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1 **Nearly Five-Year Continuous Atmospheric Measurements of**
2 **Black Carbon over a Suburban Area in Central France**

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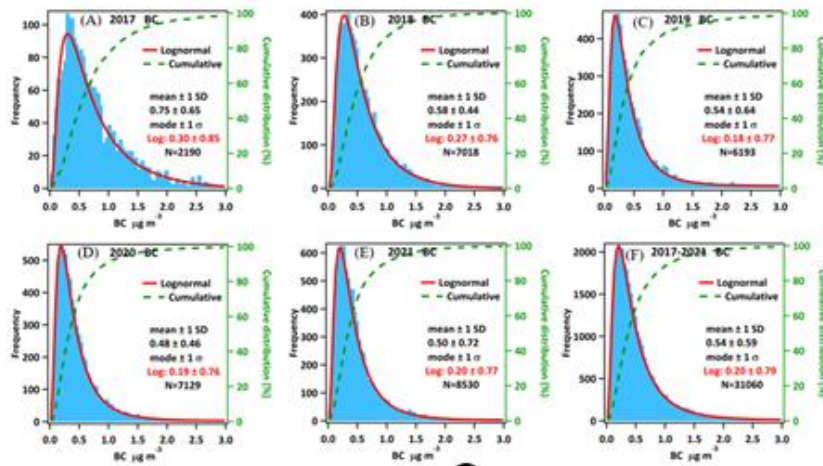
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26



27

28

29 **Highlights:**

- 30 1. Five-year BC measurements were conducted in a suburban area in central
 31 France.
 32 2. Strong seasonal variations and weekend effects were observed.
 33 3. Biomass burning contributed to more than half of winter BC.
 34 4. Lockdown in cold season and warm season had reverse effect on BC
 35 concentration.

36

37 **Abstract:**

38 Atmospheric black carbon (BC) concentration over a nearly 5 year period
 39 (mid-2017 - 2021) was continuously monitored over a suburban area of Orléans city
 40 (France). Annual mean atmospheric BC concentration were 0.75 ± 0.65 , 0.58 ± 0.44 ,
 41 0.54 ± 0.64 , 0.48 ± 0.46 and $0.50 \pm 0.72 \mu\text{g m}^{-3}$, respectively, for the year of 2017,
 42 2018, 2019, 2020 and 2021. Seasonal pattern was also observed with maximum
 43 concentration ($0.70 \pm 0.18 \mu\text{g m}^{-3}$) in winter and minimum concentration (0.38 ± 0.04
 44 $\mu\text{g m}^{-3}$) in summer. We found a different diurnal pattern between cold (winter and fall)
 45 and warm (spring and summer) seasons. Further, fossil fuel burning contributed more

46 than 90% of atmospheric BC in the summer and biomass burning had a contribution
47 equivalent to that of the fossil fuel in the winter. Significant week days effect on BC
48 concentrations was observed, indicating the important role of local emissions such as
49 car exhaust in BC level at this site. The behavior of atmospheric BC level with
50 COVID-19 lockdown was also analyzed. We found that during the lockdown in warm
51 season (first lockdown: 27 March - 10 May 2020 and third lockdown 17 March - 3
52 May 2021) BC concentration were lower than in cold season (second lockdown: 29
53 October–15 December 2020), which could be mainly related to the BC emission from
54 biomass burning for heating. This study provides a long-term BC measurement
55 database input for air quality and climate models. The analysis of especially weekend
56 and lockdown effect showed implications on future policymaking toward improving
57 local and regional air quality as well.

58

59 **Keyword:**

60 Black carbon, measurements, long-term, seasonal pattern, weekend effect,
61 lockdown.

62

63

64 **1. Introduction**

65 Black carbon (BC) is a primary aerosol emitted directly from incomplete
66 combustion processes such as vehicle exhausts (especially unfiltered diesel type),
67 domestic and industrial coal, heavy oil and wood burning, as well as forest and
68 vegetation fires (WHO, 2012). As a component of atmospheric particulate matter (PM),
69 BC plays an important role in the aerosol-planetary boundary layer (PBL) interactions
70 that can for example enhance the haze pollution (Ding et al., 2016; Zhang et al.,
71 2020).

72 BC is recognized as an efficient proxy of negative impacts on human health by
73 causing morbidity and premature mortality (Silva et al., 2013). Because of their small
74 diameter ($\leq 2.5 \mu\text{m}$, PM_{2.5}), BC particles can enter deep into the lungs and the
75 bloodstream to cause cardiovascular and respiratory diseases which may lead to
76 premature death (Anenberg et al., 2011; Gong et al., 2019; Li et al., 2016; Y. Wang et
77 al., 2021). In addition, BC affects visibility and harms ecosystems. BC aerosols play an
78 important role in the climate system, they strongly absorb solar radiation and warm the
79 atmosphere. BC is the second climate forcing agent after CO₂ with a positive radiative
80 forcing of 1.1 W m^{-2} (Pörtner et al., 2022). Because of its short atmospheric lifetime,
81 estimated to be of a few days to a few weeks, it has been suggested that mitigation of its
82 emissions is one of the most effective strategies for slowing climate change. The
83 climate will respond quickly to reductions of black carbon, especially in remote regions
84 like the arctic where the warming and melting of snow and ice could be slowed (AMAP,
85 2015; Sand et al., 2016; WMO, 2016) .

86 Because of its impact on global warming, human health and ecosystems, a large
87 body of research and monitoring activities have been dedicated to the understanding of
88 the atmospheric behavior of BC (Cui et al., 2021; Garrido et al., 2014; Kutzner et al.,
89 2018; Singh et al., 2018) and to take actions to reduce its emissions since it could be
90 considered as a key pollutant to abate from anthropogenic sources.

91 In the present paper, we report hourly, monthly, and yearly average concentrations
92 and near five years trend of BC levels from September 2017 to December 2021 at the
93 Voltaire supersite at the CNRS Campus (Orléans, France) to trace the major outflow
94 pathways and transport mechanisms for the area of the interest in the present work.

95 **2. Methodology**

96 **2.1. Measurement Site**

97 Real-time continuous measurements of BC were made at the Super-Site Voltaire
98 located in the campus of the National Scientific Research Centre (CNRS) in Orléans,
99 France, as shown in Figure 1, about 8 km south of the Orléans city center
100 ($47^{\circ}50'16.80''\text{N}$, $1^{\circ}56'39.34''\text{E}$). The site is mostly surrounded by grass and trees with
101 no obstructing buildings around it within 50 m. In addition to BC, the site is also
102 equipped with instruments to measure O_3 and NO_x .



103
104 **Figure 1.** Screenshot of the Voltaire sampling site at the CNRS campus
105 (Orléans-France, $47^{\circ}50'16.80''\text{N}$, $1^{\circ}56'39.34''\text{E}$).
106

107 **2.2. Instrumentation**

108 An aethalometer model AE33-7 (Magee Scientific Inc.) with a $\text{PM}_{2.5}$ inlet was
109 used to measure aerosol BC in real time from September 2017 to December 2021. The
110 AE33 collects particles continuously by flowing air stream through a filter tape. Air is
111 pumped through an inlet at the desired flow rate of 5.0 L/min. The aerosol analysis,

112 done at seven optical wavelengths (370, 470, 520, 590, 660, 880, 950 nm), is made by
113 measuring the transmission of light through one portion of the filter tape containing the
114 sample, versus the transmission through an unloaded portion of the filter tape which
115 acts as reference. The instrument calculates the instantaneous concentration of
116 optically-absorbing particles from the change of the attenuation of light transmitted
117 through the particle-laden filter. Two measurements are made simultaneously from two
118 sample spots with different rates of accumulation of the sample and the results are
119 combined mathematically to eliminate nonlinearities and provide the compensated
120 particle light absorption and BC mass concentration.

121 The AE33 calculates BC concentrations with high temporal resolution by
122 analyzing the attenuation of light transmission over time. The BC measurement is
123 extracted from the absorption coefficient measurement at 880 nm. The other
124 wavelengths can be used to estimate the contributions of different combustion sources.
125 The optical attenuation (*ATN*) is calculated from the measurement of the light intensity
126 measured through the “clean” filter band (I_0) and measured through the particle-laden
127 band (I) using the following mathematical law:

$$128 \quad \quad \quad ATN = -100 \ln(I/I_0)$$

129 The particle attenuation coefficient (b_{atn}) is calculated by taking into account the
130 area of the measurement (S), the flow rate (F_{in}) and the sampling time (Δt) between two
131 *ATN* measurements. Thus the attenuation coefficient, b_{atn} , induced by the particles
132 deposited, expressed in m^{-1} , is given by:

$$133 \quad \quad \quad b_{atn} = S \times (\Delta ATN/100)/(F_{in} \times \Delta t)$$

134 The flow rate F_{in} is corrected by a leakage factor, ξ , which represents the loss of
135 flow in the optical chamber. It constitutes the difference between the flow measured at
136 the input of the instrument and the actual flow rate passing through the filter:

$$137 \quad \quad \quad F_{in} = F_{out} \times (1 - \xi)$$

138 F_{out} being the measured flow rate and F_{in} the actual flow through the band.

139

140 On the other hand, the attenuation coefficient b_{atn} is corrected for the amount of
 141 light scattered by the filter strip. Thus, the absorption coefficient of the particles, b_{abs} ,
 142 represents the amount of light absorbed by the particles:

$$143 \quad b_{abs} = b_{atn}/C$$

144 C is the diffusion coefficient of the filter strip. Hence BC concentration will be
 145 obtained from :

$$146 \quad BC = b_{abs}/\sigma_{air}$$

147 σ_{air} is the mass absorption cross-section, within loading effect compensation,

$$148 \quad BC = BC_{measured}/(1 - k*ATN)$$

149 k is the compensation parameter, and the final equation:

$$150 \quad BC = \frac{S \times (\Delta ATN/100)}{F_1 \times (1 - \xi) * \sigma_{air} \times C \times (1 - k \times ATN_1) \times \Delta t}$$

151 BC emissions could be apportioned to the source of biomass burning (BC_{bb}) and
 152 fossil fuel (BC_{ff}) based on the Sandradewi et al. (2008) model. This model is based on
 153 the difference in absorption coefficient wavelength dependencies, with optical
 154 absorption coefficient being a sum of biomass burning and fossil fuel burning
 155 fractions. Hence BC_{bb} and BC_{ff} are calculated as:

$$156 \quad BC_{bb} = BB * BC$$

$$157 \quad BC_{ff} = BC * (1 - BB)$$

158 With BB (%) is the portion of biomass burning related to total BC, and calculated
 159 using a series of equations:

$$160 \quad b_{abs}(470 \text{ nm})_{ff} / b_{abs}(470 \text{ nm})_{ff} = (470/950)^{-aff}$$

$$161 \quad b_{abs}(470 \text{ nm})_{bb} / b_{abs}(470 \text{ nm})_{bb} = (470/950)^{-abb}$$

$$162 \quad b_{abs}(470 \text{ nm}) = b_{abs}(470 \text{ nm})_{ff} + b_{abs}(470 \text{ nm})_{bb}$$

$$163 \quad b_{abs}(950 \text{ nm}) = b_{abs}(950 \text{ nm})_{ff} + b_{abs}(950 \text{ nm})_{bb}$$

$$164 \quad BB(\%) = \frac{b_{abs}(950 \text{ nm})_{bb}}{b_{abs}(950 \text{ nm})}$$

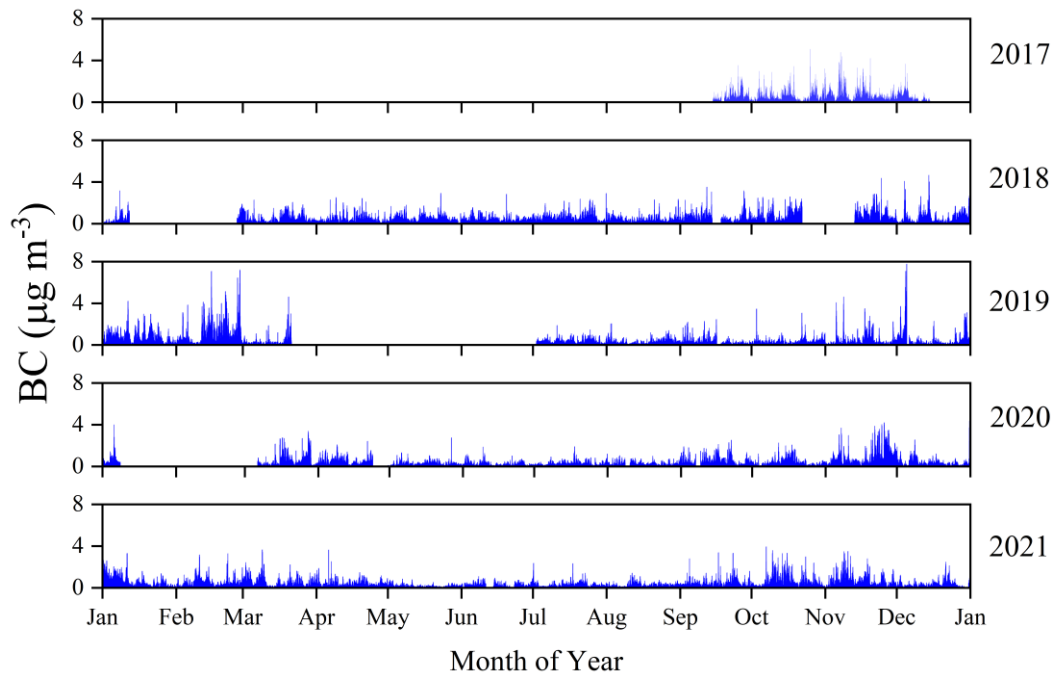
165 where $b_{\text{abs}}(\lambda)$ is absorption coefficient, λ is wavelength, $b_{\text{abs}}(\lambda)_{\text{ff}}$ a fossil fuel fraction
166 and $b_{\text{abs}}(\lambda)_{\text{bb}}$ a biomass burning fraction of absorption coefficient. Ångström
167 exponents: $\alpha_{\text{ff}}=1$ for fossil fuel and $\alpha_{\text{bb}}=2$ for biomass.

168

169 **3. Results and Discussion**

170 **3.1. Data Overview and Comparisons with Other Sites**

171 The measurements of BC were made from mid-September 2017 up to end
172 December 2021. Technical issues and maintenance of the instruments led to the loss
173 of some data for the period covering January 2018 – December 2021. For this specific
174 period, more than 71% of data has been recorded (Figure S1). Figure 2 shows an
175 overview of measured BC in the present work. In general, the measurement period
176 was characterised by a fairly good air quality in the area of interest to our study,
177 without heavy pollution days. BC was generally lower than $2 \mu\text{g m}^{-3}$ with few
178 exceptions reaching $4 \mu\text{g m}^{-3}$. The annual mean atmospheric BC concentration was
179 0.75 ± 0.65 , 0.58 ± 0.44 , 0.54 ± 0.64 , 0.48 ± 0.46 and $0.50 \pm 0.72 \mu\text{g m}^{-3}$, respectively,
180 for the years 2017, 2018, 2019, 2020 and 2021 as shown in Figure 3. The annual
181 mean of BC concentrations measured in suburban Orléans city, were 3 to 30 times
182 lower than reported in other larger European and non-European cities as displayed in
183 Table 1. Note that Orléans is a medium size city, with not much industry and traffic
184 and a population of about 120000 inhabitants.



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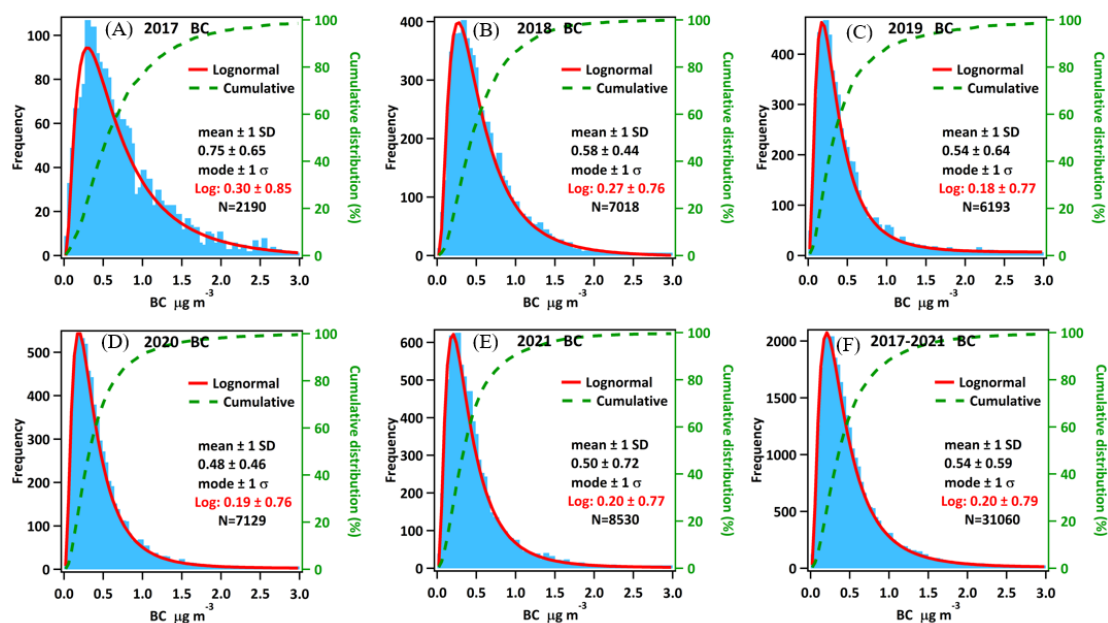
Figure 2. BC measurements during 2017-2021 in Orléans city.

Table 1. BC measurement in this work and compared with literatures.

City	Study year	BC \pm SD ($\mu\text{g m}^{-3}$)	Reference
Barranquilla, Colombia	2018	16.1 ± 16.54	Blanco-Donado et al., (2022)
São Paulo, Brazil	2017	8.5 ± 8.4 Weekday 5.2 ± 13.9 Weekday	Krecl et al., (2018)
Macau, China	2016	4.0 ± 2.6 (morning) 3.1 ± 1.9 (afternoon)	B. Liu et al., (2019)
Shanghai, China	2016	10.8 ± 3.5	M. Liu et al., (2019)
Shanghai, China	2015	11.8 ± 9.8	Lei et al., (2017)
Brisbane, Australia	2015	4.4 ± 7.3	Williams and Knibbs, (2016)
Londrina, Brazil	2015	6.35 ± 20.0 (morning) 5.10 ± 14.7 (afternoon)	Targino et al., (2016)
Shanghai, China	2014	7.28 ± 1.63 9.43 ± 1.70 8.62 ± 2.57	Li et al., (2015)
Bogota, Colombia	2013	25.6 ± 39.2	Franco et al., (2016)
Minneapolis, USA	2012	2.5 ± 1.4 (morning) 0.7 ± 1.6 (afternoon)	Hankey and Marshall, (2015)
Stockholm, Sweden	2011	2.4 ± 3.6	Krecl et al., (2014)
Berkeley, USA	2011	1.76 ± 2.58 low traffic 2.06 ± 3.23 high traffic	Jarjour et al., (2013)
Helsinki, Finland	2011	7.8 ± 4.3	
Rotterdam, Finland	2011	6.4 ± 3.3	Okokon et al., (2017)
Thessaloniki, Finland	2011	10.9 ± 9.9	
Barcelona, Spain	2009	16.7	de Nazelle et al., (2012)
Orléans, France	2017	0.75 ± 0.65	This work
Orléans, France	2018	0.58 ± 0.44	This work
Orléans, France	2019	0.54 ± 0.64	This work

City	Study year	BC \pm SD ($\mu\text{g m}^{-3}$)	Reference
Orléans, France	2020	0.48 ± 0.46	This work
Orléans, France	2021	0.50 ± 0.72	This work

189



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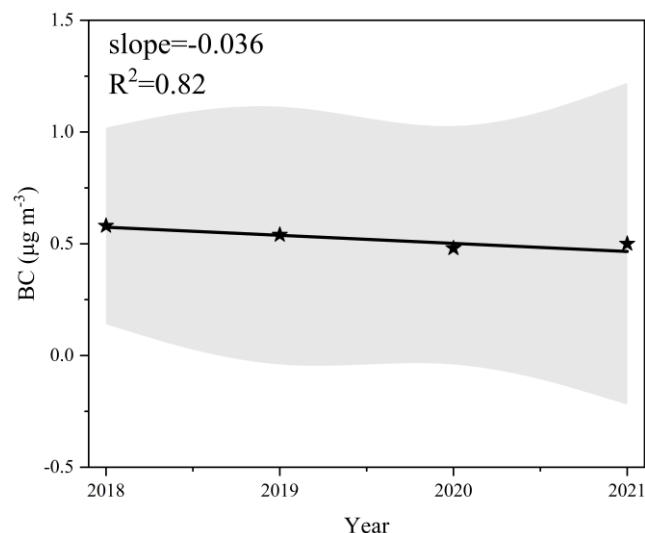
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Figure 1. Histograms of BC measurement data from 2017 to 2021.

192

193 3.2. Nearly 5 years trend of BC in Orléans

194 The continuous observations over a period of nearly 5 years (mid 2017 – end
195 2021) in Orléans (central France) provides data to check to tendency of the
196 atmospheric BC concentration in the region for the last five years. Since only 25% of
197 BC data was obtained in 2017 (Figure S1), we only used data from 2018 to 2021 to
198 discuss the trend observed in this work. As shown in Figure 4, a decrease of 3.6% per
199 year is observed in the studied area. It has to be noted that a general decrease in the
200 atmospheric BC has been reported in many other areas over Europe resulting mainly
201 from the mitigation policies of air pollution in Europe since 1990's. For example, a
202 decrease as high as 8 ± 3 % per year has been reported by Singh et al. (2018) at
203 Marylebone road in London. Sun et al. (2020) reported a decreasing trend of BC
204 concentration between -13.1 and -1.7 % per year from 2009 to 2018 over Germany.



205

206

Figure 2. Four yeras trend of BC at the Voltaire supersite during the period

207

2018-2021.

208

209 **3.2. Seasonal variations**

210

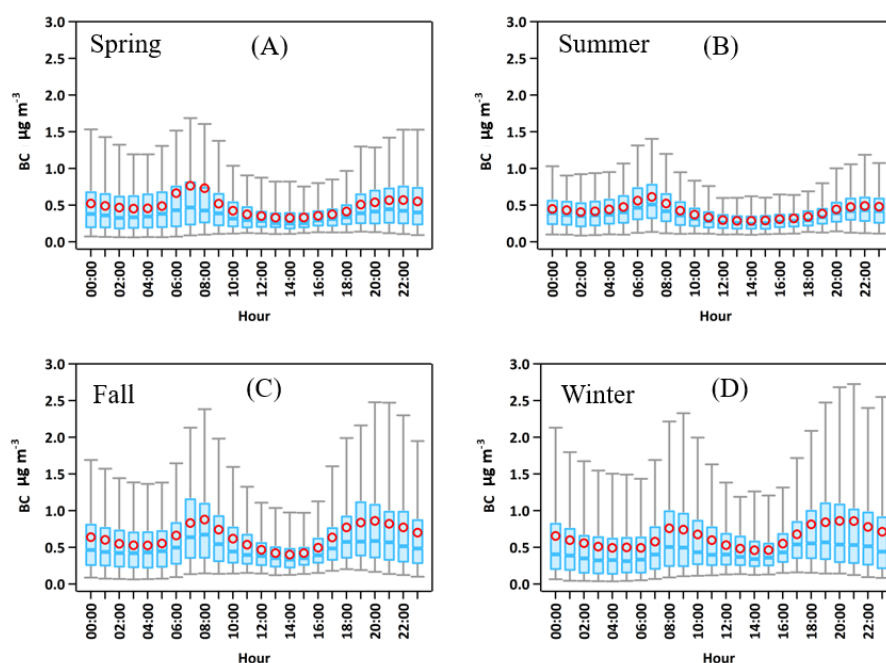
The diurnal profile of BC under different seasons at the site for the entire measurement period is depicted in Figure 5. This figure shows that the highest BC concentration occurred in winter, followed by autumn, spring and summer, with seasonal mean (\pm SD) values of 0.70 ± 0.18 , 0.64 ± 0.11 , 0.48 ± 0.11 and 0.38 ± 0.04 $\mu\text{g m}^{-3}$, respectively. Compared to spring and summer, the elevated BC concentrations in winter and autumn were likely related to the common occurrence of wood burning for household heating and relative lower boundary height due to cold weather, as reported by other studies (Fuller et al., 2014; Genberg et al., 2013).

218

Figure 5 indicates also that the diurnal variations of BC in winter and autumn were similar, within one significant morning peak during the morning rush hours and second significant peak in the evening. In spring and summer, BC concentration also increased in the morning and peaked during the morning rushing hours. However, the morning peak shifted from 7:00 (Local time, LT) in spring, summer, and autumn to 8:00 LT in winter. Due to the increasing of boundary layer height or wind speed during the day. The BC concentration starts to decrease after the peak time until 15:00

224

225 LT. Then, as shown in Figure 5, BC concentration increased rapidly from 16:00 LT to
 226 the peak at 19:00 LT in autumn and winter, which increased slowly from the
 227 minimum and did not present significant peak in the evening in spring and summer.
 228 This indicates that the wood burning was most probably the important BC emission
 229 source during cold period. Another possible reason could be the boundary layer height
 230 decreased more rapidly to capture BC close to the earth surface in autumn and winter
 231 than that in spring and summer. The reduced human activities during the night hours
 232 would be the main reason for the observed lower BC concentration from the midnight
 233 until the morning rush hour in all seasons.

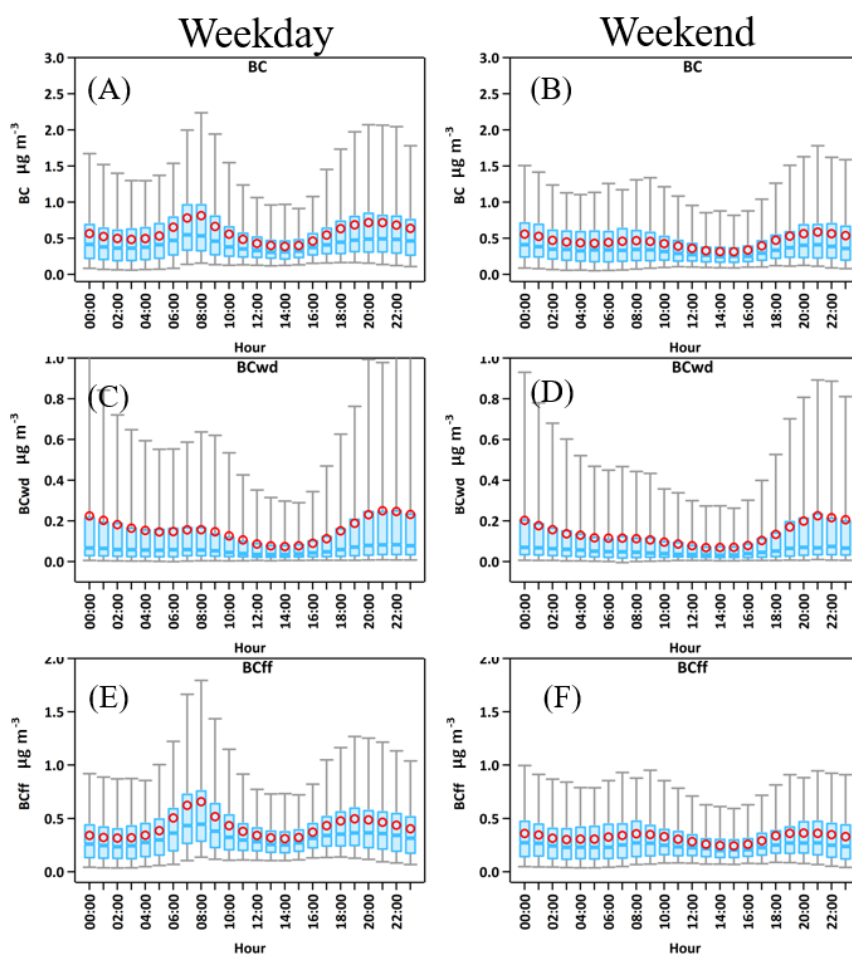


234
 235 **Figure 3.** Average diurnal variations of BC during different seasons for the period
 236 2017-2021.

237 238 3.3. Weekend effects

239 Overall, the BC concentration had a weekly cycle with slightly lower
 240 concentrations on weekends than during weekdays (Figure 6a,b). The daily median
 241 BC concentration ranged between 0.4-0.7 $\mu\text{g m}^{-3}$ and 0.3-0.5 $\mu\text{g m}^{-3}$ for weekdays and
 242 weekends, respectively. The diurnal variations of BC were different between the

243 weekdays and weekends, as shown in Figure 6. The weekdays presented two peaks
 244 pattern related to the morning and evening rush hours, but the weekends only showed
 245 slight increase in BC concentration from late afternoon. However, both weekdays and
 246 weekends had similar diurnal variation with the BC emission from fossil fuel which
 247 reveals that vehicle emission was the main BC source during the weekdays and less
 248 use of vehicle on weekends can significantly cut down the local BC concentration.
 249 Lower BC concentration on weekends compared to weekdays was also observed at
 250 traffic sites in other European cities like Bern and London (Reche et al., 2011) and
 251 Zurich (Zotter et al., 2017). Kutzner et al. (2018) reported negligible
 252 weekdays-weekends differences at urban background and industrial sites in Germany.
 253 As shown in Figure 6, a non-traffic source such as domestic heating could be another
 254 important BC source in the suburban site of our study.



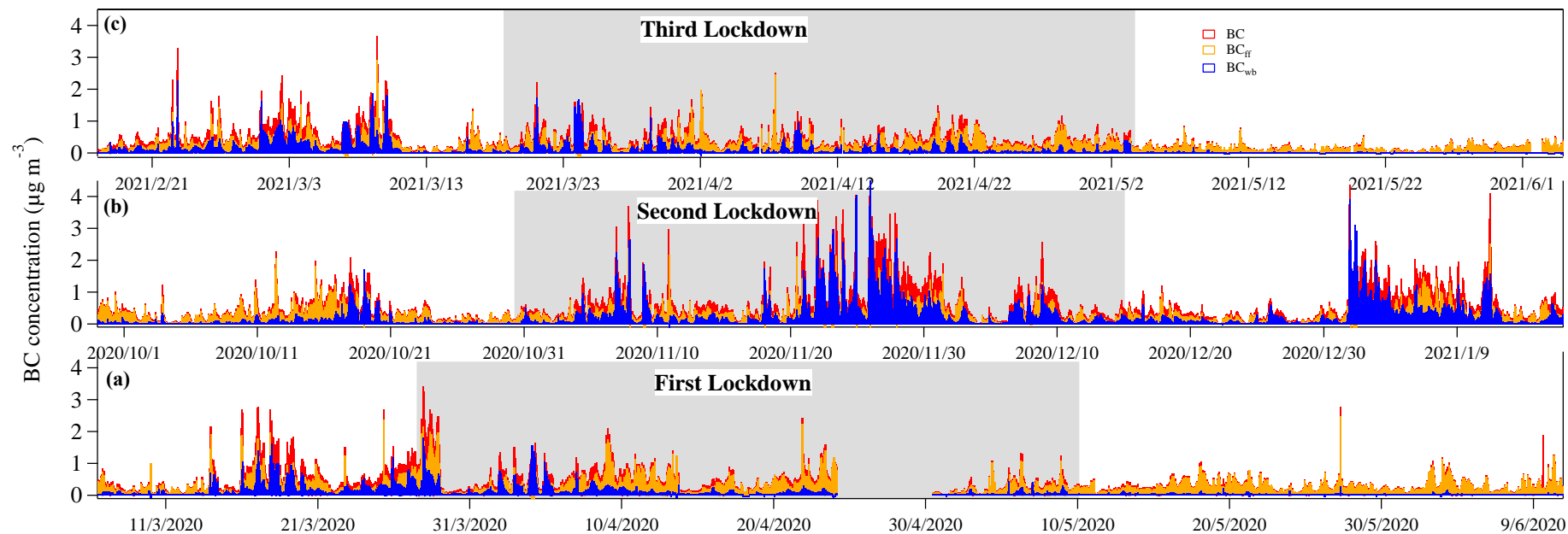
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256 **Figure 4.** Average diurnal profiles of BC, BC_{wb} and BC_{ff} during weekends and
257 weekdays.

258 **3.4. COVID-19 Lockdown impact**

259 A number of studies have reported changes in the the observed concentration
260 profiles of BC before, during and after the lockdown in some countries. For example,
261 Jia et al. (2021) reported significant decline in the BC emission in eastern and northern
262 China, respectively, 70% and 48%. Wei et al. (2022) observed a reduction of BC up
263 to 0.06 mg/m² per day in northern India in April-May 2020 during COVID lockdown.
264 We have compiled in Figure 7 the time series of BC concentrations before, during and
265 after the three French lockdowns (first: 27 March–10 May 2020, second: 29
266 October–15 December 2020, third: 17 March–3 May 2021) measured in Orléans. The
267 Figure shows that BC concentration increased in the first two days from 27 to 29
268 March 2020 after the French government announced the first lockdown. This may be
269 attributed to the increased traffic activities for residents to buy the necessary living
270 supplies. Then the BC concentration kept at a low level during the first lockdown and
271 after the lockdown. The second lockdown in France was less strict than the first one
272 with about 30% of the population allowed to go to work. The high BC concentrations
273 observed during the second lockdown was attributed, at least partly, to emission from
274 household wood burning since the temperature was low during this period. Relatively
275 high BC concentrations were also observed during Christmas Holidays period from
276 25 December 2020 to 15 January 2021 which also may be due to household wood
277 burning. During the third lockdown covering the period 17 March to 3 May 2021, low
278 BC concentration was observed. The averaged BC, BC_{ff} and BC_{wb} concentration for
279 these three lockdowns is presented in Figure 7. Interestingly, as shown in Figure 8, we
280 found that BC emission from fossil fuel were at similar levels before, during and after
281 these three lockdown periods, and the BC concentration changes was mainly due to
282 the BC emission from wood burning. The reason could be that the location of the
283 sampling site in this work was not impacted by heavy traffic and industries. This

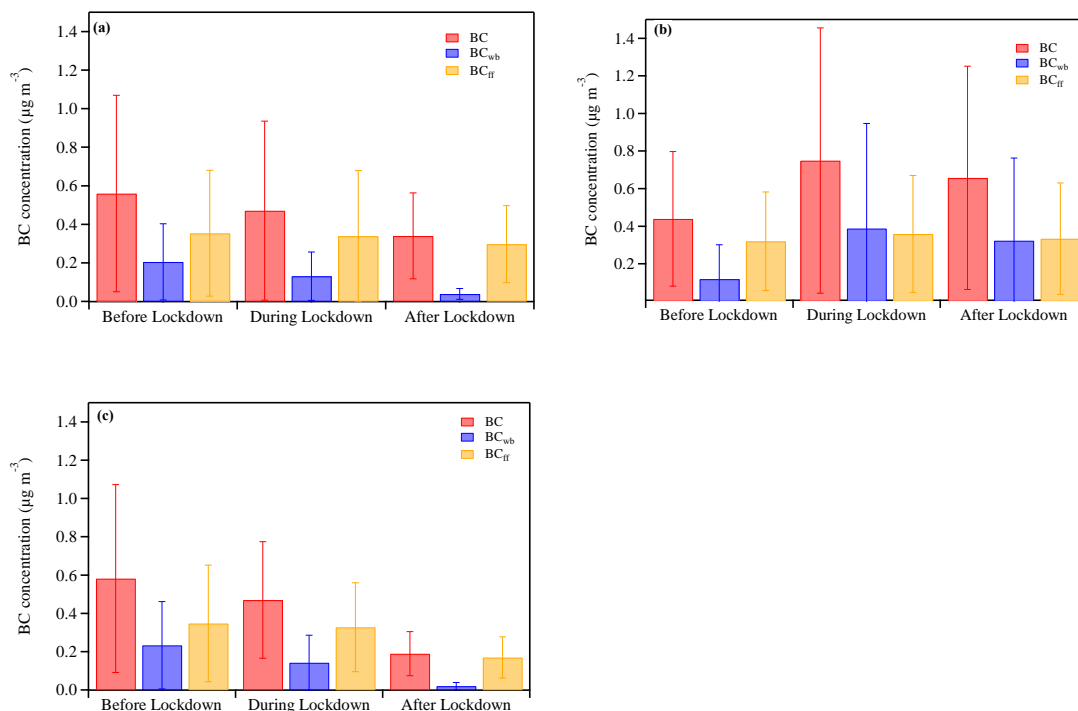
284 observation is specific to the investigated site and the situation could be different in
285 other areas such as Delhi (Goel et al., 2021) and Wuhan (Z. Wang et al., 2021). It is
286 worth noting that in this study we just compared the observed BC concentrations but
287 did not consider the meteorological impacts (e.g., from atmospheric dilution,
288 boundary layer, etc.), which may add uncertainties.



289

290 **Figure 7.** Time series of BC, BC_{ff} and BC_{wb} concentration for the three lockdowns in France, (a) First Lockdown: before lockdown (6 March–26
 291 March 2020), during lockdown (27 March–10 May 2020) and after lockdown (11 May–10 June 2020); (b) Second lockdown: before lockdown
 292 (29 September–28 October 2020), during lockdown (29 October–15 December 2020) and after lockdown (16 December 2020–16 January 2021);
 293 (c) Third lockdown: before lockdown (17 February–16 March 2021), during lockdown (17 March–3 May 2021) and after lockdown (4 May–3
 294 June 2021).

295



296

297

298 **Figure 8.** Column plots of average BC, BC_{ff} and BC_{wb} for the three lockdowns in
 299 France, (a) First Lockdown: before lockdown (6 March–26 March 2020), during
 300 lockdown (27 March–10 May 2020) and after lockdown (11 May–10 June 2020); (b)
 301 Second lockdown: before lockdown (29 September–28 October 2020), during
 302 lockdown (29 October–15 December 2020) and after lockdown (16 December 2020
 303 –16 January 2021); (c) Third lockdown: before lockdown (17 February–16 March
 304 2021), during lockdown (17 March–3 May 2021) and after lockdown (4 May–3 June
 305 2021).

306

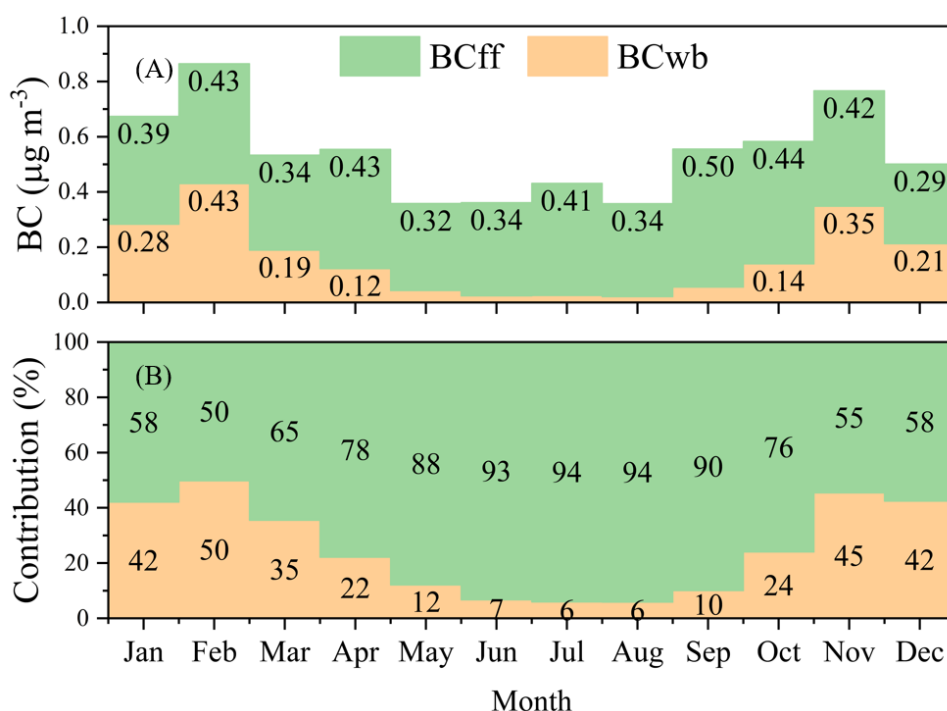
307 3.5. Wood Burning vs. Fossil Fuel

308 To further discuss the BC sources in the suburban area of this work, a monthly
 309 average of BC_{wb} and BC_{ff} concentration and their contribution to total BC was
 310 depicted in Figure 9. The BC concentration peaked in late fall (November) and winter
 311 with maxima around $0.86 \mu\text{g m}^{-3}$. As shown in Figure 9A, BC from the combustion of
 312 fossil fuel (BC_{ff}) showed a relatively flat seasonal cycle, roughly constant in the range
 313 0.29 to $0.50 \mu\text{g m}^{-3}$ throughout the year 2017 to 2021. To the contrast, BC from the

314 combustion of wood burning (BC_{wd}) showed a more pronounced seasonal dependence,
315 with negligible contribution ($<0.05 \mu\text{g m}^{-3}$) from May to September and moderate
316 contribution in other months ($0.1-0.43 \mu\text{g m}^{-3}$). Consequently, BC_{ff} made dominate
317 relative contribution to the observed BC throughout the whole year ($>50\%$, Figure
318 9B), particularly high contributions from May to September ($>88\%$, Figure 9B). This
319 result is in good agreement with other reports indicating that in the majority of
320 European cities, BC typically originates from traffic (Kutzner et al., 2018).

321 As discussed in the literatures (Becerril-Valle et al., 2017; Kumar et al., 2020;
322 Mousavi et al., 2018) the monthly variation of BC_{ff} concentration in the year is mainly
323 related to the weather conditions while that of BC_{bb} concentration is not only related
324 to the weather conditions but also human activities, such as the straw burning in
325 autumn, forest fire in summer and wood burning from domestic heating in winter. In
326 this work (Figure 9), BC from the combustion of wood burning (BC_{wb}) showed a
327 more pronounced seasonal dependence, within negligible contribution to BC from
328 May to September. The BC_{bb} concentrations tend to be higher in the cold seasons to
329 contribute 22-50% to the total BC, which was likely related to the household heating,
330 especially in the evening of winter as shown in Figure S2.

331



332
333 **Figure 9.** Monthly averages of BC_{wb} and BC_{ff} in Orléans city

334
335 **4. Conclusions and Implications**

336 To investigate the variation and the long-term trend of BC, a nearly five-year BC
337 measurement was conducted in a suburban area in central France. The BC annual
338 mean concentration was calculated as 0.75 ± 0.65 , 0.58 ± 0.44 , 0.54 ± 0.64 , $0.48 \pm$
339 0.46 and $0.50 \pm 0.72 \mu\text{g m}^{-3}$, respectively, for the year of 2017, 2018, 2019, 2020 and
340 2021, indicating a stability to a very slight decrease trend ($-0.036 \mu\text{g m}^{-3} \text{ year}^{-1}$) from
341 2017 to 2021. These BC concentrations were lower than that reported in some other
342 cities. Strong BC seasonal variations were observed, with the highest BC
343 concentrations occurred in winter, followed by autumn, spring and summer. A
344 weekend effect was also observed in the measured area of this work, within generally
345 slight high BC concentration during the workdays. Lower BC concentration was
346 always observed during the weekends which was attributed to less traffic.

347 As for the COVID-19 measures impact, three successive lockdown periods have
348 been followed in France, two in warm season (March to May) and one in cold season

349 (October to December). We found that the BC concentration decreased during the
350 lockdown in the warm season, but unexpectedly increased during the lockdown in
351 cold season, which was mainly caused by the variation of BC emission from biomass
352 burning.

353 Fossil fuel contributed more than 90% of BC emission in the summer, much
354 higher than that from wood burning. However, wood burning contributed equivalent
355 (50%) to fossil fuel burning to the BC emission in the cold seasons, revealing the
356 significant impact of winter heating from wood burning on regional air quality.
357 Moreover, the above findings indicate that local anthropogenic emissions could
358 strongly affect the BC concentration observed at the VOLTAIRE supersite as well as
359 air quality in this region. Hence, the national level of strategies to improve air quality
360 is always important, but also the local strategies toward reducing local emission such
361 as domestic wood burning and fossil fuel combustion emissions.

362

363 **Credit authorship contribution statement**

364 EI Mehdi EI Baramoussi: Investigation, Formal analysis, Writing - original draft.
365 Yangang Ren: Supervision, Investigation, Formal analysis, Writing - original draft.
366 Chaoyang Xue: Investigation, Formal analysis, Writing - review & editing. Ibrahim
367 Ouchen: Investigation. Véronique Daële: Investigation, Writing - review & editing.
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369 Investigation. Patrice Colin: Investigation. Abderrazak Yahyaoui: Investigation.
370 Oliver Favez: Investigation, Writing - review & editing. Abdelwahid Mellouki:
371 Supervision, Project administration, Writing - review & editing.

372

373 **Declaration of competing interest**

374 The author declare that they have no known competing financial interests or personal
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376

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391

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