun, G. Shan, Y. Lin, S. Wu, J. Zhu, R. Wang, Z. Shi, Y. Xu, X. Ye, Y. Song, Q. Wang, Y. Zhou, L. Ding, T. Yang, W. Yao, Y. Guo, F. Xiao, Y. Lu, X. Peng, B. Zhang, D. Xiao, Z. Wang, H. Zhang, X. Bu, X. Zhang, L. An, S. Zhang, Z. Cao, Q. Zhan, Y. Yang, L. Liang, B. Cao, H. Dai, T. Wu, J. He, H. Li, H. Kan, and C. Wang, "Long-term ozone exposure and small airway dysfunction: The China Pulmonary Health (CPH) study," Am. J. Respir. Crit. Care. Med. **205** (4), 450–458 (2022). https://doi.org/10.1164/rccm.202107-1599OC
6. M. Albright, M. A. Guttenberg, and R. M. Tighe, "Ozone-induced models of airway hyperreactivity and epithelial injury," Methods Mol. Biol. **2506**, 67–81 (2022). https://doi.org/10.1007/978-1-0716-2364-0_5
7. F. E. Hargreave, J. Dolovich, P. M. O' Byrne, E. H. Ramsdale, and E. E. Daniel, "The origin of airway hyperresponsiveness," J. Allergy. Clin. Immunol. **78** (5), 825–32 (1986). https://doi.org/10.1016/0091-6749(86)90226-5
8. R. M. Aris, D. Christian, P. Q. Hearne, K. Kerr, W. E. Finkbeiner, and J. R. Balmes, "Ozone-induced airway inflammation in human subjects as determined by airway lavage and biopsy," Am. Rev. Respir. Dis. **148** (5), 1363–1372 (1993). https://doi.org/10.1164/ajrccm/148.5.1363
9. C. E. Atkinson, M. J. Kesic, and M. L. Hernandez, "Ozone in the development of pediatric asthma and atopic disease," Immunol. Allergy. Clin. North. Am. **42** (4), 701–713 (2022). https://doi.org/10.1016/j.iac.2022.06.001
10. X. Fang, S. Huang, Y. Zhu, J. Lei, Y. Xu, Y. Niu, and R. Chen, "Short-term exposure to ozone and asthma exacerbation in adults: A longitudinal study in China," Front. Public. Health **10**, 1070231 (2023). https://doi.org/10.3389/fpubh.2022.1070231
11. P. Mallia and S. L. Johnston, "Mechanisms and experimental models of chronic obstructive pulmonary disease exacerbations," Proc. Am. Thorac. Soc. **2** (4), 361–372 (2005). https://doi.org/10.1513/pats.200504-025SR.PMID:16267363
12. E. V. Evstaf'eva, V. A. Lapchenko, A. S. Makarova, T. F. Burukhina, N. K. Abibulaeva, and I. A. Evstaf'eva, "Estimate of the dynamics of surface ozone concentration and meteorological parameters as risk factors for population health emergencies," Khim. Fiz. **38** (11), 42–51 (2019).
13. A. N. Mikerov, "Factors Participating in Modulating the Mechanisms of Immune Protection of Lungs during Pneumonia," Problemy Osobo Opasnykh Infectsii, No 111, **81–83** (2012). https://doi.org/10.21055/0370-1069-2012-1(111)-81-83
14. E. V. Stepanov, V. V. Andreev, D. V. Chuprov, and V. T. Ivashkin, "The association of high Covid-19 cases and mortality with anomalous high surface ozone concentration in Moscow city in summer 2021," Ross. Zh. Gastroenterologii, Gepatologii, Koloproktologii **32** (3), 18–22 (2022).
15. V. V. Krivosheev, A. I. Stolyarov, and A. A. Semenov, "Ozone impact on morbidity and mortality during the third wave of the Covid-19 pandemic in Europe," Obshchestvennoe Zdorov'e Zdravookhranenie, No. **4**, 5–11 (2021).
16. S. N. Avdeev, A. V. Dekhnich, A. A. Zaitsev, R. S. Kozlov, S. A. Rachina, V. A. Rudnov, A. I. Sinopal'nikov, I. E. Tyurin, O. V. Fesenko, and A. G. Chuchalin, "Federal guidelines on diagnosis and treatment of community-acquired pneumonia," Pulmonologiya **32** (3), 295–355 (2022). https://doi.org/10.18093/0869-0189-2022-32-3-295-355
17. https://rosstat.gov.ru/. Cited September 3, 2024.
18. T. N. Bilichenko, E. V. Bystritskaya, A. G. Chuchalin, A. S. Belevskii, and S. Z. Batyn, "Mortality of respiratory disease in 2014–2015 and ways of its improvement," Pulmonologiya **26** (4), 389–397 (2016). https://doi.org/10.18093/0869-0189-2016-26-4-389-397
19. A. Torres, W. E. Peetermans, G. Viegi, and F. Blasi, "Risk factors for community-acquired pneumonia in adults in Europe: A literature review," Thorax **68** (11), 1057–1065 (2013). PMID: 24130229; PMCID:

PMC3812874
https://doi.org/10.1136/thoraxjnl-2013-204282

20. E. Muthumbi, B. S. Lowe, C. Muyodi, E. Getambu, F. Gleeson, and J. A. G. Scott, "Risk factors for community-acquired pneumonia among adults in Kenya: A case-control study," Pneumonia (Nathan) **9** (17) (2017).
https://doi.org/10.1186/s41479-017-0041-2
21. J. Almirall, J. Blanquer, and S. Bello, "Community-acquired pneumonia among smokers," Arch. Bronconeumol. **50** (6), 250–254 (2014).
https://doi.org/10.1016/j.arbres.2013.11.016
22. C. Guo, T. Yu, C. Lin, L. Y. Chang, Y. Bo, M. C. S. Wong, T. Tam, A. K. H. Lau, and X. Q. Lao, "Habitual exercise, air pollution, and pneumonia mortality: A longitudinal cohort study of approximately 0.4 million adults," Am. J. Epidemiol. **191** (10), 1732–1741 (2022). PMID:
https://doi.org/10.1093/aje/kwac11335773998
23. H. T. Wang, H. Zhang, F. Z. Xue, L. Zhao, and W. C. Cao, "Associations of air pollutants with pneumonia hospital admissions in Qingdao, China: A prospective cohort study," Environ. Sci. Pollut. Res. Int. **29** (19), 27779–27787 (2022).
https://doi.org/10.1007/s11356-021-17892-7
24. R. Li, N. Jiang, Q. Liu, J. Huang, X. Guo, F. Liu, and Z. Gao, "Impact of air pollutants on outpatient visits for acute respiratory outcomes," Int. J. Environ. Res. Public. Health **14** (1), 47 (2017).
https://doi.org/10.3390/ijerph14010047
25. A. N. Mikerov, N. I. Alekseeva, S. S. Abramkina, and Yu. Yu. Eliseev, "Role of surfactant protein a and its oxidation in the susceptibility to experimental pneumonia," Izv. Samarskogo Nauch. Tsentra Ross. Akad. Nauk **12** (1–7), 1769–1773 (2010).
26. S. N. Kotel'nikov and E. V. Stepanov, "An impact of tropospheric ozone on population health," Trudy IOFAN **71**, 72–94 (2015).
27. https://mosecom.mos.ru/. Cited September 3, 2024.
28. https://mos03.ru/. Cited September 3, 2024.
29. http://aisori-m.meteo.ru/waisori/index0.xhtml. Cited September 3, 2024.
30. Y. Zhang, J. Li, C. Wu, Y. Xiao, X. Wang, Y. Wang, L. Chen, L. Ren, and J. Wang, "Impacts of environmental factors on the aetiological diagnosis and disease severity of community-acquired pneumonia in China: A multicentre, hospital-based, observational study," Epidemiol. Infect. **152** (80) (2024).
https://doi.org/10.1017/S0950268824000700
31. A. V. Trubitsyn and S. N. Kotel'nikov, "The research of time correlations between ground-level ozone concentration and population health in Russia's central regions," Vestn. MGTU MIREA, No. **1**, 235–242 (2015).
32. A. V. Cherednichenko, Aleks. V. Cherednichenko, V. S. Cherednichenko, and A. S. Nysanbaeva, "Time dynamics of the ground ozone and its influence on incidence in the major cities of Kazakhstan," Gidrometeorologiya Obrazovanie, No. **1**, 29–49 (2021).
33. P. N. Antokhin, O. Yu. Antokhina, V. V. Antonovich, V. G. Arshinova, M. Yu. Arshinov, B. D. Belan, S. B. Belan, D. K. Davydov, N. V. Dudorova, G. A. Ivlev, A. V. Kozlov, D. A. Pestunov, T. M. Rasskazchikova, D. E. Savkin, D. V. Simonenkov, T. K. Sklyadneva, G. N. Tolmachev, and A. V. Fofonov, "Interrelation between dynamics of gas composition and meteorological parameters in the region of Tomsk," Atmos. Ocean. Opt. **33** (6), 629–637 (2020).
34. E. V. Stepanov, V. V. Andreev, L. V. Konovaltseva, and S. G. Kasoev, "Surface ozone in the atmosphere of Moscow during the COVID-19 pandemic," Atmos. Ocean. Opt. **35** (6), 732–740 (2022).
35. A. M. Zvyagintsev, I. N. Kuznetsova, I. Yu. Shalygina, V. A. Lapchenko, N. E. Brusova, A. A. Arkhangel'skaya, N. V. Tereb, and E. A. Lezina, "Causes and factors of positive surface ozone anomalies in the Moscow Region and on the southeastern coast of the Crimea," Atmos. Ocean. Opt. **29** (5), 551–560 (2016).
36. B. D. Belan and T. K. Sklyadneva, "Tropospheric ozone. 4. Photochemical formation of tropospheric ozone: the role of solar radiation," Atmos. Ocean. Opt. **21** (10), 746–754 (2008).
37. D. S. Rybakov and B. Z. Belashev, "Weather factors and ambulance calls for respiratory causes in the city of Petrozavodsk," Ekologiya Cheloveka, No. **6**, 36–48 (2021).

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