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Urban vegetation and particle air pollution: Experimental campaigns in a traffic hotspot

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ABSTRACT

This work presents the main results of two experimental campaigns carried out in summer and winter seasons in a complex pollution hotspot near a large park, *El Retiro*, in Madrid (Spain).

These campaigns were aimed at understanding the microscale spatio-temporal variation of ambient concentration levels in areas with high pollution values to obtain data to validate models on the effect of urban trees on particulate matter concentrations.

Two different measuring approaches have been used. The first one was static, with instruments continuously characterizing the meteorological variables and the particulate matter concentration outside and inside the park. During the summer campaign, the particulate matter concentration was clearly influenced by a Saharan dust outbreak during the period 23 June to 10 July 2016, when most of the particulate matter was in the fraction $PM_{2.5-10}$. During the winter campaign, the mass concentrations were related to the meteorological conditions and the high atmospheric stability.

The second approach was a dynamic case with mobile measurements by portable instruments. During the summer campaign, a DustTrak instrument was used to measure PM_{10} and $PM_{2.5}$ in different transects close to and inside the park at different distances from the traffic lane. It was observed a decrease in the concentrations up to 25% at 20 meters and 50% at 200 meters. High PM_{10} values were linked to dust resuspension caused by recreational activities and to a Saharan dust outbreak. The highest PM values were measured at the *Independencia* square, an area with many bus stops and high traffic density. During the winter campaign, three microaethalometers were used for Black Carbon measurement. Both pollutants also showed a

38 reduction in their concentrations when moving towards inside the park. For PM_{10} and $PM_{2.5}$,
39 reductions up to 50% were observed, while for BC this reduction was smaller, about 20%.

40 Capsule: A positive impact of vegetation on particle air pollution has been observed

41 *Keywords: air quality, atmospheric aerosols, urban aerosols, PM_x*

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43

44 **1. INTRODUCTION**

45 Air pollution is estimated to be the cause of 400 000 deaths per year in the EU (WHO, 2018)
46 and citizens living in urban areas are particularly vulnerable to this threat, due to the high
47 concentration of population and their proximity to numerous emission sources. Within cities,
48 areas with higher air pollutant concentrations than those in the surrounding areas are known
49 in air quality terms as “hotspots”. These places are usually characterized by large spatial and
50 temporal concentration gradients and people working or living in these areas have the
51 possibility of being exposed to elevated levels. Therefore, it is important to understand this
52 spatial and temporal distribution of airborne pollutants in urban hotspots for a risk assessment
53 study taking into account actual and representative air pollution levels and exposure.

54 Ozone and particles, especially those below 2.5 μm , are considered to be the most threatening
55 air pollutants for human health. Pascal et al. (2013) found that complying with the WHO
56 guideline of 10 $\mu\text{g}/\text{m}^3$ in annual mean for $\text{PM}_{2.5}$ (particle matter with aerodynamic diameter <
57 2.5 μm) would add up to 22 months of life expectancy, corresponding to a total of 19,000
58 deaths delayed in 25 European cities. Nature-based solutions are becoming increasingly
59 important for human societies facing the broad range of challenges in urban areas. Green
60 infrastructures provide essential ecosystem services that can be vital for city sustainability. A
61 number of studies have explored the link between urban vegetation and their positive effects
62 on air pollution as one of the most relevant ecosystem service (Pearlmutter et al., 2017).
63 Beckett et al. (1998) provide an interesting revision of woodlands role in reducing the effects
64 of PM_{10} (particle matter with aerodynamic diameter < 10 μm) pollution. For instance, they
65 established that already in Manning and Feder (1980) forest canopies were more effective at
66 capturing particles than any other vegetation type, due to their much greater surface
67 roughness that increases turbulent deposition and dry deposition processes by causing
68 localized increases in wind speed. In some experiments in windtunnels, Beckett et al. (2000)
69 confirmed that the particle removal efficiency is related with the particle Stokes number, the
70 particle inertia, so more complex structures of canopies can remove more pollution. In urban
71 parks, Silli et al. (2015) found similar results, higher removal for PM_{10} than for $\text{PM}_{2.5}$. The
72 vegetation cover effect on the particles has been modelled by several authors in more recent
73 studies. McDonald et al. (2007) modelled the effect of urban tree planting on concentrations
74 and depositions of PM_{10} and predicted that increasing total tree cover in West Midlands (UK)
75 from 3.7% to 16.5% would remove an additional amount of 110 ton per year of primary PM_{10}
76 from the atmosphere. Tallis et al. (2011) estimated the removal of atmospheric particulate
77 pollution by the urban tree canopy of London between 852 and 2121 tons of PM_{10} annually;

78 representing between 0.7% and 1.4% of the suspended PM₁₀ from the urban boundary layer.
79 Fares et al. (2016) studied the reductions in PM₁ (particle matter with aerodynamic diameter <
80 1 µm) in a Mediterranean area, Rome, with vegetation similar to Madrid. This study was later
81 enlarged to the Latium region by using image mapping to estimate the ecosystem services to
82 obtain the Leaf Area Index, modelling the PM₁₀ and ozone concentrations. No differences were
83 observed between the air pollutant removal in the urban center and in the region (Fusaro et
84 al., 2017). For gaseous pollutants, Alonso et al. (2011) demonstrated the effect of a peri-urban
85 forest as a significant O₃ sink for the Madrid city and Santiago et al. (2017) for NO₂. Yli-
86 Pelkonen et al. (2017) also found that concentrations of O₃ were significantly lower in tree-
87 covered habitats than in adjacent open habitats, but concentrations of NO₂ did not differ
88 significantly between tree-covered and open habitats. A review of the O₃ removal by trees can
89 be found in Sicard et al. (2018). Although this is not an exhaustive review of the studies on the
90 influence of the vegetation cover on the atmospheric pollutants, these references provide an
91 indication of the experimental work on this subject and its link with modelling aspects.
92 However, the number of direct empirical studies is limited, fewer than modelling studies.
93 Pearlmutter et al., 2017 compiles an updated review of ecosystem services provided by urban
94 forests as green infrastructures. Nevertheless, unlike other types of infrastructures, these are
95 more dynamic, more heterogeneous, and often more fragile – because they are alive, and
96 because of their complexity, their effect can be extremely variable depending on the species
97 used in urban forests. A review on urban vegetation and air pollution by Janhäll (2015)
98 concludes that although some studies publish limited datasets to validate models, extensive
99 experimental datasets, including a thorough description of the vegetation inside urban areas,
100 are needed to improve existing models.

101 The TECNAIRE-CM (Innovative technologies for the assessment and improvement of urban air
102 quality) research project is aimed at providing new methods for monitoring and modelling air
103 pollution that can consistently describe urban pollution dynamics from continental to street
104 scale in Madrid (Spain), a city seriously affected by pollution problems with PM₁₀ annual
105 average values of 38 µg/m³ and PM_{2.5} annual average values of 20 µg/m³. (Casquero-Vera et
106 al., 2019; Kassomenos et al., 2012; Ayuntamiento de Madrid, 2016). In the framework of this
107 project, several activities have been performed, including an analysis of the application of the
108 short term air quality action plan of the city council (Borge et al., 2018). Also the development
109 of intensive experimental campaigns has been carried out in two different hotspots for a
110 better understanding of urban pollution and its sources. The first case study focused on *Plaza*
111 *de Fernández Ladreda*, whose results can be found in Borge et al. (2016). The second location,

112 the *Escuelas Aguirre* area, is a complex urban environment where some of the main streets in
113 Madrid converge in the vicinity of a large park (*El Retiro*), with a clear influence of road traffic
114 (Santiago et al., 2017).

115 This paper assesses the impact of an urban park on a heavily trafficked area in Madrid, for one
116 of the main urban pollutants, particulate matter, by measuring two parameters: particle mass
117 concentration (PM_{10} , $PM_{2.5}$ and PM_1) and Black Carbon (BC) This last component (BC) is directly
118 related to traffic emissions and not affected by other particulate sources as dust outbreaks and
119 soil resuspension. This work is based on experimental data from two field campaigns
120 performed in summer 2016 and winter 2017. The data obtained in these campaigns will be
121 used to validate models on the effect of urban trees on particulate matter concentrations, in a
122 similar way as in Santiago et al. (2017) for the NO_2 case.

123 **2. Material and Methods**

124 **2.1. Study area description**

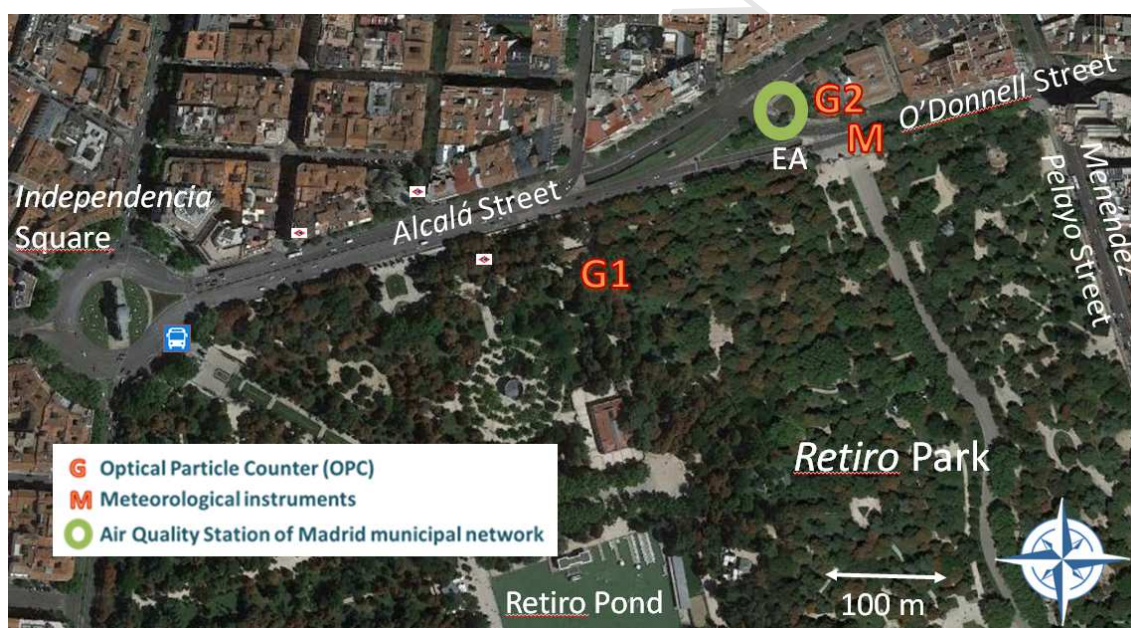
125 The Madrid metropolitan area is located in the center of the Iberian Peninsula and has more
126 than 5.5 million inhabitants, while the city is limited to 3.2 million (2017). The region comprises
127 a car fleet of 4.5 million vehicles, a high percent of which are diesel powered, accounting for
128 70.6% of total mileage within the city (Ayuntamiento de Madrid, 2018). Since the industry
129 installed in the region consists essentially of light factories, the Madrid plume is typically
130 urban, fed by traffic emissions and also by heating systems in winter. The climate in Madrid is
131 typical of a mid-latitude continental area, with hot dry summers and cold winters, most days
132 being under stability and clear-sky conditions.

133 The experimental campaigns have been performed in an urban area in downtown Madrid that
134 includes El Retiro Park, one of the largest and most popular parks in the city, a main landmark
135 in the city that is frequented by many people to work out and for other leisure activities. It has
136 125 hectares where more than 19 000 trees grow. More than 6 500 trees are horse chestnut
137 trees, representing 34.5% of the total forest mass. In a lower quantity, it is possible to find
138 plane trees (5%), Judas trees (4.1%) and the windmill palm (3.4%). There are also abundant
139 field maples, Atlas cedars, Mediterranean cypresses, European nettle trees, honey locusts,
140 holm oaks, stone pines, privets, almonds and some others, being more than 300 trees for each
141 type. Most of the paths inside the park are unpaved so dust resuspension is common,
142 especially during small van transects and some recreational activities like running. Differences
143 were observed when there was a pedestrian, a runner and a group of runners, from light to

144 intense dust resuspension. Traffic is not allowed to general public inside the park although
 145 maintenance vehicles circulate occasionally and cycling and skating are common activities.

146 In the study area, there are several main streets and avenues around Retiro Park with intense
 147 road traffic and one of the main squares in the city, *Independencia Square* (Figure 1). An air
 148 quality monitoring station (*Escuelas Aguirre*, EA) belonging to the municipal network is located
 149 in a small garden close to the intersection of the two most important avenues in the area
 150 (*Alcalá* and *O'Donnell Streets*). In this station, there were 15 daily exceedances for PM₁₀ limit
 151 value ($50 \mu\text{g m}^{-3}$ not to be exceed >35 times a year) in 2015 and recorded some of the highest
 152 annual averages (22, 24 and $25 \mu\text{g m}^{-3}$) and maximum daily values (68, 97 and $71 \mu\text{g m}^{-3}$) in
 153 Madrid, for the years 2013-2015 (Ayuntamiento de Madrid, 2016), after discarding those
 154 attributed to the natural sources like African dust outbreaks by a contrasted methodology
 155 (Escudero et al., 2007), according to the EU Directive.

156



157

158 Figure 1. Study area. It includes the locations of Grimm instruments (G1 inside the park and G2
 159 in *Escuelas Aguirre*), the bus stop (in blue), the local meteorological station (M) and an air
 160 quality station (green circle).

161

162 2.2 Periods of campaign and instrumentation

163 The first campaign (summer) was carried out in summer from 15 June to 15 July 2016, when
 164 the temperatures were high, with no rain, and a well developed mixing layer during daytime.

165 The second one (winter) took place from 25 February to 20 March 2017, with colder
166 temperatures, clear skies most of the time and a shallower mixing layer. Besides
167 meteorological conditions, the vegetation and pollutant characteristics were also rather
168 different in both campaigns, giving a wide range of scenarios to be studied.

169 The atmospheric particle mass concentrations for the size fractions PM_{10} , $PM_{2.5}$ and PM_1 were
170 measured in diverse locations in the study area. Several instruments were deployed to reach
171 this goal (Figure 1). An Optical Particle Counter Grimm 1107 instrument (Grimm and Eatough,
172 2009; Marcq et al., 2010), G1, was installed inside the park, 30 m South of the park fence and
173 at the roof of a 3 m high building. A second Grimm 365, G2, was located close to the municipal
174 monitoring station located in *Escuelas Aguirre* outside the park and 2 meters high. Both
175 instruments measured the particle mass concentrations in the three size ranges
176 simultaneously throughout the campaign.

177 Additionally to the fixed monitoring instruments, some dynamic measurements were also
178 performed in the area. A TSI DustTrak DRX instrument (Tasić et al., 2012; Rivas et al., 2017;
179 Viana et al., 2015; Fares et al., 2016) was used to measure particulate matter (PM_{10} and $PM_{2.5}$)
180 concentration levels. This was achieved by measuring at several points around the
181 experimental area and by walking with the instrument around this area at a mean adult height
182 respiration level. These transects were done during both campaigns and took between 15 and
183 30 minutes, depending on the selected transect, and covered 1 km and 2 km length
184 respectively. Because the area is large, the transects have been divided in four: two
185 longitudinal ones along the *Alcalá* Street (the first transect is from *Independencia* Square to *El*
186 *Retiro* underground station and the second case from this last point to *Menéndez Pelayo*
187 Avenue, both are shown in section 3.1.3), a perpendicular transect to *Alcalá* Street and inside
188 the *El Retiro* Park (not discussed and shown in this paper). Several paths inside the park, mainly
189 parallel to *Alcalá* street were covered to understand concentration changes depending on the
190 distance to *Alcalá* street: in the street itself, 20 and 200 meters away from it. Some other short
191 transects and measurements at singular points like a bus stop in *Independencia* square have
192 also been performed. The bus stop selected was one located in the Southwestern sector of
193 the *Independencia* square (shown in Figure 1), a heavily trafficked roundabout with very
194 frequent bus transit (one bus every two minutes on average during the measurements). In
195 total 13 transects during 6 different days were made, covering both weekdays and weekends,
196 as well as 3 measurement series in the bus stop during 3 days. The data collection frequency
197 was 6 seconds and the data obtained for every transect were averaged to represent that

198 transect. Among all these transects, the most interesting cases have been selected and
199 discussed in the following sections.

200 Prior to the campaigns, the optical instruments and the DustTrak were compared to a High
201 Volume Samplers (HVS) and the correction factors obtained were used to correct the raw
202 measurements. The comparison between HVS and the optical instruments showed good
203 correlations. The main results can be found in the supplementary material. The TSI DustTrak
204 DRX instrument was used in both campaigns: summer and winter.

205 Black Carbon (BC) measurements were also obtained in a dynamic measurement pattern only
206 during the winter campaign with three microaethalometers (microAeth® model AE51,
207 Aethlabs; Cai et al. 2014; Viana et al., 2015) at $\lambda = 880$ nm and a cut-off size of $2.5 \mu\text{m}$. The flow
208 rate was 0.1 L min^{-1} and the sampling time 60 s. Prior to the campaigns, these
209 microaethalometers were compared to a multi-wavelength aethalometer (Magee Sci. mod.
210 AE33, Aerosol d.o.o) ($\lambda = 370, 470, 520, 590, 660, 880, \text{ and } 950 \text{ nm}$) with a cut-off size of $10 \mu\text{m}$
211 and a flow rate of 5 L min^{-1} obtaining good correlations (R^2 around 0.75) and a correction
212 factor for every microaethalometer (slopes between 1.17 and 1.24) that has been applied to
213 all the raw data. The main results concerning this correction can be found in the
214 supplementary material, figure S2. Although both instruments have different cut-off sizes, as
215 the BC is usually found in the finer fraction of particles, no differences should be observed
216 because of this reason.

217 These aethalometers allowed a different approach during four days to the dynamic
218 measurements performed in the summer campaign. For two days, aethalometers were
219 installed in three different points parallel or perpendicular to the *Alcalá* Street. These points
220 were moved progressively after a sampling period towards inside the park. While these
221 sensors remained in their positions, the DustTrak was moving in a similar way as in the
222 summer campaign performing different transects. A third day was dedicated to the
223 *Independencia* Square at the bus stop location, and a fourth day was spent in some of the
224 streets in the Northern side out the park. As BC is directly related to traffic emissions, these
225 particles can show the role of green areas in mitigating these emissions.

226 A meteorological station was also installed at the experimental area to fully characterize the
227 local meteorological conditions (Figure 1). It was composed of three instruments: Vaisala
228 Weather Transmitter, thermohygrometer and pyranometer. Firstly, a *Vaisala Weather*
229 *Transmitter WXT520* provided six weather parameters: wind speed, wind direction,
230 precipitation, atmospheric pressure, air temperature and relative humidity. Besides, a

231 pyranometer (*Apogee SP-100*) recorded the downward short wave radiation (direct and diffuse
232 radiation) and a thermohygrometer (*Rotronic HC2-S3*) completed this set of measurements
233 with additional temperature and relative humidity data. Turbulent parameters were evaluated
234 from a *Young 8100* sonic anemometer data, which corresponded to the three wind
235 components (u,v,w), and estimated air temperature from the air density. This instrument
236 worked at a high sampling frequency (20 Hz) in order to obtain a really good temporal
237 resolution. The typical climatological variables (1981-2010) in the area for the summer
238 campaign period are 23.9°C, 16 mm of rain, 41% relative humidity, 2 days with precipitations
239 above 1 mm. For the winter campaign, these variables are: 11.2°C, 25 mm of rain, 55% relative
240 humidity, 4.1 days with rains above 1 mm (AEMET, 2018).

241 Long range transport processes of dust laden African air masses affected all the observed PM
242 concentrations during both campaigns. These phenomena have been documented by a robust
243 methodology (Escudero et al., 2007; Viana et al., 2010) and their impact on the Madrid area is
244 well documented (MAPAMA, 2017).

245 **3. RESULTS AND DISCUSSION**

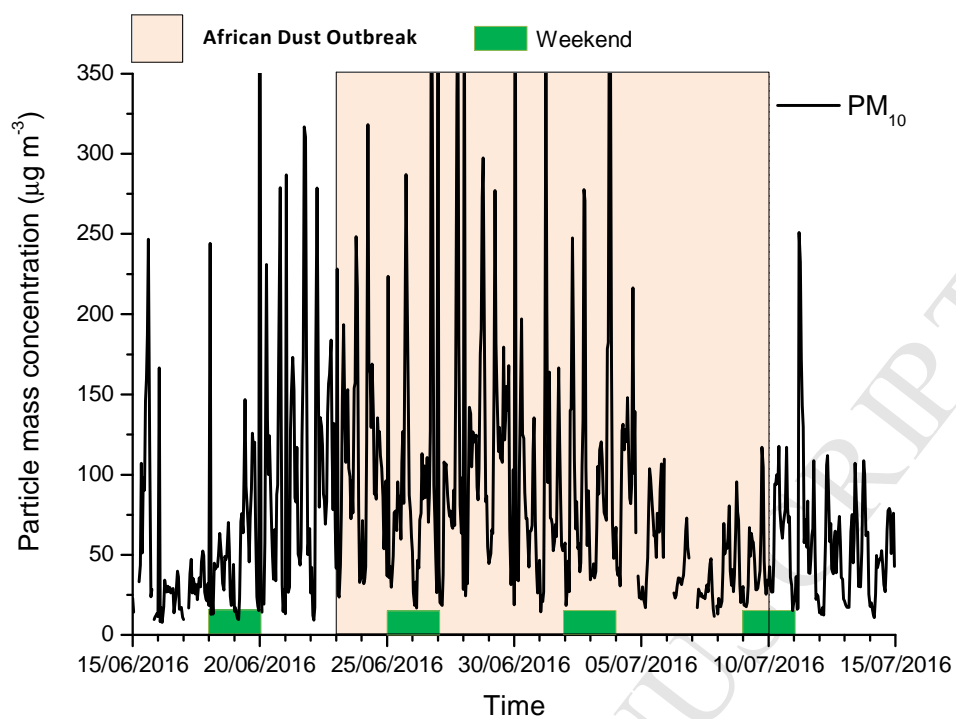
246 **3.1. Results and discussion for summer campaign**

247 3.1.1. Meteorological conditions

248 Figure S3 shows both the local measurements and the regional situation in the Madrid area.
249 The results obtained in both stations were similar, except for the wind speeds and directions.
250 This campaign took place during a warm period, warmer than usual, coinciding with air masses
251 coming from North Africa and with maximum temperatures up to 35°C, and with an average
252 relative humidity around 35% and minima of 20% in the local measurement site. Such dry and
253 hot weather provides favorable conditions for soil particle resuspension. The regional wind
254 speed was moderate, with an average value of 3.7 ms⁻¹ and without long calm periods (wind
255 speed below 2 ms⁻¹ in the regional measurements) during the campaign. Most of the days, it
256 was possible to reach values of 4 ms⁻¹ during several hours with peaks close to 10 ms⁻¹ around
257 the 26th. No significant rain occurred during the whole campaign.

258 3.1.2. PM ambient concentrations

259



260

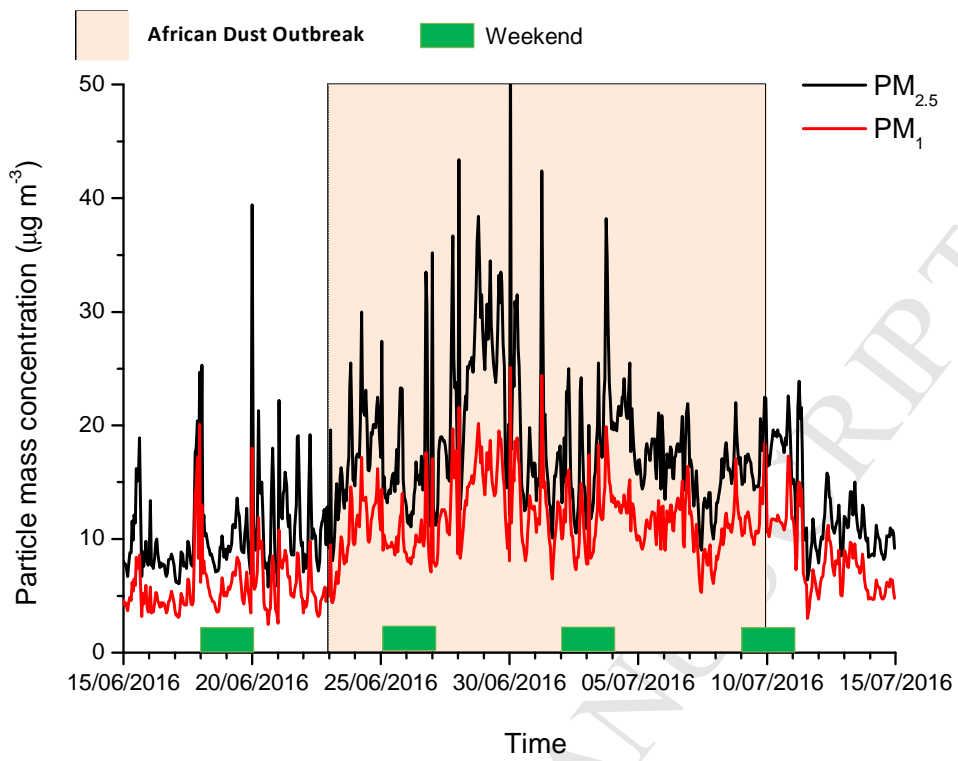
261 Figure 2a

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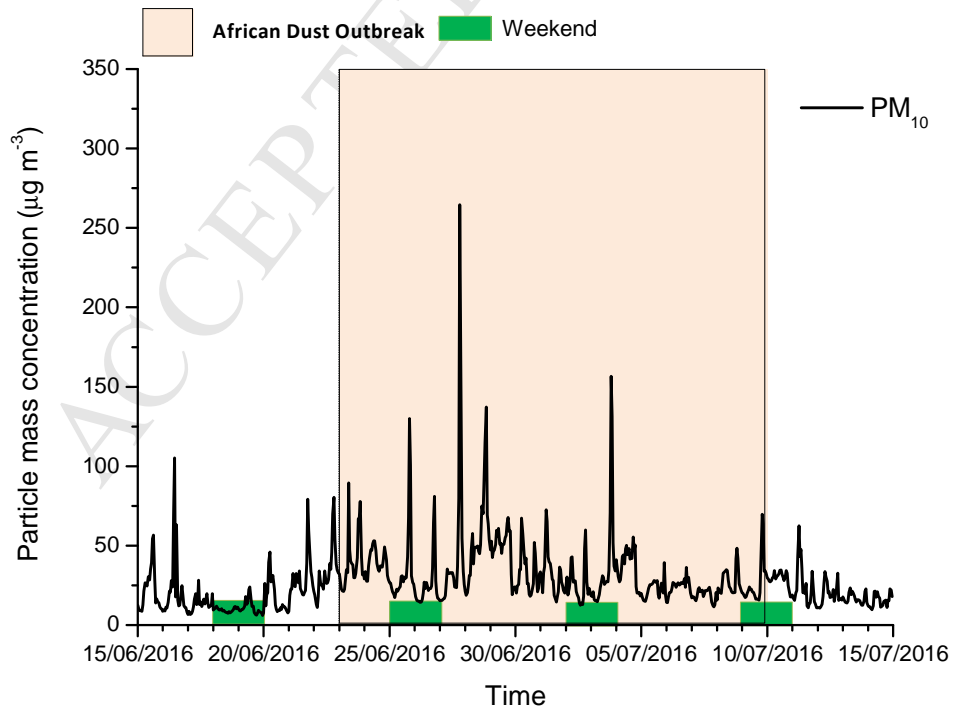
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267 Figure 2b

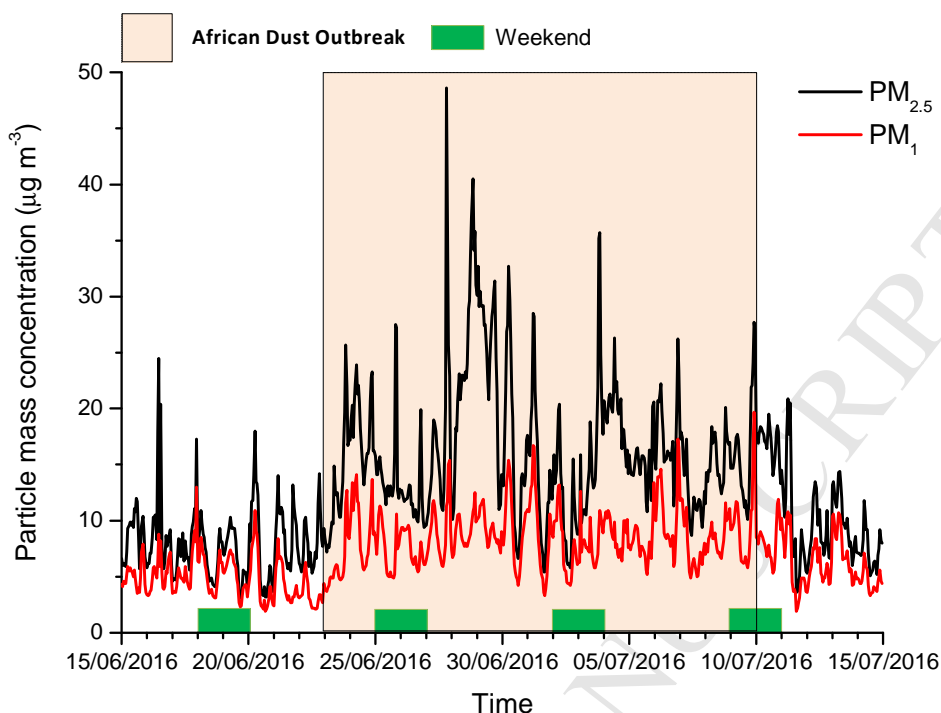
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270 Figure 2c

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273 Figure 2d

274 Figure 2. PM_{10} , $PM_{2.5}$ and PM_1 concentration measured in (a-b) *El Retiro* and (c-d) *Escuelas*
 275 *Aguirre* sites measured by the two Grimm instruments during the summer campaign. The
 276 period with Saharan dust outbreak is marked.

		Average values	SD	Maximum	Minimum
El Retiro Grimm (G1)	PM_{10} ($\mu\text{g m}^{-3}$)	79.3	71.5	564.9	9.3
	$PM_{2.5}$ ($\mu\text{g m}^{-3}$)	15.4	6.4	53.9	5.8
	PM_1 ($\mu\text{g m}^{-3}$)	9.6	4.0	25.1	2.5
Escuelas Aguirre Grimm (G2)	PM_{10} ($\mu\text{g m}^{-3}$)	27.9	20.5	264.5	6.2
	$PM_{2.5}$ ($\mu\text{g m}^{-3}$)	13.2	6.6	48.6	3.1
	PM_1 ($\mu\text{g m}^{-3}$)	7.2	2.9	19.7	1.9

277

278 Table 1. Average concentrations, standard deviation (SD), maximum and minimum particulate
 279 matter concentrations in the fractions PM_{10} , $PM_{2.5}$ and PM_1 during the summer campaign
 280 period in both sites.

281 It is clear that the highest PM_{10} concentrations were measured inside the park. This was
 282 caused by the resuspension of the particles from the soil as it is unpaved and mainly in the
 283 coarse fraction $PM_{2.5-10}$. Several activities, like sports, and the wind effect produced this

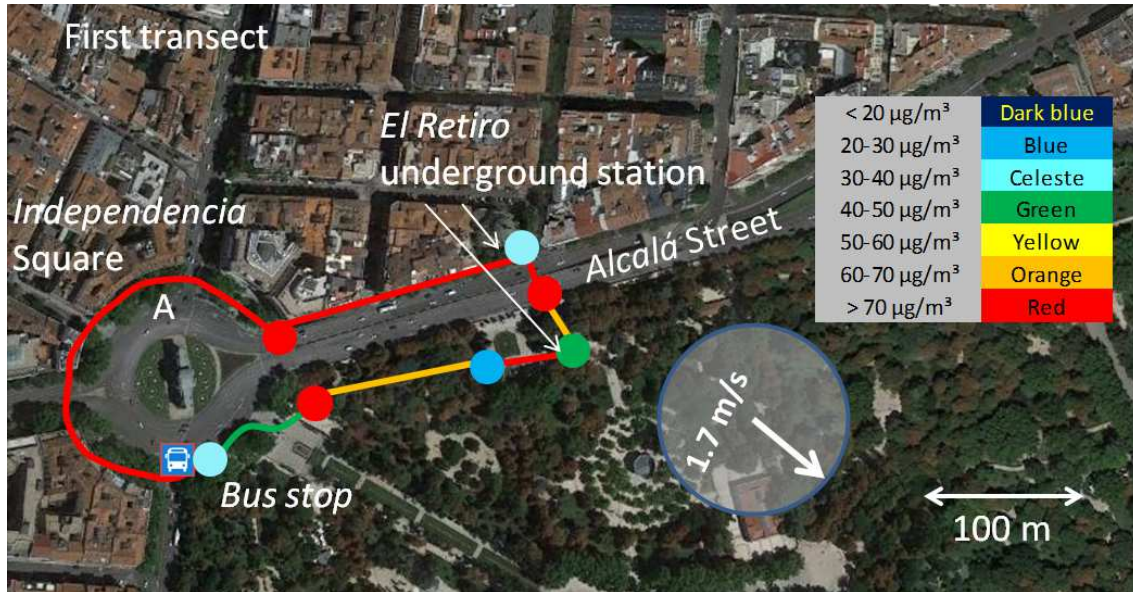
284 resuspension. $PM_{2.5}$ and PM_1 were less affected by resuspension and the concentrations were
285 similar in both sites. The particulate matter concentration measured was significantly related
286 to the Saharan dust outbreak that occurred over the period 23 June to 10 July, as shown in
287 figure 2. This can be observed given that most of the particulate matter (75 % for G1 and 50%
288 for G2 averaged during the period 23 June to 5 July) was in the coarse fraction $PM_{2.5-10}$. The
289 number of daily and hourly exceedances in both Grimm instruments can be found in table S1.
290 The PM_{10} series in both instruments started to increase their values before the African air
291 masses arrived at the site because of unknown reasons, while both, the $PM_{2.5}$ and PM_1 started
292 to be affected at the approximate time that the air masses arrived according to the models
293 (MAPAMA, 2017). The highest impact is observed in the PM_{10} fraction indicating that the
294 Saharan particles are mostly included in the size range between 2.5 and 10 μm , although they
295 are also measured in PM_1 . Another interesting aspect is that during the Saharan dust period,
296 the lowest concentrations, measured by *El Retiro* Grimm during nighttime were high, reaching
297 hourly values above $25 \mu\text{g m}^{-3}$ several nights with a maximum concentration of $50 \mu\text{g m}^{-3}$,
298 being mainly affected by this dust and very little by local emissions. The influence of Saharan
299 dust outbreak was confirmed by the measurements from the DustTrak instrument as it will be
300 discussed in the next section. At the end of this period, it was a cleaning up of the lower
301 troposphere by ventilation caused by stronger winds that reduced surface concentrations for
302 all the size fractions.

303 The Saharan dust outbreak hampered the influence of other different sources. Only in the case
304 of *El Retiro* Grimm, dust resuspension caused by human activities like gardening or running
305 had a significant impact on observed PM_{10} values. As these activities are not continuous, they
306 are detected by a noisier series for both instruments: Grimm and DustTrak.

307 3.1.3. Dynamic measurements of particulate matter

308 A DustTrak was used during walking transects in the area, see figure 3.

309



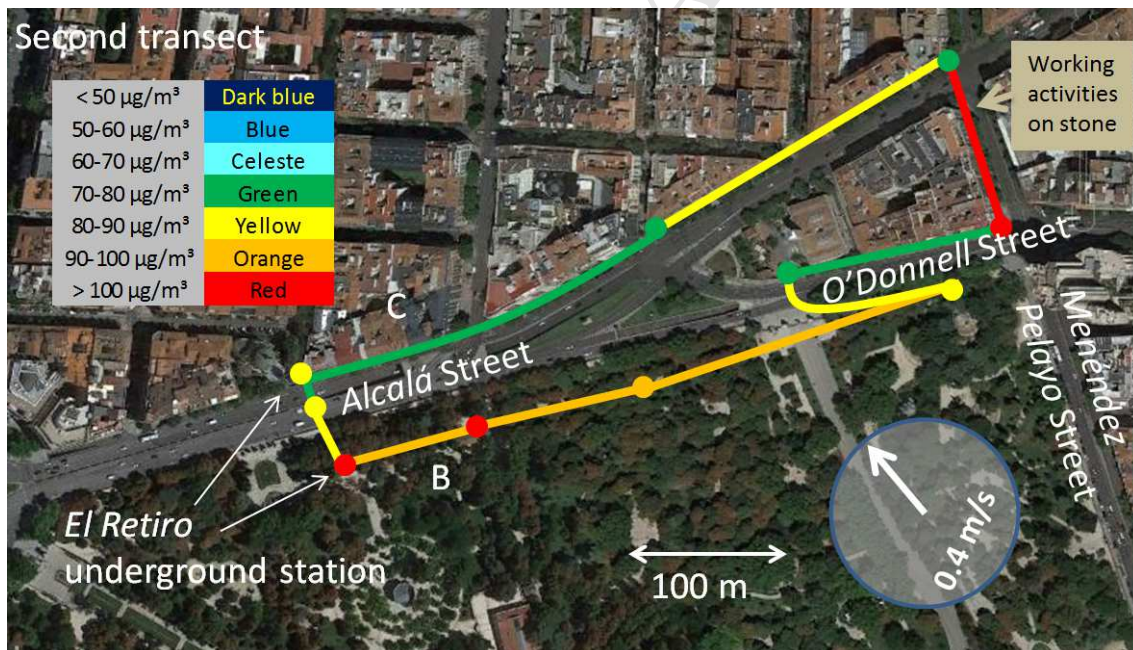
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Figure 3a

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Figure 3b

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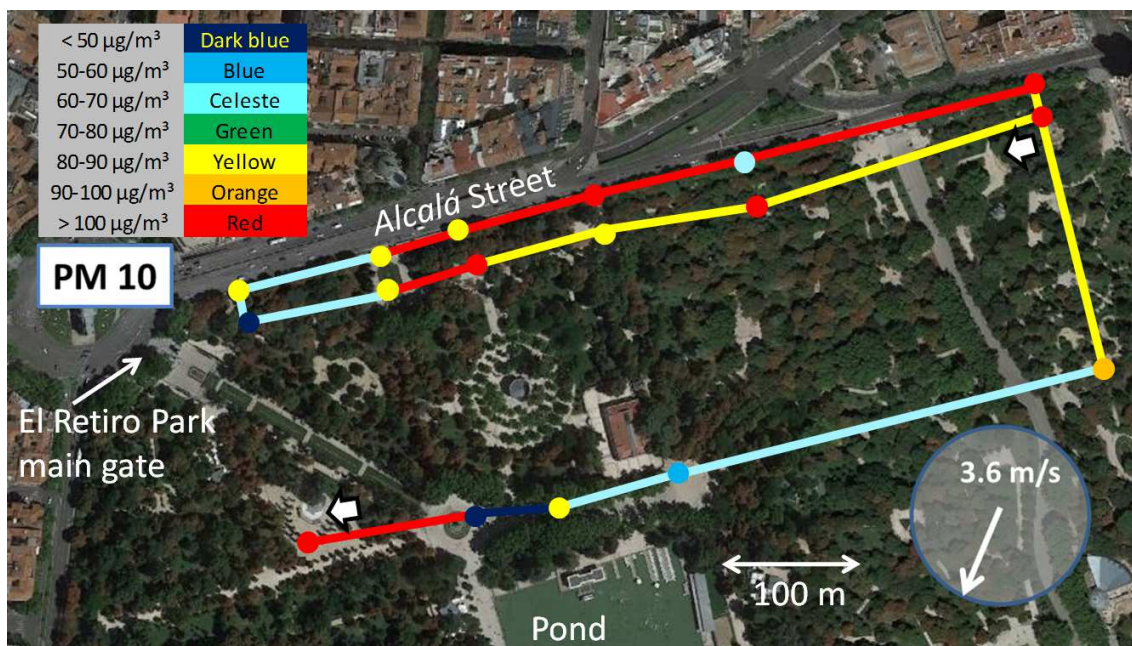
Figure 3. PM_{10} measured with the DustTrak during the longitudinal transects performed along the *Alcalá Street* (a) 21 June 2016 10:05-10:30 UTC and (b) 24 June 2016 08:03-08:37 UTC. This figure includes points, where the measurements were static for a short period (1 minute), and lines, where the measurements were dynamic, while walking. It includes the averaged wind

320 speed and direction measured at regional scale during that period as it is more representative
321 for vortex formation.

322 Some results regarding PM_{10} for the two longitudinal transects during 21 and 24 June are
323 shown in Figure 3 (a) and (b), respectively and some statistical analyses can be found in the
324 supplementary material, tables S2 and S3 and figures S4 and S5. The PM_{10} concentrations were
325 high according with the values obtained by the Grimm instruments those days. The 21 June
326 was previous to the Saharan dust event, but during the 24 June high dust concentrations due
327 to the Saharan outbreak were already detected. The 21 June, the DustTrak data showed that
328 the highest values were measured at the *Independencia Square* (left in Figure 3a), a heavily
329 trafficked area, with high intensity of (mostly diesel) buses. The measurements taken at the
330 bus stop selected for the study in this square revealed high PM_{10} values when the diesel buses
331 stopped and lower for Compressed Natural Gas (CNG) buses. The high values obtained in the
332 opposite side of the square (marked A in the figure) can be explained by the formation of a
333 vortex because of the wind direction and the presence of buildings. This vortex drags the
334 particles emitted in the bus stop area to the other side of the square. The *Alcalá Street* side
335 closer to *El Retiro* showed lower values pointing to an influence of the vegetation in the
336 particulate matter levels inside the park.

337 This result contrasts with the results for the 24 June, when higher concentrations were
338 measured inside the park (marked B) than outside (marked C) (except a point affected by some
339 works on the pavement). This could be also caused by the formation of a vortex as during the
340 21 June. In this case the wind direction is the opposite transporting the particles from the
341 street to the park.

342

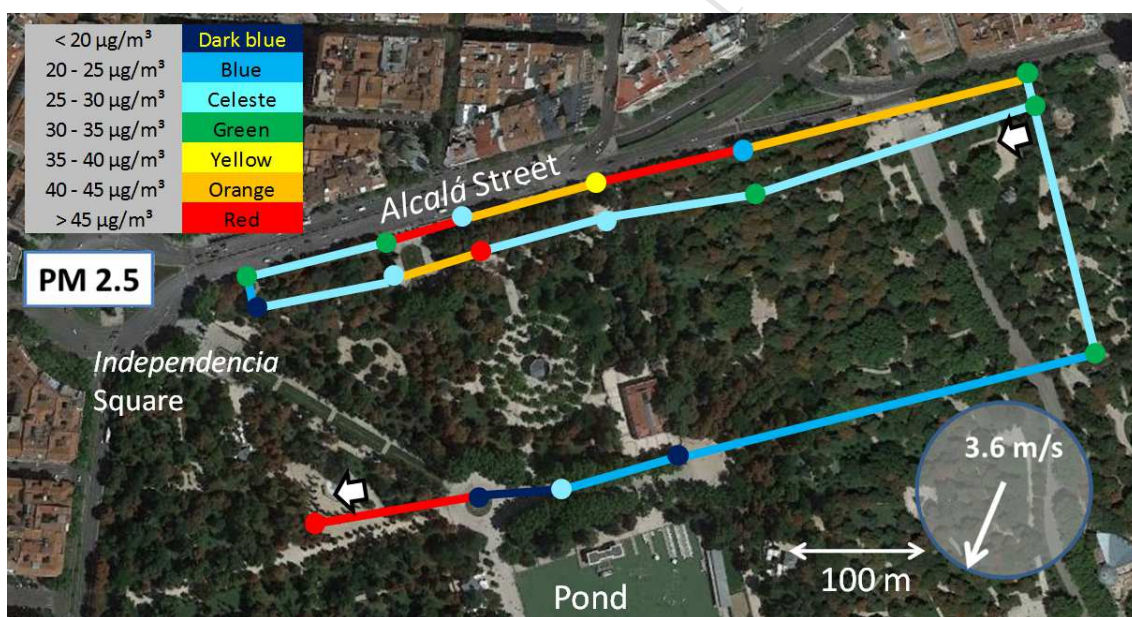


343

344

Figure 4a

345



346

347

Figure 4b

348 Figure 4. (a) PM₁₀ and (b) PM_{2.5} measured with the DustTrak during the transects performed
 349 inside *El Retiro* park on 1 July 2016 10:17-11:10 UTC. This figure includes points, where the
 350 measurements were static for a short period (1 minute), and lines, where the measurements
 351 were dynamic, while walking. The white arrows indicate the initial and final points of the
 352 transect.

353 Some additional measurements were carried out the 1st of July to clarify this point, following
354 transects parallel to the *Alcalá* Street at different distances from it. The results obtained can be
355 observed in figure 4 for (a) PM₁₀ and (b) PM_{2.5}, and some statistical analyses can be found in
356 the supplementary material, table S4 and figure S6. Both results are similar, with the
357 maximum values along the *Alcalá* Street sidewalk which decrease as we moved away from this
358 and inside the park. In the street sidewalk, the PM₁₀ average concentrations for some transect
359 fractions were higher than 100 µg m⁻³, and they decreased down to around 85 µg m⁻³ in the
360 first park path, around 20 meters inside. These PM₁₀ values decreased much more at 200
361 meters down to even 50 µg m⁻³. The highest concentration at this distance was observed in the
362 area between the main gate (*Independencia* square) and the pond, where more pedestrians
363 and runners were found, together with a dry sand soil. PM_{2.5} measurements (Figure 4b)
364 showed a similar behavior, with the maximum values found in the points close to the traffic
365 lane of the street (around 45 µg m⁻³) and in the area with higher pedestrian activity. These
366 concentrations decreased as the sampling location was moved away from the traffic lanes,
367 being 30 µg m⁻³ at 20 meters and 20 µg m⁻³ at 200 meters. This meant that the urban plant
368 cover together with the distance can produce a reduction in the particle concentration around
369 50% under the meteorological situation corresponding to these measurements.

370 **3.2. Results and discussion for winter campaign**

371 During the winter campaign, the plant cover density was smaller than in the summer, as the
372 deciduous species have lost their leaves, especially the plane trees, which show a very
373 important activity during the summer. However, the evergreen species are also numerous
374 (21% of the trees), so the vegetation cover is not negligible at all during this period.

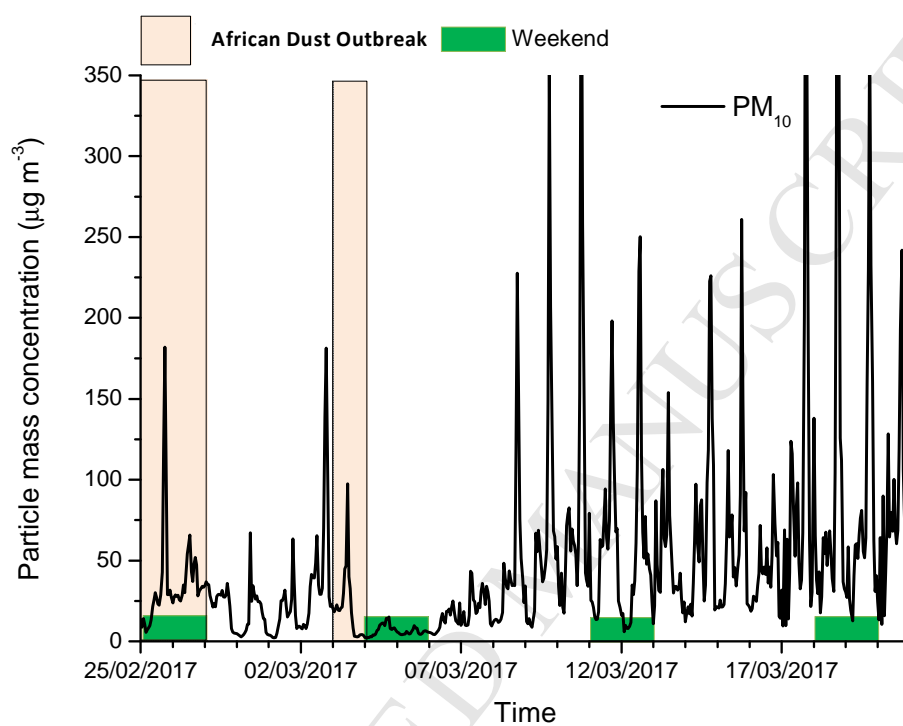
375 3.2.1. Meteorological conditions

376 The 2017 winter was rather mild in Madrid, warmer than usual, as it can be seen in the data
377 measured by the regional and local meteorological stations (figure S3). As in the summer
378 campaign the results obtained in both stations were similar, except for the wind speeds and
379 directions. Maxima daily temperatures above 20°C were reached over the periods 7-11 and 14-
380 20 March, at the same time that the wind speeds were low at regional scale, with maximum
381 values of 4 ms⁻¹ during some short times. There were other colder periods, with temperatures
382 generally below 10°C and high wind speeds, with values close to 10 ms⁻¹ and constant wind
383 direction (from NE), especially in the period 12-14 March. The relative humidity remained
384 relatively low during the central period characterized by high temperatures and stronger wind

385 speeds and high during the initial and ending periods of the campaign. Weak-rainy events
386 were observed only during a day of the campaign (3 March). Its effects can be observed in PM
387 concentrations.

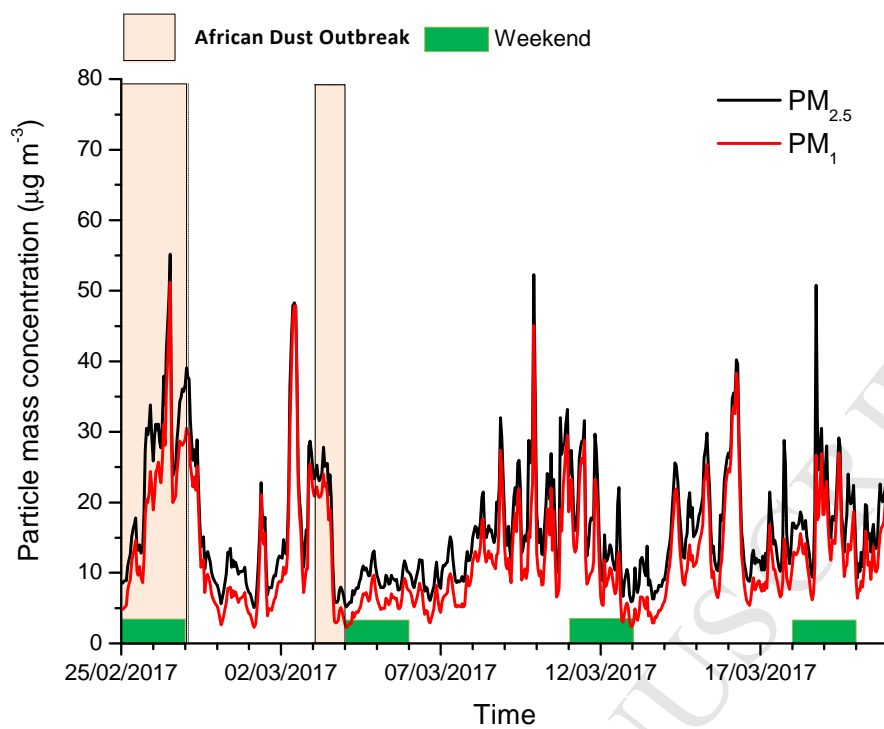
388 3.2.2. PM ambient concentrations

389



390

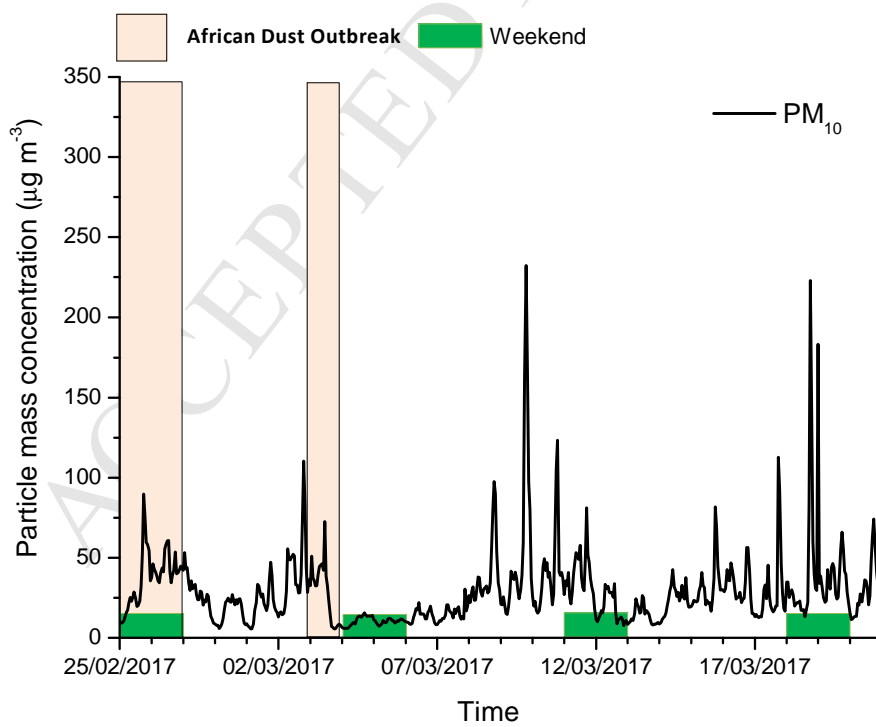
391 Figure 5a



392

393 Figure 5b

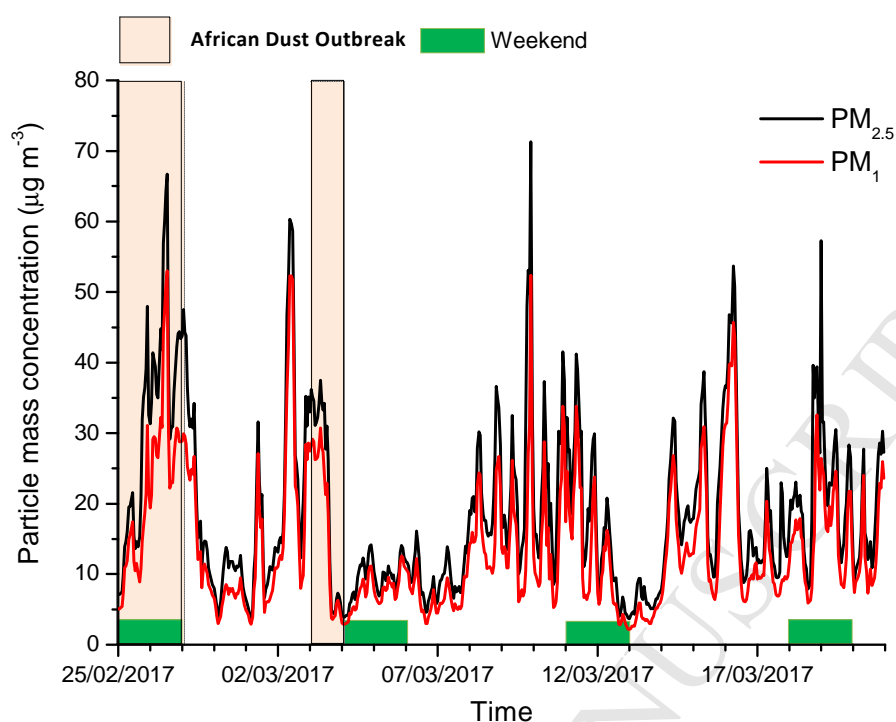
394



395

396 Figure 5c

397



398

399 Figure 5d

400 Figure 5. PM₁₀, PM_{2.5} and PM₁ measured in (a-b) *El Retiro* and (c-d) *Escuelas Aguirre* sites by
 401 two Grimm instruments during the winter campaign. The periods with Saharan dust outbreak
 402 are marked.

		Average values	SD	Maximum	Minimum
El Retiro Grimm (G1)	PM ₁₀ (µg m ⁻³)	65.3	78.6	912.7	8.6
	PM _{2.5} (µg m ⁻³)	16.6	8.8	55.2	5.1
	PM ₁ (µg m ⁻³)	12.6	8.3	51.2	2.3
Escuelas Aguirre Grimm (G2)	PM ₁₀ (µg m ⁻³)	29.0	24.1	232.5	5.5
	PM _{2.5} (µg m ⁻³)	18.9	12.2	71.3	3.6
	PM ₁ (µg m ⁻³)	14.0	9.5	53.0	2.2

403

404 Table 2. Average concentrations, standard deviation (SD), maximum and minimum particulate
 405 matter concentrations in the fractions PM₁₀, PM_{2.5} and PM₁ during the winter campaign period
 406 in both sites.

407 Average, standard deviation, maximum and minimum concentrations can be found in table 2.

408 During this campaign the particle mass concentrations measured by the Grimm instruments

409 were lower than during the summer campaign, but again PM₁₀ concentrations measured inside

410 the park, with unpaved paths, were significantly higher than those measured outside because

411 of the same reason, the soil resuspension. During 25-26 February and 3 March, there was a
412 Saharan dust outbreak and particulate mass concentrations were high. It was not a strong
413 outbreak (MAPAMA, 2017), so the instruments did not measure the maximum PM_{10} values
414 during these periods, but the $PM_{2.5}$ and PM_1 values were high, with $PM_{2.5}$ and PM_1 hourly
415 concentrations close to $50 \mu\text{g m}^{-3}$. During the warmer days, an accumulation period occurred
416 and high concentrations were reached. The Grimm instrument located at *Escuelas Aguirre*
417 showed its highest values in these days, the periods 8-12, 14-16 and 18-20 March. Between
418 these periods, the concentrations decreased due to the ventilation of the area due to the
419 higher wind speeds. The accumulation episode is clear in the $PM_{2.5}$ and PM_1 values; in both
420 cases the daily minimum concentrations were higher than during other periods. $PM_{2.5}$ reached
421 values of 40 and PM_1 of $30 \mu\text{g m}^{-3}$. The Grimm instrument located inside *El Retiro* showed a
422 similar behavior.

423 3.2.3. Dynamic measurements of particulate matter

424

425 The most interesting results were those obtained for the measurements inside the park
426 showing a better repeatability along time than during the summer campaign. An example of
427 the results can be found in figures 6 and 7 and some statistical analyses can be found in the
428 supplementary material, tables S5 and S6 and figures S7 and S8.

429 The transects done with the DustTrak during the 16th March can be found in the figure 6 for
430 PM_{10} and $PM_{2.5}$. These results gave high concentrations in the sides close to the *O'Donnell* and
431 *Menéndez Pelayo* streets and lower as the transects were towards inside the park. For
432 example in figure 6a, PM_{10} in both streets reached values of $70-80 \mu\text{g m}^{-3}$ while inside the park
433 values as low as $25-30 \mu\text{g m}^{-3}$ could be measured. This means that reduction up to 60% could
434 be observed in particular cases. In figure 6b, the $PM_{2.5}$ could reach values close to $30 \mu\text{g m}^{-3}$ in
435 both street sides, but it was reduced to $15-10 \mu\text{g m}^{-3}$ inside the park. This 50% of reduction
436 could be caused by the distance to the emission points, i.e. by dry removal, and the barrier
437 effect caused by the plant cover located in the area.

438



439

440 Figure 6a



441

442 Figure 6b

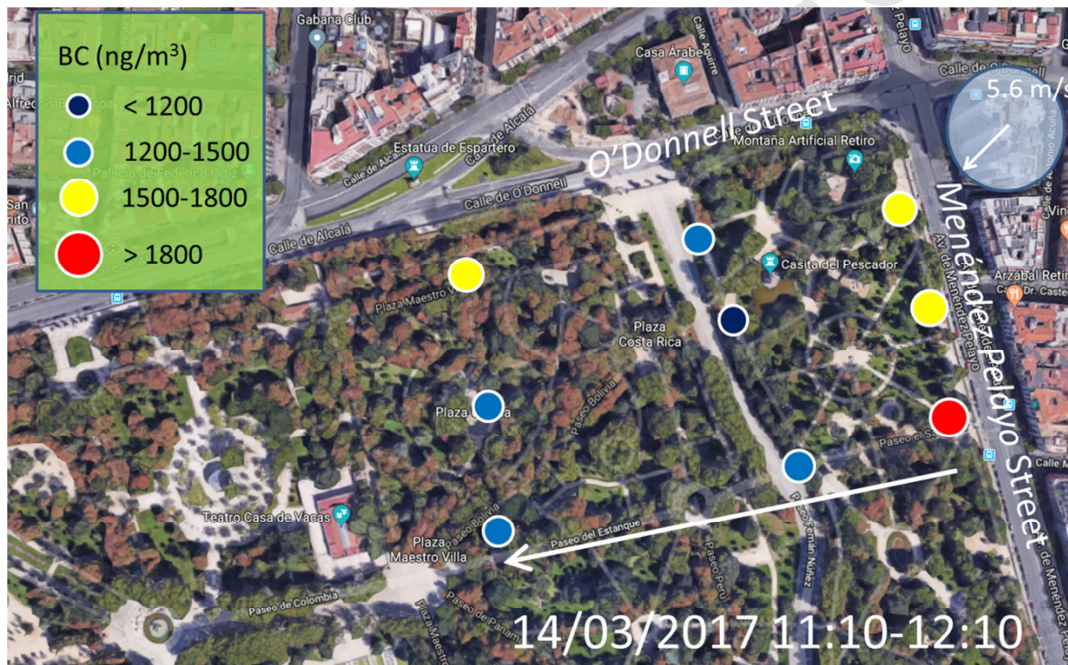
443 Figure 6. (a) PM_{10} and (b) $\text{PM}_{2.5}$ measurements during the 16 March 2017 11:05-11:25 UTC
 444 inside the *El Retiro* park for different transects.

445 The results obtained with the microaethalometers also showed the same trend as the
 446 DustTrak. The BC measurements provided an interesting picture with the highest values in the
 447 *Menéndez Pelayo* street (that perpendicular to *O'Donnell* street, at the East side of *El Retiro*
 448 park) and decreasing as moving towards inside the park. In the North-South direction, the

449 decrease in the BC concentration was also clear, from 1530 to 1220 ng m⁻³ at 100 meters,
450 which represents a 20% reduction for these measurements. The lower decrease in the BC
451 concentration in PM₁ compared with the decrease in the particulate matter in PM_{2.5} can be
452 caused by the presence of resuspended particles, not emitted by cars and with low BC
453 concentration in the fraction PM_{1-2.5}. This fraction is easier to remove by inertia mechanisms
454 when the wind interacts with the tree canopies producing a stronger decrease. The higher
455 concentration gradients for PM₁₀ could also be explained because particles included in this
456 fraction are easier removed by this same mechanism than PM_{2.5}.

457

458



459

460 Figure 7a

482 show certain dispersion in the results because of the relative influence of many parameters
483 such as particle size, flow recirculation, vegetation properties (hairiness, stickiness, thickness
484 of leaves, porosity, etc), meteorology, nearby emissions and others. There are also different
485 kinds of approaches, with long periods of measurements obtaining average values or with
486 short periods obtaining values easier to relate to the boundary conditions, i.e. meteorological
487 conditions. Individual analysis for every case is required to understand the parameters
488 influencing the effects of vegetation on air pollution and the distance effect.

489

490 **4. CONCLUSIONS**

491 Two field campaigns in different seasons of the year (summer and winter) have been carried
492 out in a complex hotspot in Madrid, very close to a large urban park (El Retiro). In both of
493 them, a positive impact of vegetation reducing air pollution has been clearly observed as
494 measured PM_{10} , $PM_{2.5}$ and BC concentrations in points affected by traffic were higher than
495 those measured inside the park, 200 m away from the street.

496 During the summer campaign, higher particulate mass concentrations were measured linked
497 to some Saharan dust outbreaks. It was possible to observe that the highest values were
498 measured in the *Independencia* square, an area with high traffic density, especially affected by
499 buses. In the transects inside the *El Retiro* park, a decrease in the PM_{10} and $PM_{2.5}$
500 concentrations of up to 25% at 20 meters and 50% at 200 meters was observed. High PM_{10}
501 values inside the park were linked to dust resuspension caused by human activities like garden
502 maintenance or running.

503 The winter campaign showed similar results. Observed concentrations were strongly
504 conditioned by atmospheric stability. Maxima values were observed during accumulation
505 periods associated to these stability events during 8-12, 14-16 and 18-20 March when the
506 pollutants reached the highest values. Similarly to the summer campaign, strong spatial
507 concentration gradients were observed near the borders of the park. For PM_{10} and $PM_{2.5}$,
508 reductions up to 50% were observed at 200 meters from the street, while for the BC case was
509 smaller, only 20%. The possible reason for the smaller BC removal is that it is included in the
510 PM_1 fraction, less affected by the inertia mechanism for particle removal by the tree canopies.

511 Although there is a high scattering in the results published in previous works on the effect of
512 vegetation on air pollution, the reductions measured in this work are globally larger than those
513 observed or modelled in those previous cases. The probable reason is that the short sampling

514 time used in this work indicates periods where maximum values were reached instead of an
515 average value as it is usually performed in other experimental studies. For a better
516 understanding, to know what extent concentration reduction is due to vegetation or simply to
517 distance from the source it would be necessary to perform modelling exercises to evaluate
518 whether these pollution reductions are only caused by the vegetation cover or also other
519 factors like distance are influencing the concentration values. CFD (Computational Fluid
520 Dynamics) modelling considering different permeability for the vegetation barriers may be
521 particularly relevant.

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527 Declarations of interest: none

528

529 REFERENCES

530 AEMET (2018)

531 [http://www.aemet.es/es/serviciosclimaticos/datosclimatologicos/valoresclimatologicos?l=319](http://www.aemet.es/es/serviciosclimaticos/datosclimatologicos/valoresclimatologicos?l=3195&k=mad)
532 [5&k=mad](http://www.aemet.es/es/serviciosclimaticos/datosclimatologicos/valoresclimatologicos?l=3195&k=mad). (accessed 07.11.2018).

533 Al-Dabbous, A.N. and Kumar, P., 2014. The influence of roadside vegetation barriers on
534 airborne nanoparticles and pedestrians exposure under varying wind conditions. *Atmospheric*
535 *Environment* 90, 113-124.

536 Alonso, R., Vivanco, M. G., González-Fernández, I., Bermejo, V., Palomino, I., Garrido, J. L.,
537 Elvira, S., Salvador, P. and Artíñano, B., 2011. Modelling the influence of peri-urban trees in
538 the air quality of Madrid region (Spain). *Environmental Pollution*, 159, 2138- 2147.

539 Ayuntamiento de Madrid, 2016. Annual Memmory for Air Quality 2015.

540 Ayuntamiento de Madrid, 2018. Inventory of Madrid city air pollutant emissions 2015.
541 Directorate General for Sustainability and Environmental Control.

542 Beckett, K.P., Freer-Smith, P.H., Taylor, G., 1998. Urban woodlands: their role in reducing the
543 effects of particulate pollution. *Environmental Pollution* 99, 347-360.

544 Beckett, K.P., Freer-Smith, P.H., Taylor, G., 2000. Particulate pollution capture by urban trees:
545 effect of species and windspeed. *Global Change Biology* 6, 995-1003.

546 Borge, R., Artíñano, B., Yagüe, C., Gómez-Moreno, F.J., Saiz-López, A., Sastre, M., Narros, A.,
547 García-Nieto, D., Benavent, N., Maqueda, G., Barreiros, M., de Andrés, J.M. and Cristobal, A.,
548 2018. Application of a short term air quality action plan in Madrid (Spain) under a high
549 pollution episode - Part I: Diagnostic and analysis from observations. *Science of the Total*
550 *Environment* <https://doi.org/10.1016/j.scitotenv.2018.03.149>.

551 Borge, R., Narros, A., Artíñano, B., Yagüe, C., Gómez-Moreno, F. J., de la Paz, D., Román-
552 Cascón, C., Díaz, E., Maqueda, G., Sastre, M., Quaassdorff, C., Dimitroulopoulou, C. and
553 Vardoulakis, S., 2016. Assessment of microscale spatio-temporal variation of air pollution at
554 an urban hotspot in Madrid (Spain) through an extensive field campaign. *Atmospheric*
555 *Environment* 140, 432-445.

- 556 Brantley, H. L., Hagler, G. S.W., Deshmukhc, P. J. and Baldauf, R.W., 2014. Field assessment of
557 the effects of roadside vegetation on near-road black carbon and particulate matter. *Science*
558 of the Total Environment 468–469, 120-129.
- 559 Cai, J., Yan, B., Ross, J., Zhang, D., Kinney, P. L., Perzanowski, M. S., Jung, K., Miller, R. and
560 Chillrud, S. N., 2014. Validation of MicroAeth as a Black Carbon Monitor for Fixed Site
561 Measurement and Optimization for Personal Exposure Characterization. *Aerosol Air Qual Res.*
562 14, 1-9.
- 563 Casquero-Vera, J.A., Lyamani , H., Titos, G., Borrás, E., Olmo, F.J., Alados-Arboledas, L., 2019.
564 Impact of primary NO₂ emissions at different urban sites exceeding the European NO₂ standard
565 limit. *Science of the Total Environment* 646, 1117–1125.
- 566 Escudero, M., Querol, X., Pey, J., Alastuey, A., Pérez, N., Ferreira, F., Alonso, S., Rodríguez, S.,
567 Cuevas, E., 2007. A methodology for the quantification of the net African dust load in air
568 quality monitoring networks. *Atmospheric Environment*, 41, 5516-5524.
- 569 Fares, S., Savi, F., Fusaro, L., Conte, A., Salvatori, E., Aromolo, R. and Manes, F., 2016. Particle
570 deposition in a peri-urban Mediterranean forest. *Environmental Pollution*, 218, 1278-1286.
- 571 Fusaro, L., Marando, F., Sebastiani, A., Capotorti, G., Blasi, C., Copiz, R., Congedo, L., Munafò,
572 M., Ciancarella, L. and Manes, F., 2017. Mapping and Assessment of PM₁₀ and O₃ Removal by
573 Woody Vegetation at Urban and Regional Level. *Remote Sens.*, 9, 791-807.
- 574 Grimm, H. and Eatough, D. J., 2009. Aerosol measurement: the use of optical light scattering
575 for the determination of particulate size distribution, and particulate mass, including the semi-
576 volatile fraction. *Journal of the Air & Waste Management Association*, 59, 101-107.
- 577 Janhäll, S., 2015. Review on urban vegetation and particle air pollution – Deposition and
578 dispersion. *Atmospheric Environment*, 105, 130-137.
- 579 Kassomenos, P., Vardoulakis, S., Chaloulakou, A., Grivas, G., Borge, R. and Lumbreras, J., 2012.
580 Levels, sources and seasonality of coarse particles (PM₁₀-PM_{2.5}) in three European capitals -
581 Implications for particulate pollution control. *Atmospheric Environment* 54, 337-347.
- 582 MAPAMA, 2017. Episodios naturales de partículas 2016 (Particulate natural episodes 2016)
583 ([http://www.mapama.gob.es/es/calidad-y-evaluacion-ambiental/temas/atmosfera-y-calidad-
584 del-aire/calidad-del-aire/evaluacion-datos/fuentes-naturales/anuales.aspx](http://www.mapama.gob.es/es/calidad-y-evaluacion-ambiental/temas/atmosfera-y-calidad-del-aire/calidad-del-aire/evaluacion-datos/fuentes-naturales/anuales.aspx)).
- 585 Marcq, S., Laj, P., Roger, J.-C., Villani, P., Sellegri, K., Bonasoni, P., Marinoni, A., Cristofanelli, P.,
586 Verza, G. P. and Bergin, M., 2010. Aerosol optical properties and radiative forcing in the high
587 Himalaya based on measurements at the Nepal Climate Observatory-Pyramid site (5079 m asl).
588 *Atmospheric Chemistry and Physics*, 10, 5859-5872.
- 589 Manning, W.J., Feder, W.A., 1980. *Biomonitoring Air Pollutants With Plants*. Applied Science
590 Publishers, London.
- 591 McDonald, A.G., Bealey, W.J., Fowler, D., Dragosits, U., Skiba, U., Smith, R.I., Donovan, R.G.,
592 Brett, H.E., Hewitt, C.N. and Nemitz, E., 2007. Quantifying the effect of urban tree planting on

- 593 concentrations and depositions of PM10 in two UK conurbations. *Atmospheric Environment*
594 41, 8455–8467.
- 595 Pascal, M., Corso, M., Chanel, O., Declercq, C., Badaloni, C., Cesaroni, G., Henschel, S., Meister,
596 K., Haluza, D., Martin-Olmedo, P. and Medina, S., 2013. Assessing the public health impacts of
597 urban air pollution in 25 European cities: Results of the Aphekom project. *Science of the Total*
598 *Environment* 449, 390-400.
- 599 Pearlmutter, D., Calfapietra, C., Samson, R., O'Brien, L., Krajter Ostoic, S., Sanesi, G., Alonso del
600 Amo R. Editors, 2017. *The Urban Forest. Cultivating Green Infrastructure for People and the*
601 *Environment*. Springer, ISSN 1876-0899. DOI 10.1007/978-3-319-50280-9
- 602 Rivas, I., Mazaheri, M., Viana, M., Moreno T., Clifford, S., He, C., Bischof, O. F., Martins, V.,
603 Reche, C., Alastuey, A., Alvarez-Pedrerol, M., Sunyer, J., Morawska, L. and Querol, X., 2017.
604 Identification of technical problems affecting performance of DustTrak DRX aerosol monitors.
605 *Science of the Total Environment* 584–585, 849–855.
- 606 Santiago, J.L., Borge, R., Martin, F., de la Paz, D., Martilli, A., Lumbreras, J., Sanchez, B., 2017.
607 Evaluation of a CFD-based approach to estimate pollutant distribution within a real urban
608 canopy by means of passive samplers. *Science of the Total Environment* 576, 46-58.
- 609 Setälä, H., Viippola, V., Rantalainen, A.-L., Pennanen, A. and Yli-Pelkonen, V., 2013. Does urban
610 vegetation mitigate air pollution in northern conditions? *Environmental Pollution*, 183, 104-
611 112.
- 612 Sicard, P., Agathokleous, E., Araminiene, V., Carrari, E., Hoshika, Y., De Marco, A. and Paoletti
613 E., 2018. Should we see urban trees as effective solutions to reduce increasing ozone levels in
614 cities? *Environmental Pollution*, 243, 163-176.
- 615 Silli V., Salvatori E., Manes F., 2015. Removal of airborne particulate matter by vegetation in an
616 urban park in the city of Rome (Italy): an Ecosystem Services perspective. *Annali di Botanica* 5,
617 69-78.
- 618 Tallis, M., Taylor, G., Sinnett, D. and Freer-Smith, P., 2011. Estimating the removal of
619 atmospheric particulate pollution by the urban tree canopy of London, under current and
620 future environments. *Landscape and Urban Planning* 103, 129-138.
- 621 Tasić, V., Jovašević-Stojanović, M., Vardoulakis, S., Milošević, N., Kovačević, R., & Petrović, J.,
622 2012. Comparative assessment of a real-time particle monitor against the reference
623 gravimetric method for PM 10 and PM 2.5 in indoor air. *Atmospheric Environment*, 54, 358-
624 364.
- 625 Tiwary, A., Reff, A. and Colls, J.J., 2008. Collection of ambient particulate matter by porous
626 vegetation barriers: sampling and characterization methods. *Journal of Aerosol Science* 39, 40-
627 47.
- 628 Viana, M., Salvador, P., Artíñano, B., Querol, X., Alastuey, A., Pey, J., Latz, A. J., Cabañas, M.,
629 Moreno, T., García Dos Santos, S., Herce, M. D., Díez Hernández, P., Romero García, D. and

- 630 Fernández-Patier, R., 2010. Assessing the Performance of Methods to Detect and Quantify
631 African Dust in Airborne Particulates. *Environmental Science & Technology* 44, 8814-8820.
- 632 Viana, M., Rivas, I., Reche, C., Fonseca, A.S., Pérez, N., Querol, X., Alastuey, A., Álvarez-
633 Pedrerol, M. and Sunyer, J., 2015. Field comparison of portable and stationary instruments for
634 outdoor urban air exposure assessments, *Atmospheric Environment*, 123, 220-228.
- 635 WHO (2018) [http://www.who.int/news-room/fact-sheets/detail/ambient-\(outdoor\)-air-quality-and-](http://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health)
636 [health](http://www.who.int/news-room/fact-sheets/detail/ambient-(outdoor)-air-quality-and-health). (accessed 07.11.2018).
- 637 Yli-Pelkonen, V., Scott, A. A., Viippola, V. and Setälä H., 2017. Trees in urban parks and forests
638 reduce O₃, but not NO₂ concentrations in Baltimore, MD, USA. *Atmospheric Environment* 167,
639 73-80.
- 640

Highlights

A positive impact of vegetation by reducing particle air pollution has been observed

PM₁₀, PM_{2.5} and BC concentrations were higher at points affected by traffic

A decrease in particle concentrations up to 50% at 200 meters inside the park was found

BC concentration reduction by vegetation was smaller than for particle concentration