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ABSTRACT

Background Exposure to air pollution can affect the health of individuals with respiratory disease, but may also impede the health and performance of athletes. This is potentially relevant for people travelling to and competing in the Olympic and Paralympic Games (OPG) in Paris. We describe anticipated air quality in Paris based on historical monitoring data and describe the impact of the process on the development of monitoring strategies for future international sporting events.
Methods Air pollutant data for July to September 2020–2023 and pollen data for 2015–2022 were provided by Airparif (particulate matter ($PM_{2.5}$), nitrogen dioxide (NO_2) and ozone (O_3)) and RNSA stations in the Paris region. Airparif's street-level numerical modelling provided spatial data for the OPG venues.
Results The maximum daily mean $PM_{2.5}$ was 11±6 µg/m^3 at traffic stations, below the WHO recommended daily air quality threshold (AQT). Daily NO_2 concentrations ranged from 5±3 µg/m^3 in rural areas to 17±14 µgm^3 in urban areas. Near traffic stations, this rose to 40±24 µg/m^3 exceeding the WHO AQT. Both peaked around 06:00 and 20:00 UTC (coordinated universal time). The ambient O_3 level exceeded the AQT on 20 days per month and peaked at 14:00 UTC. The main allergenic taxa from June to September was Poaceae (ie, grass pollen variety).
Conclusion Air pollutant levels are expected to be within accepted air quality thresholds at the Paris OPG. However, O_3 concentrations may be significantly raised in very hot and clear conditions and grass pollen levels will be high, prompting a need to consider and manage this risk in susceptible individuals.

WHAT IS ALREADY KNOWN ON THIS TOPIC

⇒ Air quality affects the health of susceptible individuals depending on the type of pollutant and its concentration. WHO publishes air quality guidelines to protect human heath, which are exceeded every year in major European cities.

WHAT THIS STUDY ADDS

⇒ We now know the daily, hourly and maximum concentrations of each pollutant in the Paris region over the last four summers, their diurnal variations and the number of exceedances, and what to expect during the Olympic and Paralympic Games.

HOW THIS STUDY MIGHT AFFECT RESEARCH, PRACTICE OR POLICY

⇒ By comparing these levels with those in their area, athletes and spectators can see if they need to take steps to avoid or reduce their exposure. They can discuss this with their doctor and plan their activities to avoid the times and types of places where pollution is highest.
⇒ This approach to reporting the anticipated air quality for a major sporting event can help inform best practise for committees involved in planning future major sporting events.

INTRODUCTION

The XXXIII Olympic and Paralympic Summer Games will take place primarily in Paris from 26 July to 8 September 2024. Paris will host hundreds of thousands of spectators, as well as athletes, support staff, volunteers and workers. In anticipation of possible heatwaves, it is recommended that organisers take steps now to protect the health of everyone who attends the 2024 Games in any capacity.[1] A similar recommendation could be made about air pollution. Athletes can be affected by environmental factors,[2–4] despite generally being in good physical condition. Inhaling air pollution during exercise may pose health risks, depending on exposure levels and the presence of chronic diseases,[5 6] such as cardiovascular and respiratory diseases.[7 8] This is especially true for endurance athletes,[9] who are susceptible to allergic symptoms and lower respiratory tract disorders. While synergistic effects between climate change, meteorology, air pollutants and aeroallergens have been suggested to link with respiratory allergy,[10 11] the current literature lacks conclusive evidence.[12] Separately, heat, air pollution and pollen during exercise can impair performance, and lead to premature exhaustion.[13–18] Consensus recommendations based on the latest science aim to prevent athlete health problems and provide acclimatisation methods for training in hot[2 13] or polluted[19 20] environments. Environmental monitoring is thus crucial before and during events[2 20] to minimise athletes' risks and determine acclimatisation strategies. Monitoring allergens at sports venues offers valuable information for athletes with allergies and their healthcare providers to prepare for competition.[9 19 21] Occasionally, information about potential weather conditions and allergens during the Summer Olympics is released in advance.[21–23]

The aim of this study is to provide data on air quality, including allergen types, in the Paris region and at the venues during the upcoming 2024 Olympic and Paralympic Games, that is, between

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July and September. This information will help participants anticipate and manage potential air quality and allergen conditions, allowing them to take appropriate preventive measures to protect their health and optimise their performance.

METHODS

Equity, diversity and inclusion statement

Our work applies to everyone equally. No participants were involved. The authors (four women, including the lead author, and six men) come from a variety of disciplines. We did not address diversity among the authors' team. The study considered inclusivity by reporting data for both Paralympic and Olympic Games.

Air pollution measurements

The description of spatial and temporal variations of air pollution in Ile-de-France is based on data from the 50 permanent automatic monitoring stations of the Airparif network (figure 1A; online supplemental table 2S). These stations provide continuous measurements on an hourly basis allowing real-time monitoring of pollutants. The measurement methods and associated standards are shown in online supplemental table 1S. There are three main types of stations: urban/suburban and rural background stations, and traffic stations near traffic lanes. Airparif monitoring stations operate in accordance with regulatory requirements. Most of the background stations are located at street level, except for a few urban stations, which are located on the top of buildings, and a few rural stations (online supplemental table 2S).

Raw data are available to the public and can be downloaded from the Airparif OpenData website.[24]

Air pollution modelling

At the Olympic and Paralympic venues

In addition to the measured data, the concentrations of the main pollutants during the 3 month summer season were calculated for 2020–2023. To take into account the meteorological variability,[25] which is crucial for the concentration variations, we chose a 4 year period with 3 months in each year. A model-based assessment of air pollution is thus carried out at Olympic sites from Airparif's modelling systems. The modelled concentrations are extracted at a representative point of each site. To do this, the ESMERALDA interregional air quality operational platform, which derives from CHIMERE chemistry-transport model,[26 27] provides information on background pollution levels of ozone (O_3), nitrogen dioxide (NO_2), and fine particles ($PM_{2.5}$) at a resolution of 3 km. At the local scale, ESMERALDA is combined with the model ADMS-Urban[28] to include more precisely the impact of traffic emissions. In addition, observation data from monitoring stations are assimilated in the chain to reduce uncertainties. At the end, Airparif Real-Time modelling chain provides concentrations of NO_2, PM_{10} and $PM_{2.5}$ particles at resolutions from 12.5 m (city of Paris) to 50 m (whole region).

Ozone concentrations at Olympic sites were extracted from the ESMERALDA regional model. With NO_2 and $PM_{2.5}$, for sites less directly impacted by traffic, such as indoor sites and sites affected by traffic restrictions (numbers 3, 5, 6, 7, 17 on table 1/online supplemental figure 1S), we used the background concentrations from the regional model. For these sites, background concentrations from the regional model were also used to assess air quality. Finally, the local model was used to include the impact of traffic emissions in the assessment for outdoor sites without road traffic restrictions.

Clustering of air pollution at the Olympic sites

A clustering on simulated concentrations was performed on the Olympic sites to identify categories of sites with similar pollution levels. At each site, the median profiles were calculated and the k-means algorithm was applied to the median profiles. Thus, we identified two clusters for $PM_{2.5}$ and three clusters for NO_2. For O_3, no significant difference was found between the sites in terms of median profiles. All profiles are thus discussed together.

Reference values air quality thresholds

Air quality recommended thresholds (AQTs) for each pollutant during the day (8 to 24 hours mean) were from WHO. They recommend that the following values are not exceeded for more than 3–4 days a year: 15 µg/m^3 per 24 hours for $PM_{2.5}$, 25 µg/m^3 per 24 hours for NO_2 and 100 µg/m^3 per 8 hours for O_3. The WHO AQT indicates the lowest levels of exposure for which there is evidence of adverse health effects for each pollutant. France also has hourly regulatory limits for O_3. The information and alert 1 thresholds (180 and 240 µg/m^3 hourly average, respectively) indicate the concentrations above which short-term exposure poses a risk to human health in the sensitive population (information) and the general population (alert 1). These thresholds lead the local authorities to trigger the information or alert procedure when local health authorities recommend intensive sport is not practised.

Aerobiological survey

This section describes the material and methods used to understand the variability and sources of aeroallergens affecting the Ile-de-France region in 2015–2023 based on knowledge obtained from previous works.[29] The aerobiological monitoring sites are located in Paris and Saclay (online supplemental figure 1S and online supplemental table 2S), and are part of the French Aerobiological Surveillance Network (RNSA, France) and The Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS, https://www.actris.eu).[30]

Daily pollen concentrations were collected using a volumetric impaction sampler (VIS) via a Hirst-type spore trap (VPPS 2000, Lanzoni, Bologna, Italy).[31] The spore traps were placed on the roofs of buildings (15 m above the ground) without any adjacent vegetation. Air was continuously pumped always facing the prevailing wind. Particles with an aerodynamic diameter between 2 µm and 200 µm were collected by impacting them on a rotating drum mounted on a cellophane adhesive tape coated with silicone.

After 7 days, the impacted tape was removed and cut into seven equal parts. Each part, corresponding to one sampling day, was stained with fuchsin-based staining reagent (Prolab Diagnostics, Switzerland) to distinguish pollen grains from fungal spores. A light microscope (Realux, France) with a magnification of ×400 was used for optical reading and counting. The standardised pollen count technique was longitudinal, and results were available as 2 hour averages.

RESULTS

Air pollution measurements

Fine particles ($PM_{2.5}$)

Daily mean $PM_{2.5}$ concentrations are higher at traffic locations (11±6 µg/m^3) than at urban sites (7±4 µg/m^3) and rural sites (5±4 µg/m^3) (figure 1A). There is a pronounced diurnal cycle in $PM_{2.5}$ concentrations with 2 hourly maxima at 06:00 and 20:00 UTC at traffic sites; this is less evident at urban sites when looking at the mean, but this variation becomes more pronounced when

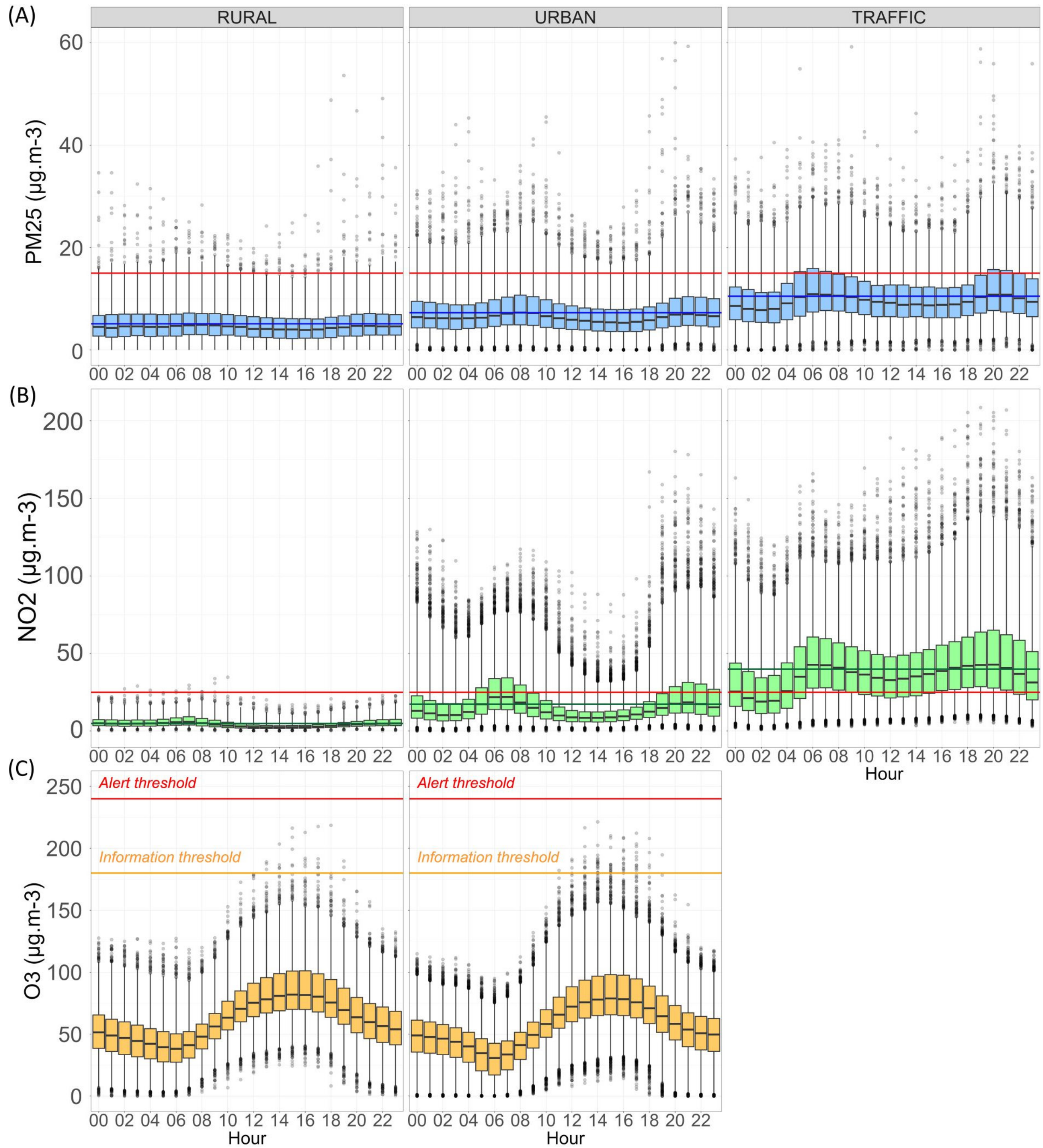


Figure 1 Hourly diurnal cycle of (A) particulate matter ($PM_{2.5}$), (B) nitrogen dioxide (NO_2) and (C) ozone (O_3) concentrations measured in the Paris area at traffic, urban and rural sites of the Airparif air quality network for the summer months (July–September) of the period 2020–2023. UTC: coordinated universal time. The distributions of hourly values are represented by boxplots indicating the median, interquartile 25–75, interpercentile 0.01–0.99. The circles are the outliers, that is, the 1% lowest and highest values. (A) The blue line indicates the daily global mean and the red line indicates the daily WHO recommended level (15 µg/m^3) not to be exceeded more than 3–4 days per year for $PM_{2.5}$. To keep the value scales homogeneous between the figures, the 16 highest values are not present in the figure with a maximum value of 107 µg/m^3; (B) horizontal green line indicates the daily global mean, and the red line indicates the daily WHO recommended level not to be exceeded of 25 µg/m^3. To keep the value scales homogeneous between the figures, the nine highest values (all at traffic station) are not present in the figure with a maximum value of 323 µg/m^3; (C) horizontal red line indicates the French information (hourly mean 180 µg/m^3) and alert (hourly mean 240 µg/m^3) thresholds.

looking at the maxima, with peaks at 08:00 and 22:00 UTC. The diurnal cycle almost disappears at rural sites. There is wide variation in concentration for each site at different hours during the day, with maxima between 5 and 10 times the median value. The maximum hourly concentration of $PM_{2.5}$ that was measured was 60 µg/m^3 (urban site).

The observed daily mean values of $PM_{2.5}$ concentrations are mostly below the WHO 24-hour mean recommended threshold (figure 1A), especially at urban sites, which are the most representative of human exposure in cities. The number of days per month when this threshold is exceeded in summer is higher at traffic stations, reaching 20 days in August 2020, September

Table 1 Detail of the stations

Number of the map on figure 1	Name of the Olympic site	Sport	Outdoor (O)/Indoor(I)	ESMERALDA HR real-time modelling chain	Number of sensors			Comment on traffic
					O_3	NO_2	$PM_{2.5}$	
17	La Concorde	Basketball 3×3, BMX freestyle, breaking, skateboard	O	Background	0	1	1	
6	Pont Alexandre III	Swimming, marathon, triathlon, road cycling	O	Background	0	1	1	
5	Trocadéro	Road cycling, athletics	O	Background	0	1	1	
7	Arena Champ de Mars	Judo, wrestling	I	Background	0	1	1	
9	Arena Porte de la Chapelle	Badminton, rhythmic gymnastics	I	Background	0	1	1	
3	Invalides	Archery, athletics, road cycling	O	Background	0	1	1	
4	Hôtel de Ville	Athletics	O	Background	0	1	1	
14	Grand Palais	Fencing, taekwondo	I	Background	0	1	1	
1	Stade Roland Garros	Tennis, boxing	O	Background+local	0	2	1	Close to the highway A13
2	Parc des Princes	Football	O	Background+local	0	2	1	Close to the peripheral ring
10	Arena Paris Sud 1	Volleyball, boccia	I	Background	0	1	1	
11	Arena Paris Sud 4	Table tennis	I	Background	0	1	1	
12	Arena Paris Sud 6	Goalball, handball, weightlifting	I	Background	0	1	1	
8	Arena Bercy	Basketball, artistic gymnastics, trampoline	I	Background	0	1	1	
22	Stade Yves Manoir	Hockey	O	Background+local	1	1	1	
16	Arena Paris Nord	Boxing, modern pentathlon	I	Background	1	1	0	
20	Site d'escalade du Bourget	Climbing	O/I	Background+local	1	1	1	
23	Stade de France	Athletics, rugby	O	Background+local	1	2	1	Close to the A1 and A86 highways
18	Centre Aquatique	Artistic swimming, diving, water polo	I	Background	1	1	1	
15	Paris La Défense Arena	Swimming, water polo	I	Background	1	1	1	
19	Stade Nautique	Sprint canoeing, rowing, slalom canoeing-kayaking	O	Background+local	1	0	0	
21	Château de Versailles	Equestrian sports, modern pentathlon	O	Background+local	1	0	0	
26	Colline d'Elancourt	Mountain bike	O	Background+local	1	0	0	
25	Vélodrome National	Track cycling	I	Background	1	0	0	
24	Stade BMX	BMX racing	O	Background+local	1	1	0	Close to the highway A12
27	Golf National	Golf	O	Background+local	1	0	0	

2020 and September 2021, while there are few days per month when the threshold is exceeded at rural stations (figure 2A). In urban stations, a maximum of 5–8 days of exceedance at some stations have been observed in July 2022 and 2021, and in September 2020, 2021 and 2023, whereas some stations did not observe any days of exceedance.

Nitrogen dioxide (NO_2)

The highest concentrations are found at the traffic sites located along the main roads (40±24 µg/m^3 daily average) and then at the urban background sites (17±14 µg/m^3), and much lower concentrations at rural sites (5±3 µg/m^3). There is a very pronounced diurnal cycle in mean concentrations, with peaks at 06:00 and 20:00 UTC (figure 1B). On an hourly time scale there is a large variability, with values sometimes exceeding 200 µg/m^3 at traffic sites and 175 µg/m^3 at urban sites. The number of exceedances of the WHO daily recommended threshold (25 µg/m^3) is very high at traffic sites, varying from 5 days (one exception being 0 days of exceedance in August 2020) to 31 days near the major roads (figure 2B). The number of exceedances at urban sites can still be greater than 15 days per month during September at some stations, and between 10 and 15 days in August (2020 and 2022). Some stations did not observe any exceedance.

Ozone (O_3)

The concentrations of O_3 are quite similar at rural and urban sites (figure 1C). Ozone diurnal cycle of concentrations reach a maximum at 14:00 UTC (16:00 local time). It increases from 08:00 UTC, peaks at 14:00 UTC (16:00 local time) and then decreases. The number of exceedances of the WHO recommended threshold (100 µg/m^3 8 hour mean) is similar in urban and rural areas (figure 2C). It can reach 20–25 days a month at certain stations and varies greatly from one month or year to the next. In 2021, the weather was rainy in June and July and cloudy in August, and only one exceedance of the information threshold was recorded. We observed that exceedances of the French information threshold (180 µg/m^3 hourly mean) occurred only in the afternoon, from 11:00 at the earliest to 19:00 UTC.

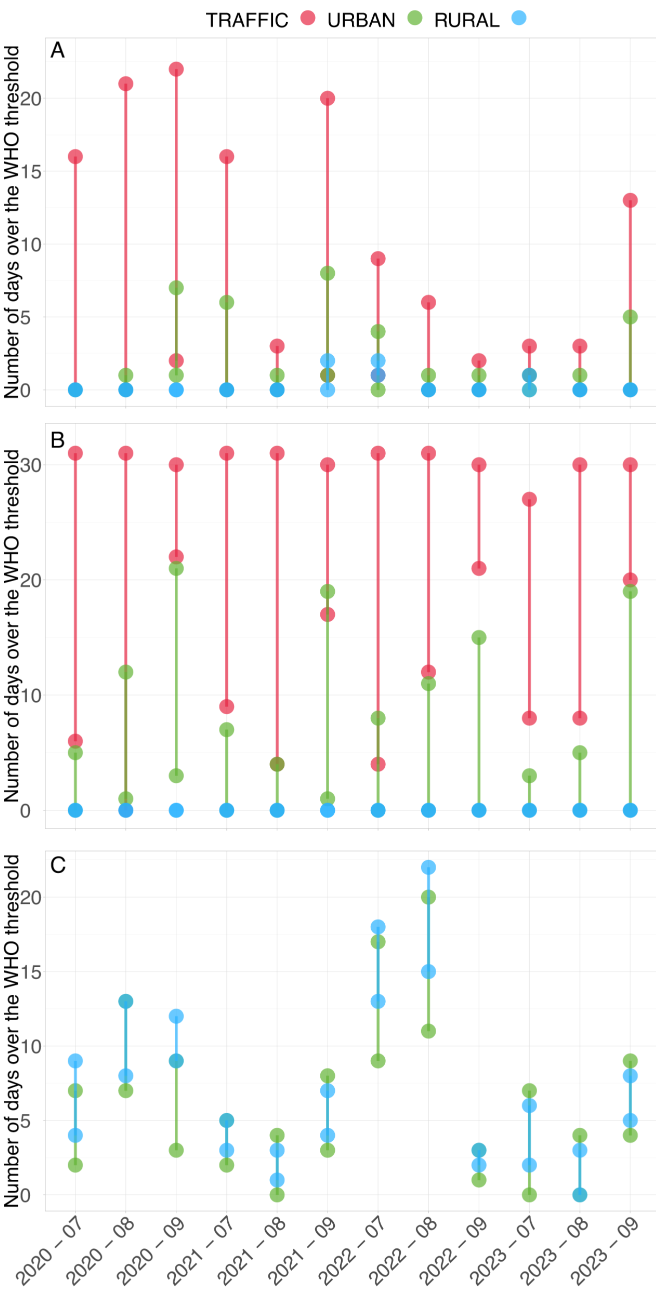


Figure 2 Minimum and maximum number of exceedances per summer month (period 2020–2023) of the WHO threshold for (A) daily fine particles ($PM_{2.5}$), (B) daily nitrogen dioxide (NO_2) and (C) 8 hour mean ozone (O_3) concentrations measured at traffic, urban and rural stations. Blue points are the minimum and maximum numbers of exceedances observed among the rural stations; green points are the minimum and maximum number of exceedances observed among the urban stations; red points are the minimum and maximum number of exceedances observed among the traffic stations. The number of exceedance days is based on the WHO recommended daily guidelines, which are 15 µg/m^3 not to be exceeded for more than 3–4 days per year for $PM_{2.5}$ and 25 µg/m^3 for NO_2. For O_3, the recommended daily guideline is an 8 hour mean concentration of 100 µg/m^3. Y-axis: data are expressed as year-month.

Over the 2020–2023 period, the information threshold has been exceeded from 1 to 9 days per year and the alert threshold has not been exceeded, the maximum hourly O_3 concentration measured being 221 µg/m^3. It is noteworthy that extreme values were measured far from urban centres, not at Olympic sites.

Air pollution at Olympic sites in the Paris region from models

By using simulated pollutant fields at street level, we can assess pollution levels at exact Olympic site locations where there are no monitoring stations. Rather than discussing each site individually, we have defined clusters of sites as described in the Methods sections. We have plotted the clustered daily median profiles for $PM_{2.5}$ concentrations during the summer months (figure 3B). Cluster 1 corresponds to the Olympic sites with the highest simulated concentrations. These sites are in the centre of Paris and the inner suburbs (8±4 µg/m^3). Cluster 0 brings together the Olympic sites with slightly lower estimated $PM_{2.5}$ average concentrations (7±4 µg/m^3). They are all located further from the centre of Paris. However, even if average levels estimated at Olympic sites in the centre of Paris are close to those measured in the outer suburbs, hourly levels can be significantly higher.

For NO_2, cluster 2 gathers the Olympic sites with the highest average daily concentration (26±16 µg/m^3). This cluster includes sites close to major roads (sites 1, 2 and 23 in table 1 and online supplemental figure 1S) (figure 3A). For cluster 1, the simulated average concentration is 19±14 µg/m^3. It corresponds to the Olympic sites located in the centre of Paris and the inner suburbs. For cluster 0, simulated values are lower (11±9 µg/m^3). This cluster brings together the Olympic sites further from the city centre (sites 19, 21, 25, 26 and 27 in table 1 and online supplemental figure 1S). Although located in St Quentin-en-Yvelines, in the remote suburb, the BMX track belongs to cluster 1 due to its proximity to the A12 highway. These results confirm a greater variability in NO_2 levels between Olympic sites, depending on their geographical location and the potential influence of roads.

Identification of allergenic pollens in the Paris region during the summer

Two peaks in pollen concentration occur in April and June (figure 4A). From the peak in June, the concentration of pollen decreases until September, but is still present during these months. The general pollen concentration is three times lower than in April (figure 4). A total of 19 interesting taxa including *Ambrosia* were identified during the summer, but only the most abundant are shown in figure 4B. Urticaceae (mainly *Urtica*), Castaneae and Poaceae represent 92.2% of the atmospheric aerobiological content (figure 4B). Their allergenicity is low, except for Poaceae, which is highly allergenic. The peak is higher in Saclay compared with Paris (figure 4A), with a similar atmospheric composition in terms of the main allergenic taxa.

DISCUSSION

Air quality in Paris during the summer can be characterised mainly by high O_3 levels in the afternoon, especially on sunny and hot days. Localised increases in $PM_{2.5}$ and NO_2 can occur near busy roads and in urban areas. Hourly maximum concentrations observed during the four summers (2020–2023) were 221 µg/m^3 for O_3, 60 µg/m^3 for $PM_{2.5}$ (urban) and 200 ug/m^3 for NO_2 (traffic). Finally, some tree and grass pollen may still be present during the Olympic Games. In the summer, pollen levels are much lower than in spring, but the Poaceae can be problematic for those with allergies.

The first information is aimed at those travelling to the Paris region for next summer's Olympic and Paralympic Games. Depending on their country of origin, concentrations of air

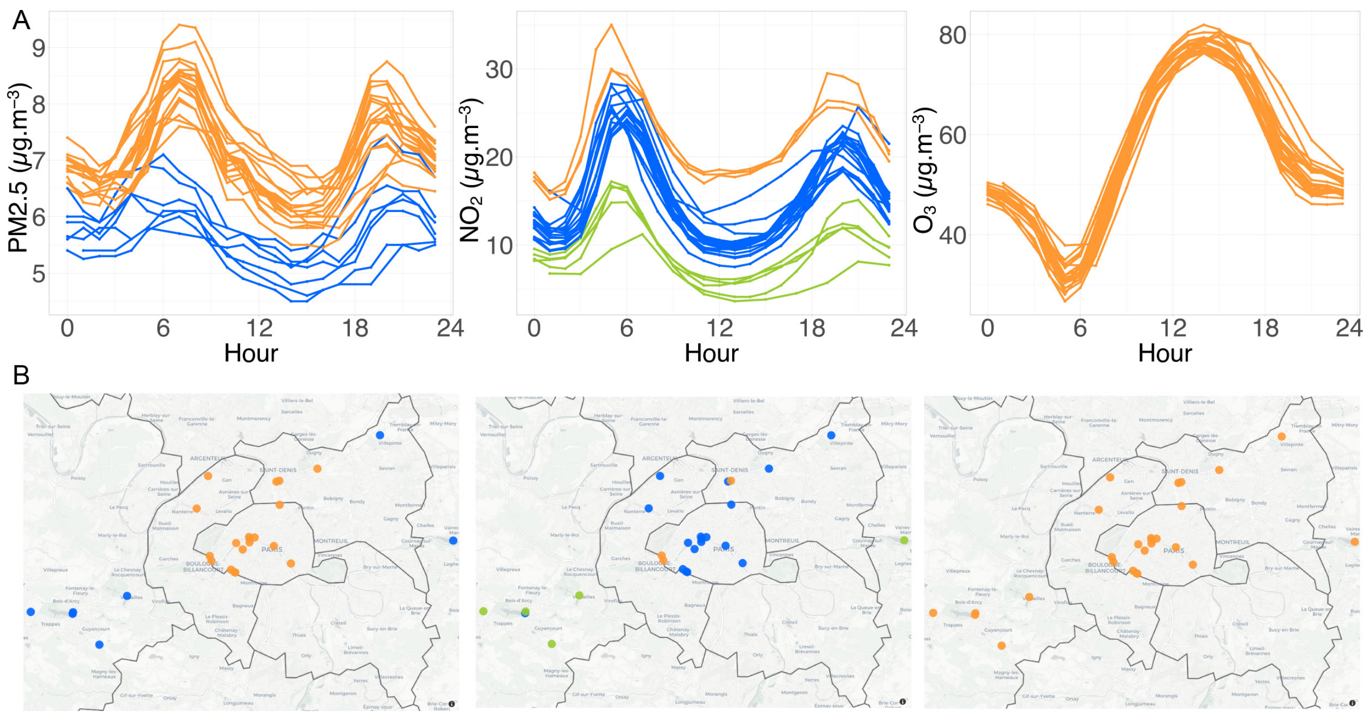
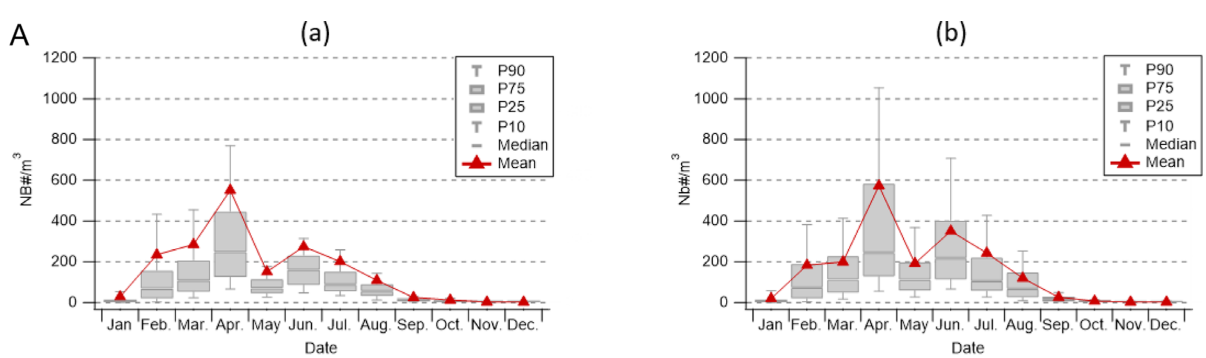


Figure 3 Clustered summertime daily profiles for (A) fine particle ($PM_{2.5}$) and (B) nitrogen dioxide (NO_2) concentrations from 2020 to 2023. There are two clusters for $PM_{2.5}$, three clusters for NO_2 and only one cluster for O_3. The colour of the station points on the map corresponds to the colour of the cluster.

pollutants may be higher than usual at some time points, especially for traffic-related air pollution and O_3. Although lower than for long-term exposure, the relative risks of all-cause and specific-cause mortality, hospital admissions or emergency department visits increase with increasing short-term air pollutant concentrations (from one hour to several



B

Pollen and/or family	Allergenicity	Summertime contribution
Urtica (Urticaceae)	Low	39.9%
Castanea (Fagaceae)	Low	34.1%
Poaceae	Strong	18.2%
Cupressaceae-Taxaceae	Strong	1.8%
Plantaginaceae	Medium	1.8%
Artemisia (Asteraceae)	Strong	0.7%
Pinus (Pinaceae)	Low	0.6%
Others	-	2.9%

Figure 4 Variability of total pollen grains concentration from 2015 to 2022 in (a) Paris and (b) Saclay. (A) Seasonal variability and (B) allergenic pollen distribution and their allergenicity in the Ile-de-France region during the summertime (June–August). The error bars on the monthly distribution of pollen concentration represent the 90th, 75th, 25th and 10th percentiles. NB#/m^3: number per m^3; P: percentile. The date (Y-axis) is expressed as month/year. The description of the pollen may be found on the RNSA website.[85]

days).[32–35] In France, short-term exposure to ozone above the threshold of 100 µg/m^3 per 8 hours was estimated to cause an excess mortality of about 0.20%.[34] A recent meta-analysis also reported a linear relationship between $PM_{2.5}$ concentrations and daily all-cause, cardiovascular and respiratory mortality, with each 10 µg/m^3 increase, increasing mortality by 0.68%, 0.55% and 0.74%, respectively, with no discernible threshold effect.[33] This association was stronger in locations with lower annual PM concentrations, possibly indicating adaptation to high levels of pollution, with people living in high PM areas being less sensitive to small changes in air pollution.[33] Despite the lack of evidence towards an additive effect of ozone and $PM_{2.5}$ on the association between pollutants and mortality, larger effects of air pollutants have been observed when the temperatures are warmer.[33 36] In the Paris region, the ozone threshold recommended by WHO can be exceeded in summer, sometimes for several days, with hourly values that have never exceeded the French alert 1 threshold and rarely the information threshold over the last four summers. Daily levels of NO_2 and $PM_{2.5}$ may also be elevated in traffic and urban areas, with an hourly bimodal diurnal variation, resulting in an additional potential incidence of hospital admissions or emergency visits.[32 37] It is noteworthy that daily $PM_{2.5}$ is generally below the WHO recommendations. In general, our data suggest that the concentrations observed may have a limited impact on healthy people who will be in Paris for a short period during the Olympic and Paralympic Games, but may have a greater impact on certain vulnerable groups such as people with chronic diseases (eg, cancer, COPD, diabetes, cardiovascular diseases asthma, etc), children and the elderly, and in particular those who are highly sensitive to pollutants. Among these, people from countries or regions less exposed to air pollution, especially ozone under the likely Olympic conditions, may be more affected than others.[38 39] In addition to the concentration of air pollutants, the intensity and duration of physical activity and pre-existing conditions of sensitive groups may have a synergistic effect on various health outcomes.[40] Unfortunately, when it comes to people with physical disabilities and Paralympic athletes, there is not enough literature to be able to assess the risks of exposure to air pollution for this specific group. No deaths, emergency admissions or hospitalisations related to air pollution have been reported in Olympic or international athletes who have spent several days training or competing in a polluted environment. However, these outcomes have not been studied.

A second set of information is aimed at athletes or healthy active people, usually young adults, for whom the question of safe exercise in a polluted environment arises. In the case of air pollution, the main concern is the respiratory system, with a particular focus on athletes with asthma or, more generally, lower respiratory disease. However, these concerns are not supported by existing randomised control trials and the health effects are unclear.[41] A recent systematic review found that the only evidence of respiratory symptoms and decreased lung function in the athlete population was for O_3.[41] However, the concentrations studied in the literature are well above those found in Paris. A focused review of the exercise literature covering healthy active individuals or athletes exposed to O_3 levels below 221 µg/m^3 (about 0.12 ppm), the highest hourly average recorded in Paris over four summers, showed variable effects on respiratory symptoms and lung function, suggesting individual susceptibility to O_3.[42–49] Only four studies involved competitive endurance athletes (cyclists or runners) exposed to O_3 at or below 0.12 ppm.[42 44 48 49] Among 50 athletes exercising for 1 hour at 50% VO_2max in 0.08 ppm O_3 versus filtered air (32°C, 42% relative humidity), no significant changes in lung function or performance were found.[42] Similarly, two studies of endurance athletes showed no changes in lung function or respiratory symptoms after high-intensity exercise when exposed to 0.10 ppm or 0.12 ppm O_3 compared with filtered air.[48 49] However, at these concentrations, 10% of cyclists[48] and 40% of runners[49] were unable to complete the exercise maximally, and this figure rose to 100% when heat was added to the O_3 (31°C, 70% relative humidity).[49] Notably, in another study, a significant decrease in lung function (−5.6% for forced expiratory volume in 1 s (FEV_1) and −7.6% for forced vital capacity (FVC)) was observed in highly trained cyclists after 1 hour of exercise at 70% VO_2max in 0.12 ppm O_3 compared with filtered air (31°C, 35% relative humidity).[44] None of the cyclists had exercise-induced bronchoconstriction after exposure to filtered air compared with four cyclists after exposure to O_3 (24%), one of whom had a decrease in FEV_1 of more than 25%.[44] A diagnosis of mild asthma or exercise-induced bronchoconstriction (EIB) has not been observed to be a risk factor of respiratory symptoms or decrement in lung function when exercising in O_3 in athletes, but as shown in the previous studies, some of them are high responders, and if those athletes have asthma or EIB, ozone-induced EIB may be more severe.[14] Acclimatisation studies in healthy volunteers at very high ozone concentrations suggested that the first few days of exposure caused the worst respiratory symptoms and lung function decline, with at least 3 days of adaptation required, possibly longer for high responders.[14] There is also evidence that people accustomed to ozone or traffic-related air pollution may experience reduced health or performance effects from acute exposure.[34 50]

Recent recommendations may help to mitigate the health and performance impacts of air pollution, especially while exercising.[19 20 51] Primary prevention involves minimising exposure and contribution to air pollution, including pollen. To lower $PM_{2.5}$ and NO_2 concentrations, reducing private car use and favouring public transport is advised, although underground stations can have higher $PM_{2.5}$ concentrations than roads.[52–54] Active transport users should avoid busy roads and opt for car-free areas during peak hours. Individuals can reduce in-vehicle NO_2 and $PM_{2.5}$ inhalation by considering car factors like age, cabin size, filter quality, fan speed and window use. Face masks (N95, KN95, FFP2) may also be effective against $PM_{2.5}$ during peak hours or during transport[55 56] if used correctly and fitted properly, but are ineffective against O_3 or NO_2. Their prolonged use during a heatwave is not recommended.[57] Athletes' staff should be encouraged to consider the air quality and meteorological conditions in Paris prior to the Games, and accordingly, to encourage athletes to follow the recommendations for heat acclimatisation and O_3 mitigation strategies before attending the summer Olympics.[2 20] Overall, similar to heat exposure,[58] unacclimatised individuals may be particularly at risk, as previously mentioned. Sensitive people should therefore avoid the afternoon O_3 peak, for example by staying indoors. We did not assess indoor air pollution in our study, but for indoor sports events, the air exchange rate and O_3 loss to indoor surfaces impact indoor O_3 concentrations. Indoor ozone is generally lower than outdoor,[59 60] with a ratio of indoor to outdoor concentration varying from 25% to 73%, following the diurnal variation of outdoor O_3.[59] Non-acclimatised athletes may be advised to arrive a few days before their event to acclimatise if high O_3 is forecast in Paris. Finally, being physically active has been suggested to protect sensitive individuals from the harmful effects of air pollution,[61–64] and we can only encourage those attending the Olympic and Paralympic Games to get regular exercise before they go. The role of usual medication in protecting against air pollution induced exacerbations is not yet clear, especially for respiratory diseases. People with ischaemic heart disease taking cardioprotective medication may be protected from impaired vascular function when walking in a polluted area.[65] However, sports physicians should be aware that the short-acting β2-agonists often used as rescue inhalers by athletes or asthmatics when they experience respiratory symptoms, including those due to ozone pollution,[66] may not be so effective as usual in treating ozone-induced EIB in some athletes or asthmatics.[67–69] Moreover, although insufficiently studied, concurrent heat, pollution and/or aeroallergens may act synergistically to increase the relative risk of respiratory symptoms and airflow obstruction in susceptible athletes, as suggested for asthma.[70] Certain pollens are present in Paris from June to August, and in the concentrations observed, it's almost exclusively Poaceae pollens that are problematic for allergy sufferers. It is currently considered to be the most important airborne biological pollutant and the main cause of pollen allergy worldwide.[71] The main measures can be consulting pollen forecasts, avoiding outdoor activities when pollen levels are high or during pollination periods, avoiding drying laundry outdoors, washing clothes after exposure, washing hair at night and wearing pollen protective glasses or face masks.[72] The highest concentrations of Poaceae are generally observed between 9 am and 6 pm local time,[72–74] but vary around these hours depending on the species; if present during the Olympics, it is therefore recommended to open windows and ventilate homes after 9h pm local time, and to perform outdoor activities early in the morning, before 9 am local time.[73] During the Olympic and Paralympic Games, a real-time pollen alert network will be set up in the frame of ACTRIS Eu project to inform the athletes on pollens events on an hourly basis, allowing them to adapt their behaviour more precisely. International guidelines can be consulted to assist in the management of allergic diseases.[75 76]

The study's main limitations are the lack of direct measurements at individual Olympic venues, as not all venues have dedicated sensors. To respond to this situation, we propose a two-step strategy. First, we used the existing network and the typologies used by air quality agencies (traffic, urban, rural) to provide a robust initial estimate of the air quality to be expected in the Paris region in these different environments. We then simulated pollutant concentrations at precise locations using an air quality modelling platform that is also used for operational forecasting. It should be noted that daily $PM_{2.5}$ is generally used as the main trigger for exacerbation or mortality in air pollution exposure, rather than instantaneous or hourly levels, and people are likely to be out and about during the day. Moreover, inter-station variability is generally dependent on the road proximity, the importance of traffic on this road, and meteorological conditions, which finally correspond to the main message and observation. The data we used are based on models but do not consider an unforeseen change in traffic; either an increase in traffic from spectators in the Olympic venues and the wider Paris region, or a decrease due to traffic reduction measures. Indeed, the centre of Paris will be extremely difficult to access by car due to the total closure of the city to traffic and the introduction of reserved lanes on the A1 and A13 motorways and the 'Boulevard périphérique'. These measures will probably have a positive impact on NOx and PM emissions in the densely populated area, where the most exposed venues are located, such as the Parce des Princes stadium, The Stade de France and the Roland Garros stadium. Finally, while we cannot completely rule out PM events in the summer of 2024, that is, wildfires, Saharan sand[77] or volcanic eruptions,[78] they are considered unlikely in Paris and typically have minimal impact on surface concentrations. In addition, the Ile-de-France region experienced its first episode of thunderstorm asthma in June 2023, with a significant increase in emergency department visits for respiratory problems.[79] In this case, susceptible individuals are advised to stay indoors during thunderstorms to minimise risk.[80]

Considerations for future event planning

Forecasting not only the weather, but also air quality and airborne allergens in indoor and outdoor sports venues can help organisers and other stakeholders determine what pollution people are exposed to when exercising and to educate people on individual concrete strategies to reduce the inhaled dose. The models we used for estimating air pollution at sports venues, as we used in the study, and based on official city air pollution sensors, can be useful for predicting air quality before an event and should be made visible to participants. Airborne allergens measured by city or regional sensors can also be helpful and should be readily available to athletes. Recent studies suggest an individualised approach to allergy, considering local and temporal meteorological and air quality conditions, including pollen, in conjunction with daily symptoms, to provide personalised advice on prevention and treatment.[81 82] The monitoring of some hyper-local air pollutants, such as NO_2, PM, CO, volatile organic compounds, and also pollen in sports venues, to provide sports operators with recommendations to minimise exposure for athlete communities and to guide event planning is currently at an experimental stage[83 84] and may be the future.

CONCLUSION

People attending the Olympic Games should be informed about the air quality forecasts for Paris and the potential effects on their health, especially those in sensitive groups. The most probable air pollutant during summer 2024 will be ozone, if the weather is clear, warm and sunny. Although in our study the importance of NO_2 and $PM_{2.5}$ is confined to traffic areas and urban centres, it is currently extremely difficult to predict the mobility behaviour of visitors to the Olympic and Paralympic Games. If most visitors prefer to travel by car, it is likely that traffic-related pollution will increase, but current organisers and authorities have planned important road closures that will probably decrease the traffic in the centre of Paris for the Games. Whatever the pollutant, the first thing people should do is limit their exposure and follow the recommendations to do so. Athletes, especially the most sensitive, could be advised to acclimatise to avoid respiratory symptoms during the event, which can be achieved by arriving a few days in advance. In the case of medical treatment, those concerned should check with their doctor to ensure that their treatment plan considers any aggravation caused by ozone or the presence of grass pollen. In the event of an emergency, signage at Olympic venues should be easily visible.

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