Dear Editor,

Hereafter is enclosed the revised version of the manuscript "Physico-chemical characterization of urban aerosols from specific combustion sources in West Africa at Abidjan in Côte d'Ivoire and Cotonou in Benin in the frame of the DACCIWA program" by Adon et al. In this new version, we took into account all the comments made by the referees. Following their advices, we totally changed the structure of the paper. We would like to thank them for their effort to review this paper. In our opinion, the paper is well improved.

Thanks also for your understanding for the delay that you gave us to allow this revision.

Reviewer Comments

REWIEVER 1

Main comments

This paper presents valuable data for an understudied region, which is mainly attributed to logistical difficulties associated with obtaining data. Therefore, the authors must be commended in presenting this dataset that warrants interest from an international audience. In addition, comprehensive data analysis and processing were conducted on the collected dataset from which the authors draw insightful deductions.

However, unfortunately there are too many text and language errors throughout the manuscript. I extensively reviewed the manuscript up until the Results section (detailed comments indicated in the attached PDF file) with approximately 80% of the comments (124 comments in total) relating to text and language issues. Therefore, I suggest that the authors address each of these comments made and also apply these comments/suggestions to the rest of the manuscript in order to improve the manuscript. In its current format, the large number of text and language errors clouds the review/critical evaluation of the science presented in this paper. I will continue with my review of the manuscript as soon as all the text and language problems are addressed by the authors. In addition to the comments related to text and language in the manuscript, certain comments also relate to the general structure of the paper and scientific matters that must also be addressed by the authors.

Following this advice, paper structure was totally changed. The 'Methodology paragraph' is improved including important details which were asked by the reviewers. Then, a paragraph presents the 'main results' specie by specie. A 'discussion' paragraph is proposed, focusing on the main striking features obtained site by site, the inter-annual variability of aerosol composition in each site and the comparison of our results with literature data. Due to these change, most of comments have been taken into account. We only kept in the following, the important questions that we resolved in the new version. English was improved all along the text.

Detailed review

32- Abstract must be one paragraph and can also be shortened.

Please improve the Abstract

It was done in the new version, stressing the main points of our results.

54-Just be clear on where you presented and discussed OC or POM in the paper. In figures and tables only OC are presented and not POM.

Be careful not too use POM and OC intermittently, since it is not the same.

POM is derived to conduct the aerosol chemical closure, shown in Figure 13.
We checked all the text to be sure that POM is only mentioned in the comment of figure 13.

70- I agree with this statement. However, I think the results van be better unpacked. You have three sites in Abidjan representing different types of sources and one additional traffic sites at another locations. Therefore, I suggest that the differences between the three sites at Abidjan are presented and discussed, and the results at the traffic site at Cotonou are brought in to contextualise/compare with the traffic site in Abidjan.

Also, I ask myself the question what is the value/significance of only comparing the traffic sites for two different cities and not the two other sites representative of different sources (domestic burning and waste burning).

The aim was to compare two cities with different vehicle fleet typical from West Africa.

However, I think this can be solved by better structuring of the presentation and discussion of the results.

It is what we tried to do.

97- Are you only writing this paper from a health perspective?

As indicated in the conclusion, biological studies were performed in parallel on the same samples and results of such crossed studies will be given in a next paper.

127-Was this site on ground level?

Details are now better given in the methodology part concerning the height of sampling of the different sites.

148-Nothing is presented in this section on how filters were pre-treated (is it were), stored, transported etc. Maybe end of indicating that all filters were sent for analysis in Toulouse.
It is now better indicated in the text.

150- Does this mean that during each intensive campaign one 3-hour sample was obtained for three consecutive days, i.e. three size-resolved samples per site during each campaign.
Yes, this is right. It is now better indicated in the text.

151- What are the size fractions for all these impactors?
It is now better indicated in the text.

153-154- Were the back filter concentrations subtracted from the course, fine and ultra-fine fractions to compensate for particulates formed from volatile organics on the filters?
This is a very interesting question. It is now better indicated in the text.

160 -What is meant with "pooled"? It is now better indicated in the text.
178- Abbreviation
  BC or EC? In your case it is EC
EC was put everywhere.

224- It is definitively not necessary to indicate all these different methods to calculate/estimate the dust contribution. Only describe the two methods that were used.
We decided to discuss only three methods in order to give an idea of the range of uncertainties linked to the methods of dust calculations.

266- Why are two different methodologies used to calculate/estimate dust. I suggest that you only use the Guinot et al method throughout OR clearly motivate the use of the two method for different results.

We decided to follow this advice. Now figure 12 present dust concentrations obtained from Guinot methodology.

319- Indicate that the bulk concentrations are presented in the black boxes above each campaign for each site.

All the figures have been improved in order to take into account these comments.

REVIEWER 2

Main comments

This manuscript describes a dataset that measured and characterized aerosol particles in Abidjan and Cotonou during the DACCIWA project. The dataset explores aerosol mass and composition, during two dry seasons and two wet seasons. This is an important and rich dataset. The manuscript does address relevant scientific questions and is within the scope of ACP. I would recommend major revisions before the manuscript it accepted. I have inserted comments on the attached pdf that I would recommend are addressed.

This is rich dataset with a lot of detailed information. As structured currently, I find it difficult to read and remember all the linkages and trends. I do understand this is in part due to the large amount of information in the dataset. However, I do find it detracts from the quality of the manuscript and thus, the impact of this dataset. I found it difficult to review the robustness of the conclusions, as the results that supported such conclusions (e.g. wood burning at ADF) are across so many different sections and the linkages between them (e.g. total, EC and OC masses) are not clearly stated.

I was wondering, if the article was restructured, if it would help. One way I thought of was what if the main findings are presented (i.e. PM, EC, OC, dust mass) first at a very high level, and then the results and discussion moves to a full discussion of the results site by site. As can be seen in my comments, in the Results section I struggled with making connections between these for the sites (i.e. PM total mass, EC, OC, etc), and what that "means" for each site. As such, I was wondering if a change in structure to a full discussion of site by site, and then comparisons across sites would assist in the structure. I thought in this way the points of each site could be made all at once, as all of the data to support these conclusions would be presented at once. I do believe it is clear in my comments on the pdf that I am recommending that some change in the structure or reporting of the results is necessary; this restructuring is just a suggestion of a way to address these concerns.

As the results and discussion are so detailed with so much information, I would recommend the conclusion is more a synthesis. I would recommend that it is more concise and highlights what these results all "mean" when taken as a whole. I do find that synthesis is missing some from the current version.

I would recommend that the title is changed. The results show that the aerosols are not just from combustion sources, and thus the title is misleading.

Following this advice, paper structure was totally changed. The 'Methodology paragraph' is improved including important details which were asked by the reviewers. Then, a paragraph

presents the 'main results' specie by specie. A 'discussion' paragraph is proposed, focusing on the main striking features obtained site by site, the inter-annual variability of aerosol composition in each site and the comparison of our results with literature data. The conclusion is now a synthesis of the results. Due to these change, most of comments have been taken into account and highlights better appear. We only kept in the following, the important questions that we resolved in the new version. English was improved all along the text.

Detailed review:

46-Are these 24-hr averages?

47-I would recommend showing these as average 24-hr averages with +/- 1 std deviation to show variability in data as well

55-TSP? PM10? PM2.5?

60-to PM2.5? or PM10? Throughout, I would recommend being specific about which fraction of PM this is in relation to, in order to be precise. This applies below as well.

These questions are resolved with a better description in the methodology part.

88-This is not a complete list of air quality studies in Africa, nor air quality on health in Africa. These are two papers from Senegal and one from a study in Cote d'Ivoire. I would recommend expanding the literature cited here, and constrain this sentence to just the areas that the cited papers discuss (e.g. perhaps just Western African cities).

Thanks for this comment. We expanded the literature comparison.

101- This manuscript seems to build off of Djossou et al., 2018 work. I see it is compared to below, but I would recommend including it in introduction as it is key literature.

Djossou et al. is a paper focusing on weekly aerosol measurements using different aerosol sampling. It is now better indicated.

150- Which three hours? were they the same always? This is important as I assume there is a diurnal cycle in PM.

It is now better indicated. The aim was to only sample the period of the day of three hours with maximum of pollution (not the diurnal cycle).

160- I would recommend an expanded explanation here as this is quite a brief statement. It is not clear to me what "pooled" means exactly.

It is now better indicated.

181- The uncertainties are listed here for all of the methods, but I do not see them applied in the final results. The propagation of this uncertainty (in all of these methods) to the results should be shown.

It is now indicated in each graph.

200- I don' believe these should be italized. And for Ca ++ is used while Mg uses 2+, this should be consistent with each other and also with ACP style guidelines.

We do not italize anymore.

312- When is biomass burning period in this region? This may not be place to mention it, but I would recommend adding it to introduction.

It is now better indicated.

336- But this wasn't seen in 2016 (in 2016 dry > wet at ADF). This was seen in 2015 only. If it is this drying of food (i.e. local activity) why would it have been so different in 2016? Are there other reasons/drivers that could impact on inter-annual variability?

It is now better indicated. We did a special paragraph dealing with the inter annual variability which is different following the species and the season.

340- I would recommend using "wet and dry season" or "summer and winter" or always show both. An international audience does not know seasons as well, so it will be confusing for them to flip between, and trying to remember which is which.

Done.

379- As per the text, this list is explaining the differences between sites (not the difference between years). So why would points 4-7 impact the sites, specifically within the same city differently?

It is now better indicated. It depends on the distance between the studied source and the site and also the strength of the studied source.

388- But you sampled only 3 hours per day. Are you comparing same 3 hours? I assume there is a diurnal cycle, so it is important to know where within that cycle the measurements were taken (e.g. peak, lowest values)?

As more clearly mentioned now in the text, our sampling always occurs at the peak of the studied source in each site.

394- Also during the same time period? And same or different averaging period? What does weekly mean? Their samples ran a full week? Or are continuous and averaged to a week?

Weekly means 'ran a full week'.

398- I would recommend stating these differences before discussing values. I would find it helpful to have this context of how the other measurements were done first, and then see the results.

Now done with the new structure.

432- but only for 2015, not for 2016. Also, these are small differences in EC for 2015, but large differences in 2015 for PM. If the difference was wet wood combustion leading to incomplete combustion, why are the differences between EC so low in wet and dry in 2015 so low?

This conclusion is really important for OC (more than for EC).

448- I don't think this has been explained. Earlier it was stated that in the wet season the wood would be wet, and thus more PM. However, that doesn't explain why 2016 wet is higher than 2015 wet. Also, it does not explain why dry 2017 is highest EC at ADF of all. You state that these activities increased in 2016. How do you know that? Can you provide some data or a citation or is it personal observation? Also, if this statement is true, and the statement that more wet wood leads to higher EC and PM, then higher EC and PM would be expected in Wet season 2016 than dry

season 2017, but that is not seen. Dry season 2017 has higher EC and PM than wet season 2016 (this whole comment is just discussion of ADF).

It is now better indicated. You are right about the activities. We did a special paragraph dealing with the inter annual variability which is different following the species and the season.

481- But total PM (Fig 6) does not follow this trend. CT is always greater than AT (except 2016, where it is very close). Why would the decreases in traffic would impact OC concentrations, but not total?

We tried to be clearer in all these explanations. Decrease in traffic can impact OC but not total PM. For example, you could have a decrease of traffic OC and at the same time an increase of dust due to another source. Results on total PM will not be changed in that case.

-596- Are there trace gas measurement of SO2 or NOX published that could also help to understand or provide context for these results in this section?

It is a good idea but the trace gas measurements in these sites have not the same temporal sampling.

1   **Physico-chemical characterization of urban aerosols from specific combustion**

2   **sources in West Africa at Abidjan in Côte d'Ivoire and Cotonou in Benin in the frame**

3   **of the DACCIWA program**

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30 **Abstract**

Air pollution in West Africa has yet to be well characterized and was one of the principal motivations of the "Air Pollution and Health" work package in the DACCIWA (Dynamics-Aerosol-Chemistry-Cloud Interactions in West Africa) program. Intensive measurement campaigns were performed in two West African capitals (Abidjan in Côte d'Ivoire and Cotonou in Benin), in dry season (January 2016 and 2017) and wet season (July 2015 and 2016), in order to examine the size distribution of particulate matter (PM) and their chemical composition including elemental carbon (EC), organic carbon (OC), water-soluble organic carbon (WSOC), water-soluble inorganic ions (WSI) and trace metals. In this study, we characterize PM from different sites in Abidjan, which are representative of domestic fires (ADF), traffic (AT) and waste burning (AWB) sources and from one traffic site in Cotonou (CT). All these sites, impacted by large amount of pollution, are representative of the main combustion sources in South West Africa (SWA).

Results show very high PM concentrations at the SWA sites and a well-marked seasonality as well as a strong spatial variation. The average $PM_{2.5}$ mass concentrations during the wet season are 517.3, 104.1, 90.3 and 69.1 $\mu g.m^{-3}$ at the ADF, CT, AT and AWB sites, respectively. In the dry season, $PM_{2.5}$ concentrations decrease to 375.7 $\mu g.m^{-3}$ at the ADF site, while they increase to 269.7, 141.3 and 175.3 $\mu g.m^{-3}$ at the CT, AT and AWB sites, respectively. The annual $PM_{2.5}$ levels at almost all sites are significantly higher than the WHO guideline level of 10 $\mu g.m^{-3}$. As for PM mass, carbonaceous aerosol concentrations are also maximum at ADF site, accounting up to 69% of the total PM mass. The largest amount of these species on the ADF site in both seasons are due to the intensive human activities such as domestic cooking using wood and food smoking and roasting activities, known to be an important source of PM in SWA. Dust contributions are dominant at CT (57-80%), AT (20-70%) and AWB (30-69%) sites and specially in the coarse and fine particle modes at CT and in the coarse fraction at AT site, while there is no clear distribution at AWB site. This result reflects the specificity of most of SWA cities permanently impacted by dust emissions from the desert around and re-suspended particles from the roads. The contributions of WSI to the total PM mass are highly variable but remain less than 30%. Values are generally 1-3 times higher in the wet season than the dry season. The total proportion of WSI is driven by the individual contribution of three species such as chloride, nitrate and calcium, which may peak in the fine and/or large particles according to the site. This means that different types of sources (anthropogenic emissions from fuel combustion, nitrate formation by reaction processes and natural emissions) contribute to WSI emissions in the studied sites. The concentrations of element traces well reflect the trends

64 of dust at the traffic and AWB sites, with a predominance of Al, Na, Ca, Fe and K, keys markers

65 of crustal dust.

66 Our study highlights the contribution of different traffic emissions in two major West African

67 cities to atmospheric aerosol composition. It also highlights the role of domestic fires and waste

68 combustion sources. It constitutes an original database that characterizes urban air pollution

69 from specific African combustion sources.

71 **Keywords**: atmospheric pollution, chemical composition, physicochemical characterization,

72 Particulate matter, traffic, waste burning, domestic, biomass burning.

73

1.   Introduction

75 The impact of anthropogenic pollution on environment and health has been demonstrated by

76 numerous studies in Europe and North America, which have contributed to the implementation

77 of emission reduction policies. By contrast, air pollution in Africa is far from being well

78 characterized, although it is suspected to be responsible for negative health outcomes (*WHO,*

79 *2014*). This is a major problem since Africa is an intense emitter of pollution from

80 anthropogenic sources that includes domestic fires, vehicular traffic, waste burning as well as

81 growing oil and mining industries. It has also one of the fastest growing urban populations in

82 the world, especially in West and East Africa. As a consequence, it has been shown that massive

83 urbanization and rapid economic growth could be responsible for tripling anthropogenic

84 emissions in Africa between 2000 and 2030 (*Liousse et al., 2014*). Moreover, it is important to

85 recall the impact of biomass burning and dust sources in the African atmospheric composition,

86 especially occurring during the dry season. All of this results in a major degradation of urban

87 air quality and an impact on the health of exposed populations. Only a few studies on this

88 subject have been conducted in West Africa (*Val et al., 2013*; *Dieme et al., 2012*; *Kouassi et*

89 *al., 2009*) despite the high atmospheric pollutant concentrations already measured to be of the

90 same order as in Asian megacities and well above WHO international standards (*WHO, 2014*).

91 West Africa is then an "unique laboratory" to study urban pollution. Previous studies conducted

92 under the framework of the AMMA (Analyses Multidisciplinaires de la Mousson Africaine)

93 and POLCA (POLlution des Capitales Africaines) programs, have revealed very high

94 particulate pollution concentration levels in Cotonou (Benin), Bamako (Mali), Dakar (Senegal)

and Yaoundé (Cameroun) during the dry season (*Doumbia et al., 2012; Val et al., 2013*), suggesting that the population may be affected by negative health outcomes. For example, *Val et al. (2013)* showed that the inflammatory impact of combustion aerosol depends on the type of emission sources and determined the predominant role of particulate organic matter. Moreover, fine and ultrafine aerosol fractions, as well as their content in trace metals and organic compounds, have been shown to induce biological effects due to their ability to reach the distal lung (*Cassee et al., 2013*). Such reasons highlight the need to better understand the size-speciation of aerosol chemical composition for the main West African anthropogenic sources during the different seasons. Within this context, the DACCIWA (Dynamics-Aerosol-Chemistry-Cloud Interactions in West Africa) program, dedicated a specific work package to "Air Pollution and Health" dealing with pollutant characterization related to health issues through toxicological studies and epidemiological studies.

Intensive and extensive campaigns have been organized from December 2014 to March 2017 in Abidjan and Cotonou. The strategy was to measure aerosol chemical composition in different sites, representative of the main prevailing urban sources in West Africa following *Liousse et al. (2014)* and *Keita et al. (2018).* Two typical traffic-sampling sites were chosen, one in Abidjan (Côte d'Ivoire) and another one in Cotonou (Benin), to take into account differences in terms of fleets, type of fuel used and quality of roads. Indeed, in Cotonou, the majority of population uses two-wheel vehicles susing gasoline fuel or gasoline and oil fuel, whereas in Abidjan, the vehicle fleet is dominated by four-wheel engines using diesel fuel. Measurements were also performed at domestic fire and waste burning sites, both located in Abidjan.

During the extensive campaign, $PM_{2.5}$ mass and carbonaceous aerosol were weekly measured and results are discussed in *Djossou et al. (2018).* In this paper, we focus on the results from the intensive campaigns. We present measurements obtained at each site during the wet and dry seasons of the studied periods: (i) PM size distribution and mass concentrations and (ii) PM chemical composition including carbonaceous aerosol, water-soluble organic carbon, water-soluble inorganic ions, dust and trace elements in different size fractions. Experimental method including description of sites, types of measurements and analyses, meteorological conditions, will be presented in the section 2, whereas results and discussion are discussed in the sections 3 and 4 of the paper, respectively.

2. Experimental method

2.1. Description of sites

Measurement campaigns have been performed in wet season (July 20-26, 2015 and July 4-13, 2016) and dry seasons (January 7-15, 2016 and January 5-14, 2017) at three sites in Abidjan (Côte d'Ivoire), representative of different sources, i.e. ADF for Abidjan Domestic Fires, AWB for Abidjan Waste Burning and AT for Abidjan Traffic (Figure 1), as well as one traffic site in Cotonou (Benin) (Figure 2).

As shown in Figure 3 which presents pictures of the different sampling sites, the ADF site (5° 19' 44 "N, 4° 06' 21" W) is situated on a platform, 5 m above ground level, in Yopougon Bracody district near a market (Figure 1). This geographical area is highly populated with various small commercial activities such as a fish and meat-smoking by women. There are also many formal and informal settlements, which mainly use wood and charcoal as a source of fuel for private and professional combustion activities. Other sources of concern contributing to the mix of pollutant emissions in the area include transportation-related emissions, biomass burning, garbage bins or small landfills and various other fugitive sources. The AT site (5° 21' 14" N, 4° 01' 04" W) is located in Adjamé, on the roof of « 220 pharmacie logement building », about 7 m above ground level and roughly 10 m away from the main road. This site, close to the Adjamé market and to a bus station, is highly affected by traffic (Gbaka, bus, taxi, woro-woro, private cars…). The AWB site (5° 21' 12" N, 3° 56' 16" W) is located at Akouédo in the district of Cocody, on the roof of « Talafiguié », a building 15 m above ground level. This site is close to the big waste burning area of Abidjan established since 1965, which covers an area of 153 ha. The Cotonou Traffic (CT) (6° 22' 19" N, 2° 26' 5" E) site is located in Cotonou, on the «Sogema» building roof, about 7 m above ground level. This site is close to the Dantokpa market and also to the biggest crossroad of Cotonou (intersection of 4 main roads). This site is highly influenced by intense traffic activities. As previously mentioned, such a site is interesting because the vehicle fleet and fuels are different in Cotonou compared to Abidjan: (1) there are many two-wheel vehicles in Cotonou whereas a few only in Abidjan; (2) in Cotonou, gasoline is of poor quality due to the illegal fuel transport from Nigeria and (3) the roads are in worse conditions in Cotonou than in Abidjan.

2.2. Measurements

During each intensive campaign, two 3-hour samples collected with cascade impactors operating in parallel are obtained for three consecutive days (i.e. six size-resolved samples per site during each campaign), to allow size-speciated characterization of the aerosol chemical composition. Note that the choice of the 3-hour periods is linked to the period of maximum pollution for each site (e.g. morning at ADF site, afternoon at AT site, morning at CT site). There is no specific period at AWB site since the activities are roughly the same during the day. The first impactor with 4 stages ($PM_{>2.5}$; $PM_{2.5-1}$; $PM_{1-0.2}$; $PM_{<0.2}$) includes 4 quartz fiber filters (QMA, Whatman) for mass and carbonaceous aerosol (EC, OC and WSOC analysis). The second impactor with 3 stages ($PM_{>2.5}$; $PM_{2.5-1}$; $PM1_{-0.1}$) is equipped with three Teflon filters (Zefluor, Pall Corporation®), dedicated for water-soluble ions species and trace elements. Due to operational problems in july 2016, this second 3-stage cascade impactor is replaced by another 3-stage cascade impactor with different size cuts ($PM_{>10}$, $PM_{10-2.5}$, $PM_{2.5-1}$). For consistency, results will be presented as an ultrafine (UF), fine (F) and coarse (C) classification. The two first stages ($PM_{>2.5}$ and $PM_{2.5-1}$) being considered as the coarse particulate fraction, the $PM_{1-0.1}$ or $PM_{1-0.2}$ stage, the fine particulate fraction and the $PM_{<0.2}$ stage, the ultrafine fraction. All the filters are prepared and analyzed at the Laboratoire d'Aerologie in Toulouse under different protocols described in the following paragraphs. Note that the quartz filters are prefired before sampling.

2.3. Analyses

2.3.1. Gravimetric analyses

Aerosol mass concentrations are obtained using a high-precision balance (SARTORIUS MC21S), placed under a controlled temperature and humidity atmosphere (Person and Tymen, 2005). Before weighing, the filters are kept 24 hours in the weighing room at an ambient relative humidity of 30 ±15%. The filters are weighed before and after sampling. Result of a gravimetric measurement consists of the average of 2 to 4 weighing whose differences do not exceed 5μg. The standard error on a gravimetric measurement is therefore less than 10 μg, typically representing less than 5% of the particles mass.

2.3.2. Carbonaceous aerosols

Carbonaceous aerosol is determined with thermal analysis with a two-step method adapted from Cachier et al. (1989). Two aliquots of the same filter are separately analyzed.

One portion is directly analyzed for its total carbon content (TC). The other portion is first submitted to a pre-combustion step (2 h at 340°C under pure oxygen) in order to eliminate Organic Carbon (OC), and then analyzed for its Elemental Carbon (EC) content. Organic carbon (OC) concentrations are calculated as the differences between TC and EC. Note that the aerosol carbon content is quantified by a non-dispersive infrared (NDIR) detector with G4 ICARUS instrument with a detection limit of the order of 2 $\mu gC.cm^{-2}$. Uncertainty is in the order of 5% for TC, while being in the range of 5-20%, for EC and OC.

2.3.3 Water Soluble Organic Carbon analysis

WSOC measurements are performed using a total organic carbon analyzer (Sievers M9). A detailed description of this technique is reported in Favez et al. (2008). Briefly, the full oxidation of total organic carbon into CO_2 is obtained by coupling chemical oxidation (with ammonium persulphate) and UV light. CO_2 is then quantified by conductivity. Analyses are conducted on 20 ml of solution extracts. For UF samples, solutions to be analyzed are obtained using a total filter surface of 3cm² (6x0.5 cm² punches symmetrically taken out of each QMA filter), whereas, for C and F sizes, due to the geometry of the spots at the surface of the filters, samples are divided into equivalent parts (1/2 or 1/4 of 47 mm filters, rest of the filters being used for carbonaceous analysis). The extraction protocol consists of 16h soaking under soft shaking in an Erlen-Meyer containing 20mL of ultra-pure water. Prior to WSOC analysis, water extracts are filtered through Teflon (PTFE) filters (0.2μm pore size diameter) in order to remove any suspended particle. Measurement uncertainty, given by the manufacturer, is of the order of 7%. The overall calculated blank value is of the order of $2.27 \pm 0.33\,\mu gC.cm^{-2}$, which represents $16.4 \pm 8.5\%$ of the mean WSOC content. For each sample, duplicate analyses show a good reproducibility.

2.3.4. Water-soluble ionic species

Water-soluble ionic species (Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}, SO_4^{2-}, NO_3^- and Cl^-) are analyzed using ion chromatograph (IC), following the analytical protocol described in Adon et al. (2010). Briefly, the aerosol water-soluble fraction is first extracted from half-sampled Teflon filter (the other part being used for trace element analysis), with a 10-min sonication in plastic vials including 6 ml or 10 ml of purified water with a controlled resistivity of 18.2MΩ. Then these vials are subjected to ionic chromatograph analysis or stored at +4°C if not analyzed immediately. Cations are analyzed with Dionex DX-100 and anions with Dionex DX-500 with

a detection limit of 1 to 6 ppb depending on ionic species. Uncertainties in the range of 1-50% is found depending on ionic species.

2.3.5. Trace elements

The protocol to measure trace element concentrations is developed and performed at the Laboratory of Environmental Geosciences of Toulouse. Half-sampled Teflon filters (the other part being used for water-soluble ionic species, see below) are mineralized by acid digestion with a 10 ml concentrated HNO_3 and 0.5 ml HF solution (Lamaison, 2006) using a closed vessel microwave accelerated reaction system (MARS 5, CEM Corporation) at high pressure (700 psi) (Celo et al. 2010). The digestion is realized in 3 steps: a rise in temperature at 130°C in 3min and holding for 1 min, then, a second rise at 160°C in 1 min and holding for 30 seconds and finally a third rise to 180°C in 1 min and holding for 3min. After a 12 h cooling period, the solutions are evaporated at 80°C, and concentrated in 7 ml of 2% concentrated HNO_3 solution, before analysis by ICP-MS which are performed with a 7500 ce Agilent Technologies instrument equipped with a collision cell, and using In and Re as internal standards. The detection limit is less than 10 ppt. For all the samples, the final blank values and detection limit on filters are taken into account for final concentrations calculations. 13 trace metals are considered in this work: Al, Ti, Cr, Mn, Fe, Ni, Cu, Zn, Ba, La, Th, Pb and Cd.

2.3.6. Dust calculation

Many methods can be used to quantify dust concentrations. We have selected three methods (Sciare et al. 2005, Guinot et al. 2007, Terzi et al. 2010) to underline the uncertainties linked to dust estimates.

(1) Sciare et al. (2005) method consists of using soluble calcium data obtained with Ionic Chromatography (IC), to estimate the dust concentrations following the relationship: dust = $10.96*nss-Ca^{2+}$, where nss-Ca^{2+} ($=1.02*Ca^{2+}-0.038*Na^+$) refers to non-sea-salt calcium concentration.

(2) Guinot et al. (2007) method is based on a chemical closure where fine and coarse particle aerosols are separated in 4 components (EC, POM, WSI and dust). EC, WSI, and total aerosol mass are directly experimentally determined (see below paragraphs). POM concentrations are obtained from OC concentrations experimentally determined and k, the OC/POM conversion factor. Dust concentrations are obtained from measured Ca^{2+} concentrations and f, the abundance of calcium in dust. The k and f values are obtained from a linear regression (L) between the reconstructed and the weighed aerosol

249 mass concentrations. Briefly, first step consists of focusing on the aerosol coarse

250 fraction. k is fixed to 1.8 and as a result of (L) just mentioned, f is obtained to be in the

251 range of 0.012 to 0.15 depending on our sites. Second step deals with the aerosol fine

252 fraction. The f values just obtained for the aerosol coarse fraction are applied to the fine

253 fraction and k ratios are estimated using (L) to be in the range of 1.2 to 2.1. Note that at

254 all of our sites, the correlation between Ca^{2+} and the missing mass between the weighed

255 and the reconstructed aerosol mass is sufficiently good (r^2=0.9) to support the

256 consistency of this simple approach for the evaluation of dust. Also, f and k values are

257 included in the range of values provided in the literature (He et al. 2001; Sun et al. 2004;

258 Guinot et al. 2007). However, it is important to mention that the range of f and k

259 coefficients are large which is due to the source mixing observed in this study.

260 (3) In Terzi et al. (2010) method, dust is obtained with the following relationship: dust =

261 1.89[Al] + 1.21[K] + 1.95[Ca] +1.66[Mg] + 1.7 [Ti] +2.14[Si] + 1.42[Fe]. In our study,

262 all these elements are determined except Silica (Si). Consequently, we used mean Si

263 values obtained from different relationships available in the literature (SiO_2 = 3*Al_2O_3

264 for Alastuey et al., 2005, Si = 4.0*Al for Zhang et al., 2003 and Si = 2.03*Al for

265 Chiapello et al., 1997).

266 The results of dust concentrations estimated from the three methodologies above described are

267 summarized in the Table 1 for wet season (WS) 2016 and dry season (DS) 2017. Indeed, Ca,

268 Al, and Fe concentrations measured by ICP-MS are only available in WS2016 and DS2017 due

269 to experimental problems, whereas Ca^{2+} concentrations measured by IC are available for all

270 campaigns. As shown in table 1, the dust obtained from Ca^{2+} measured by IC (Sciare et al.,

271 2005) and by the Guinot et al. (2007) method is lower than that obtained from trace elements

272 (Terzi et al., 2010) for DS2017 whereas in the same order of magnitude in WS2016. Such

273 results are in agreement with methodological aspects. Indeed, Al, Fe, Ca … obtained by ICP-

274 MS include both soluble and insoluble particles whereas Ca^{2+} measured by IC only include

275 soluble particles. During the dry season, comparison of Ca measured by ICP-MS (not shown

276 here) is higher than that of the IC, by a factor of 1.7, 1.8, 2.2 and 1.1, at the ADF, AWB, AT,

277 and CT sites respectively. By contrast, this factor is low and constant (1.3) in the wet season

278 for all the sites. In our study, due to the lack of trace element data for WS2015 and DS2016,

279 dust estimations are performed from Guinot et al. (2007) method. This choice globally implies

280 an underestimate of dust concentrations by a factor of 1.5 to 3.5 in DS2017.

281

2.3.7. Aerosol chemical closure methodology

As previously mentioned and detailed, aerosol chemical closure is performed following the Guinot et al. (2007) methodology.

2.4. Meteorological conditions

In Figure 4, meteorological data (surface temperature, wind directions and speed) issued from the NOAA Integrated Surface database (ISD; see https:// www.ncdc.noaa.gov/isd) and the ASECNA (Agence pour la Sécurité de la Navigation Aérienne en Afrique et à Madagascar) are presented for the South-West Africa region including Abidjan and Cotonou. As expected, this area is under the influence of the Convergence Zone of two air masses of a different nature, i.e. Harmattan (hot and dry continental trade winds) from the north and Monsoon (humid maritime trade winds) from the south (Figure 4). Ground contact between these two air masses constitutes the intertropical front (ITF) of which the fluctuations during the year determine the seasons in the Gulf of Guinea (Tapsoba, 1997). During the dry season (from November to March), temperatures are relatively high with maximum around 30°C on the coast. The humidity is low, since the prevailing Harmattan wind blows from the desert, usually bringing dust (Figure 4, lower line). The period from June to September, especially in July is the wet season period when daytime temperatures are slightly lower, with maximum around 26/28°C on the coast (Figure 4, upper line). At this season, the humidity level is high across the region. On the coast, rains may occur from March to November.

During our campaigns (not shown here), temperatures are roughly the same at Abidjan and Cotonou, reaching 28°C and 26°C in the dry and wet seasons, respectively. Gentle to moderate wind speeds are observed during the measurement campaigns at the two cities, with average values of 15-20 and 15-22 km.h^{-1} at Abidjan and Cotonou, respectively. There is no precipitation at CT site during the studied periods. In Abidjan on the contrary, low rains occur both in wet and dry periods with cumulative precipitation higher in DS2017 (7mm), than in WS2016 (4.7mm) and WS2015 (2mm). There is no rain in DS2016 (https://www.historique-meteo.net/afrique/).

2.5. Backward trajectories

The Hybrid Single-Particle Lagrangian Integrated Trajectory (HYSPLIT) modelling system (Air resources laboratory, Draxler and Rolph, 2012) is used for the trajectory analysis. HYSPLIT model is run to compute 120 h back trajectories ending at Abidjan and Cotonou at

314 50 m a.g.l. (Figure 5). Global Data Assimilation System reanalysis database is used as

315 meteorological input, with a 0.25 × 0.25 degrees horizontal resolution. Results presented in

316 Figure 5, confirm that air masses mainly come from the north with a few from the south-west

317 in January, whereas from the south-west and the south in July. Therefore, in January, Abidjan

318 and Cotonou are mainly impacted by polluted air masses from surrounding areas and northern

319 countries with possible dust and west African biomass burning influences, whereas in July, the

320 impact of oceanic sources and of long-range south African biomass burning may be observed.

321

3. Results

3.1. Aerosol size distribution and mass concentration

324 In Figure 6, the relative mass distribution of PM for Coarse (C), Fine (F) and Ultra-Fine

325 (UF) particle sizes in percentages are presented with bulk mass concentration averages

326 indicated in the black boxes for each site and for each campaign. As it may be seen, bulk

327 concentrations vary widely from site to site and from campaign to campaign. During the wet

328 season, the average total concentrations range from 82 to 676 μg.m^{-3} in 2015 and 56 to 358

329 μg.m^{-3} in 2016, with the maximum at the Abidjan Domestic Fire (ADF) site. While during the

330 dry season, values range from 168 to 269 μg.m^{-3} in 2016 and from 114 to 559 μg.m^{-3} in 2017,

331 with maximum concentration obtained at the Cotonou Traffic (CT) and ADF sites. In terms of

332 size distribution, concentration peaks may be observed for all aerosol size-fractions which are

333 found to exhibit different seasonal patterns. UF particles (<0.2 μm) represent the highest

334 contributor to the bulk mass at the ADF site, by up to 60 % (335.3 μg.m^{-3}) in DS2017. F particles

335 (1-0.2 μm) are the second most important contributor and both combined particle sizes account

336 for more than 85 % of the total mass at the ADF site. In this site, ultra-fine and fine fractions

337 are also found to be maximum during WS2015 and WS2016 by up to 90 and 83%, respectively.

338 Let us note that C particle contribution in bulk is relatively higher in the traffic and waste

339 burning sites than in ADF site (40%) whereas F and UF particle contributions are on the order

340 of 60%.

341 In terms of PM 2.5, the results of this work are presented in Figure 7. The mass

342 concentration of PM2.5 averaged over DS2016 and DS2017 are 154 ± 74, 144 ± 42, 134 ± 7

343 and 211 ± 51 μg.m^{-3} at the ADF, AWB, AT and CT sites, respectively and 338 ± 24, 45 ± 3, 52

344 ± 4 and 70 ± 1 μg.m^3 over the wet seasons (2015-2016). The increase in PM2.5 is of the order

345 of 54% at ADF from dry to wet season, whereas a sharp reduction (more than 60%) is obtained

346 at AWB, AT, and CT sites.

3.2. Carbonaceous aerosol

3.2.1. EC and OC concentrations

349 In Figure 8, EC relative mass contributions are presented for each size, site and

350 campaign: wet season 2015 (WS2015), wet season 2016 (WS2016), dry season 2016 (DS2016)

351 and dry season 2017 (DS2017). Mean EC bulk mass concentrations are added in the black boxes

352 for each size and for each campaign. The most striking feature is that the ADF site

353 concentrations are higher than at the other sites in WS2016 and in DS2017, whereas of the same

354 order of CT site concentrations in the other seasons. Mean concentration at the CT site ($16\mu g.m^-$

355 ^{3}) is slightly higher than at the AT site ($10\mu g.m^{-3}$), whereas the lowest concentrations are found

356 at the AWB site. Results of the EC size distribution are very consistent among the different

357 sites (Figure 8). Whatever the site and the season, higher EC concentrations are found in C

358 (42%) and UF (43%) particles compared to F particles.

359 Same data are presented for OC concentrations in Figure 9. It may be underlined that

360 ADF OC values are always higher than in the other sites by a factor ranging from 6 to 30, for

361 all seasons and particle sizes, with highest and lowest values respectively in DS2017 and DS

362 2016. In terms of size distribution, maximum OC concentrations at the ADF site may be found

363 in UF (53%), then F (29%) and finally C (18%) particles. The same distribution is observed for

364 the traffic sites in DS2016, however, for the other campaigns, OC size distribution looks like

365 the EC ones with higher concentrations in UF and C particles than in F particles.

366 As shown in Figure 10, the highest OC/EC ratios are always obtained at the ADF site

367 with a value as high as 25 for F particles in WS2016 whereas the lowest values are found in

368 DS2017. This is the same feature for the other sites with ratios lower than 2 in DS2017. OC/EC

369 ratios in AWB site are higher than in the traffic sites. Note that values at AT site are higher than

370 CT values in the wet season whereas lower in the dry season. Finally, it is interesting to

371 underline that linear correlations between EC and OC are obtained in the ultrafine and fine

372 modes in all campaigns, particularly in DS2017 (r^2 = 0.8, 0.8, 0.9 and 0.9) at the ADF, AWB,

373 AT and CT sites, respectively. This suggests that different studied sources can be assessed as

374 significant sources of both EC and OC.

375

3.2.2. Water-Soluble Organic Carbon

Concentrations of WSOC and WSOC/OC ratios are presented in Table 2 for each size (UF, F, C and PM$_{2.5}$) and campaign. As seen, WSOC are always higher at the ADF site than in other sites, at least by a factor of 12. Maximum values are obtained in WS2016 with an average of 16.47, 17.08 and 79.68 µgC.m^{-3} for coarse, fine and ultra-fine fractions, respectively, followed by WS2015 and DS2017. WSOC concentrations are the lowest in DS2016, with an average of 4.14, 6.95 and 21.89 µg.m^{-3} for coarse, fine and ultrafine fractions, respectively. In terms of seasonality, there is not a clear trend in WSOC values at the AWB and AT sites, whereas at the CT and ADF sites, WSOC values are found to be respectively higher and lower in dry seasons compared to wet seasons. It is also interesting to note that WSOC are maximum in UF sizes in the AT, ADF and AWB sites. At the CT site, the highest values are found in the coarse particulate fractions, except in DS2016.

As expected, WSOC is strongly correlated with OC (r=0.7 at ADF, 0.8 at AT, 0.5 at AWB and 0.7 at CT), whereas correlations with EC are weaker, especially at the AWB and CT sites with values ranging from 0.1 to 0.4, respectively. Finally, when looking at WSOC/OC ratios (Table 2), maximum values are obtained at the ADF site with PM2.5 ratios as high as 43%, followed by the AT and AWB sites with 32%. The lowest value (23%) is found at the CT site. Also, Table 2 shows that there is no clear seasonality in WSOC/OC values, excepted at ADF where maximum values occur during the wet season. Note as for WSOC, that ratios are maximum in UF and F fractions for all sites except at the CT site where the ratio for coarse fraction is the highest.

3.3. Water-soluble ionic species

Figure 11 shows the relative contribution of the major ions to the total concentration (also given) of the ions in the different particle modes (C and F) at the ADF, AWB, AT and CT sites for the different measurement campaigns. Let us recall here that only C and F fractions may be documented due to the our experimental protocol. Total concentrations present maximum values in ADF and CT sites. Values in AWB and AT sites are of the same order of magnitude and lower by a factor of 2 than in ADF and CT sites. The contribution of different ions show significant variations from site to site. The dominant ionic species at the ADF site over all campaigns is chloride (Cl$^-$), with a 26% contribution, followed by nitrate (NO$_3^-$) (16%), calcium (Ca^{2+}) (13%) and potassium (K^{2+}) (12%). Sulfate (SO$_4^{2-}$), ammonium (NH$_4^+$), sodium

407 (Na$^+$) and to a lesser extent magnesium (Mg^{2+}) contributions are lower, ranging from 4 to 7%

408 of the total ion species. The lowest contribution is for organic acids with their total value lower

409 than 5%. NO$_3^-$ is the major ionic component at the AWB and AT sites, representing 24% and

410 29% of the total water soluble inorganic concentration, respectively. The second major

411 contributor in AWB and AT is SO$_4^{2-}$, accounting for 21% and 17% of the ion mass, respectively

412 followed by Ca^{2+} (12% and 15%) and Cl$^-$ (15% and 13%). In CT, Ca^{2+} is predominant with a

413 relative abundance of 24%, followed by NO$_3^-$ (23%), SO$_4^{2-}$ (19%) and Cl$^-$ (13%). Na$^+$, NH$_4^+$

414 and K$^+$ contributions are lower and in the same order of magnitude in AT, AWB and CT sites,

415 ranging from 4 to 9% of the total ion species. Note that organic gases contributions at AT, CT

416 and AWB is of the same order than in ADF, with lower values at CT. It is interesting to

417 underline in the Figure 11, that NO$_3^-$ contribution is always higher in the coarse than in the fine

418 size. Conversely, K+ is always higher in the fine than in the coarse size. In CT, Ca^{2+} in the fine

419 fraction is as high as in the coarse fraction whereas in AT, AWB and ADF, Ca^{2+} coarse fraction

420 is predominant. Fine particle contribution may be noticed for Cl$^-$ in ADF whereas in the other

421 sites, Cl$^-$ is most likely dominated by coarse particles. Finally, SO$_4^{2-}$ is mainly found in the fine

422 mode at the AT, AWB and CT sites, but in the coarse mode in ADF site.

423 In terms of seasonal variations, it may be shown in Figure 11 that higher Cl$^-$ values are found

424 in wet seasons than in the dry seasons everywhere, except in ADF site where there is no marked

425 difference between seasons. For example, the mean relative total percentages of Cl$^-$ at the CT

426 site are 38 and 24% in the WS2015 and WS2016, respectively, while these percentages decrease

427 significantly to 18 and 13% in the DS2016 and DS2017, respectively. The Cl$^-$/Na$^+$ ratios are

428 about 1.5 everywhere in both seasons, in agreement with the typical sea water ratio (1-1.2)

429 (Hara et al.,2004), except at the ADF site where these ratios increase to 4 and 5 in wet and dry

430 season, respectively and at the AWB site in the dry season (2). K$^+$ and Ca^{2+} are always higher

431 in dry season than in wet season except for Ca^{2+} in ADF where values are of the same order.

432 Finally, the same trend is observed for NO$_3^-$ and SO$_4^{2-}$ with higher values in dry than in wet

433 seasons at AWB and CT sites whereas values at ADF and AT sites are of the same order of

434 magnitude for the two seasons.

435 **3.4. Trace element concentrations**

436 Table 3 shows the mean values of the major trace elements in bulk aerosol at the

437 different studied sites in WS2016 and DS2017, with their corresponding relative abundances in

438 the total aerosol mass into brackets. Let us recall that data are not available in WS2015 and

439 DS2016. The concentrations of trace elements span a wide range, from 0.2 to 25.2 μg.m^{-3}.

440   Among the measured elements, Al, K, Na and Ca are the most abundant, followed by Fe and

441   Mg. In DS2017, Al and Na concentrations are higher in AWB than in the other sites. The

442   minimum value for these species is found in ADF site. Values in traffic sites are of the same

443   order of magnitude and higher than in ADF site. Maximum of Ca and K values may be found

444   in CT and ADF site respectively. It is interesting to note that Al, K, Na concentrations are higher

445   in the dry season than in the wet season. Such feature is less clear for Ca, whose seasonal

446   variability is less marked except in AWB and AT sites. In terms of Mg, maximum values are

447   observed in ADF site and of the same order of magnitude whatever the season. Fe abundance

448   is higher in AWB and CT sites than in ADF and AT sites and higher in DS2017 than in WS2016

449   everywhere. The other metals (Ti, P, Zr, Zn, Cr, Mn, Pb and Ni) represent less than 0.5% and

450   2% of the total mass in WS2016 and DS2017, respectively, at all sites, with Cr, Mn, Pb and Ni

451   exhibiting less seasonal variability compared to the rest of the metal elements.

452   To assess the relative contribution of crustal and non-crustal origin of elemental aerosol

453   loadings, source enrichment factor (EF) of a trace element X have been first calculated with the

454   following formula using both literature data of the typical elemental composition of the upper

455   continental crust (Mason and Moore, 1982; Taylor, 1964), measured elemental composition

456   from this study and Al as a reference element :

457
$$EF_X = \frac{\dfrac{[X]_{atm}}{[Al]_{atm}}}{[X]_{soil} \Big/ [Al]_{soil}}$$

458   Where $[X]_{atm}$ and $[Al]_{atm}$ are the concentrations of the chemical element X and Al in the

459   atmosphere, respectively, and $[X]_{soil}$ and $[Al]_{soil}$ are the typical concentrations of the element

460   X and Al in the earth's crust, respectively. Al is frequently used as a reference element assuming

461   that its anthropogenic sources in the atmosphere are negligible (Gao et al., 2002; Cao et al.,

462   2005; Xu et al., 2012). In all sampling sites, EF values typically lower than 5 are obtained for

463   several trace elements (Be, Sc, Ti, V, Fe, Ga, Sr, Nb, Rh, Ba, La, Ce, Pr, Nd, Sm, Eu, Gd, Tb,

464   Dy, Ho, Er, Tm, Yb, Lu, Ta, Th and U). This suggests a natural origin of these species (Freitas

465   et al., 2007; Gao et al., 2002). The most enriched elements (EF>100) are Sb, Sn, Zn, Se, Te,

466   Cd, Pb, Bi and Mo at nearly all of the sites, indicating significant anthropogenic origin (Wang

467   et al., 2006). These elements are mainly emitted into the atmosphere through fossil fuel

468   combustion, traffic emission, wear of brake lining materials and industrial processes (Watson

469   and Chow, 2001; Samara and al., 2003). Secondly, source contributions have been estimated

470   from these EF values following the method described by Arditsoglou and Samara (2005). Note

471   that this study refers to ratios for a limited list of sources, perhaps not including the African

source specificities. As a result, it may be seen that 30% of trace element concentrations is of anthropogenic origin at ADF site whereas about 17 % at the others sites.

3.5. Dust

Figure 12 shows dust concentrations calculated from Guinot et al. (2007) methodology (see paragraph 2.3.6) for C and F particle sizes at the different sites for each season. Note that as for WSI and trace element and due to our sampling procedure, there are values for fine and coarse particles for all seasons excepted for WS2016 with values for coarse particles only. During the wet season, coarse dust concentrations range from 5 to 25 µg.m^{-3} in 2015 and 9 to 37 µg.m^{-3} in 2016, with higher values at the CT and ADF sites in 2015 and at AT, CT and ADF in 2016. In WS2015, fine dust concentrations range from 12 to 49 with maximum values at AFD and CT sites also. During the dry season, values range from 38 to 156 µg.m^{-3} in 2016 and from 41 to 116 µg.m^{-3} in 2017, with maximum concentrations obtained at the CT site, followed by AWB site. When considering mean values of the dry seasons, total dust at Cotonou traffic (CT) is 2.4 times the values found at AT, 1.6 times at AWB and 3.4 times at ADF. Seasonal comparison shows that total dust concentration is higher in the dry seasons than in WS2015 by a factor of 3 in AT, 2.6 in CT and 4 in AWB, but of the same order of magnitude in ADF site.

3.6. Aerosol chemical closure

The aerosol chemical closure obtained using the Guinot et al. (2007) method (see below) at the different sites for each season is presented in Figure 13. Results show clear intra- and inter-annual variations at all of the sites, as well as significant differences among the sites. In total, dust accounts for 39 to 75% of the bulk PM mass at both traffic sites, with no clear seasonal cycle and higher contributions in Cotonou (Figures 13c and 13d). These percentages vary from 32 to 64% at the AWB site, and from 18 to 35% at the ADF site, with percentages 1.8 times higher in the dry season than in the wet season in AWB and no clear seasonal difference in ADF (Figures 13a and 13b). Carbonaceous aerosol, the sum of EC and POM, show large contributions at the ADF site (from 49 to 69% of the total PM mass), with relatively similar proportions in each season (Figure 13a). The absence of a clear seasonal pattern is also observed in CT whereas carbonaceous aerosol is slightly higher in WS than in DS in AWB (23 and 16% respectively) and AT (37 and 21% respectively) (Figures 13b-d). Carbonaceous aerosol contribution accounts for about 11- 49% of the total mass at both traffic sites with higher values in AT (mean of 30%) than in CT (13%). The ion percentages in PM fractions present the same pattern at AT, CT and AWB sites with higher values in wet than in dry seasons. In

504   these sites, we may notice that coarse particles are larger in the wet season whereas of the same
505   order of magnitude than fine particles in the dry seasons. In ADF, no marked difference may
506   be found between the seasons and the sizes (Figure 13).

507

4. Discussion

509   A discussion of the results site by site (Abidjan domestic fire site, traffic sites both together and
510   waste burning site) will be first proposed. We will scrutinize (1) the proximity between the sites
511   and the sources; (2) the source specificity with more or less incomplete combustion (e.g. wood
512   combustion and two-wheel vehicle emission factors are higher than gasoline emission factors
513   (Keita et al., 2018); (3) the relative influence of other local sources or transported sources to
514   the studied sites such as dust and biomass burning; (4) the occurrence of continental air masses;
515   (5) the variation of the boundary layer height (as reported by Colette et al., 2007); and (6) the
516   meteorological parameters (e.g. temperature, relative humidity and wet deposition) to explain
517   the differences of pollutant concentrations and their seasonal and inter-annual variabilities.
518   In a second part, we will present comparison of our values with other DACCIWA values and
519   also with literature values for other intensive campaigns in Africa.

520

4.1. Abidjan Domestic Fires (ADF)

522   As shown in the above paragraphs, maximum values are obtained at the ADF site, for aerosol
523   mass, EC, OC, WSOC, water-soluble ionic species (e.g. Cl^-, NO_3^-, Ca^{2+} and K^+) and some trace
524   elements such as Mg and K (whereas Al, Na and Fe are lower than in the other sites). Also,
525   aerosol $PM_{2.5}$ values are well above the annual and daily WHO guidelines of 25 and 10 $\mu g.m^{-3}$
526   respectively, whatever the season.
527   Such pattern is due to the proximity of the ADF site to the studied combustion source: in that
528   area, the use of wood combustion is very active due to commercial activities of women drying
529   fish and meat and domestic cooking. This is also confirmed by the high relative importance of
530   total carbon in aerosol mass whatever the size (49 to 69%) and by values of source enrichment
531   factor. Indeed, at least 30% of trace element concentrations are of anthropogenic origin at ADF
532   site. In addition, wood combustion is well known to be highly pollutant due to incomplete
533   combustion: this is shown here by the measurements of very high OC/EC ratios at ADF, on the
534   order of the one measured at the source level by Keita et al. (2018). This is also shown by
535   WSOC relative importance which is expected for wood burning following Yu et al. (2018),

536 Tang et al. (2016), Feng (2006) and Saxena and Hildemann (1996) and by the strong correlation

537 of WSOC with biomass burning K^+ tracer.

538 Chloride is most likely associated with sea salt origin (55% of total composition of the sea

539 water) or secondary aerosol production (Li et al., 2016). Its high concentration at the ADF site

540 remains lower than the typical concentration in sea-water, suggesting a secondary production

541 source. The size distributions of Cl^-, K^+, NH_4^+ and SO_4^{2-} support the conclusion that the

542 predominance of these elements in fine particle mode at the ADF site could be associated with

543 anthropogenic emissions, particularly biomass combustion and domestic fires, or with

544 secondary inorganic aerosols origin. This is confirmed by Cl^-/Na^+ ratio values as shown earlier.

545 Contrarily, Ca^{2+} and NO_3^- contributions to the total ions at the ADF site peak mainly in the large

546 particle fraction and may be attributed to quasi natural origin, primarily to dust emissions and

547 nitrate formation by reaction processes, respectively. In addition, Na^+ and Mg^{2+} display similar

548 size distributions at the ADF site, with the major contribution in the coarse particle fraction,

549 suggesting the common sea salt origin of these two elements (Belis et al., 2013).

550 As we have shown above, the lower proportion of metal elements at the ADF site (6.5% of the

551 bulk concentration) can be explained by the less dominant influence of re-suspended dust

552 particles compared to traffic sources. Elements such as Cr, Mn, Pb and Ni have less seasonal

553 variability than other metallic elements. These small proportions of these non-crust elements

554 suggest a low contribution of elements emitted mainly by anthropogenic activities such as

555 industrial processes (Viana et al., 2007 and 2008; Minguillón et al., 2014). Finally, the Zn/Cd

556 ratio has been also examined. A value of 29 close to ratio reported for gasoline vehicle (27, Qin

557 et al., 1997) is obtained for the ADF site, indicating that this site is also impacted by traffic

558 sources.

559 High values of WSOC/OC ratios are expected to be harmful to health (Ramgolam et al., 2009,

560 Val et al., 2013). This effect is being enhanced by the particulate size measured at this site (Kim

561 et al., 2003; Wilson et al., 2002). Indeed, the relative mass distribution of PM and OC particle

562 sizes shows a major contribution of particles less than 1 µm (as high as 85% for PM). This

563 could be due to the fact that carbonaceous aerosols are formed near emission sources and are

564 mainly of submicron size (Boucher, 2012). Note that EC also presents large coarse particle

565 contribution.

566 In terms of seasonality, higher concentrations of aerosol mass, OC, WSOC, EC and total water

567 soluble ionic species (SO_4^{2-}, NH_4^+ and NO_3^-) are observed in WS2015 and WS2016 than in

568 DS2016. This may be explained by a more incomplete combustion in the wet seasons than in

569 DS2016 due to the use of moist wood for cooking and smoking fish, which leads to large

570 amount of smoke and higher particulate emission factor values. Note that DS2017 values are
571 as important as the ones of wet seasons, which will be explained later in the text. With regard
572 to WSOC, their variabilities may be also linked to meteorological factors, such as solar radiation
573 (Tang et al., 2016; Favez et al., 2008) and relative humidity (Liang et al., 2016). At ADF site,
574 temperatures are roughly similar in both seasons. However, RH variability may play a role since
575 it is higher in wet season than in dry season. Finally, our results indicate no clear seasonal cycle
576 for Cl$^-$, which confirms its anthropogenic origin, as previously shown.

577

4.2. Traffic sites (Abidjan traffic and Cotonou Traffic sites)

579 Let us recall first that the two traffic sites have been chosen since they are representative of the
580 traffic diversity in West Africa. At CT site, both personal cars, taxis and an important two-
581 wheel fleet may be found whereas at AT site, there are buses, taxis and personal cars. Also, the
582 distance between the site and the traffic sources is the same for the two traffic sites, slightly
583 larger than the distance between the site and the wood burning sources at ADF site.
584 In these two sites, concentrations are high with PM$_{2.5}$ values well above the WHO guidelines.
585 Average aerosol mass, EC, OC, dust and water soluble ionic concentrations (with NO$_3^-$ and
586 Ca^{2+} maximum at AT and CT sites respectively) are higher at CT than at AT site by a factor of
587 1.5 to 2. Note that this poor air quality found in Cotonou has been reported by Cachon et al.
588 (2014). The higher values found in Cotonou could be due to more intense traffic in Cotonou
589 than in Abidjan. Also in Cotonou, this traffic is associated with the lack of public transportation
590 and the use of highly polluted mopeds (aged over 15 years) (Gounougbe, 1999; Avogbe et al.,
591 2011), despite the effort in the last 10 years to restrict their use. Several studies such as MMEH
592 (2002) have shown that more than 94,000 mopeds and 350,000 second-hand vehicles are in
593 circulation in Cotonou. Other factors contributing to the local pollution include outdoor
594 restaurants using charcoal and motorcycle garages, which are more present around the Cotonou
595 traffic site compared to Abidjan site. It also includes anthropogenic dust. Indeed, at Cotonou,
596 the lack of road infrastructure favours the resuspention of dust particles. Finally, other sources
597 may potentially influence aerosol seasonal composition in these two sites, including marine
598 aerosols, transported dust and biomass burning particles as well as anthropogenic aerosols from
599 the surrounding countries (Figure 5). Note also that source enrichment factor values show that
600 about 17% of trace element concentrations are of anthropogenic origin at both traffic sites and
601 that the relative importance of total carbon in mass is higher at AT than at CT sites. As a
602 consequence, aerosol mass, composition and size depend on the season and the two traffic sites
603 are differently affected.

604 The EC and OC concentrations measured in both traffic sites, are higher in dry than in wet
605 season. Such variations may be explained by several factors: particulate wet deposition
606 occurring during the wet season, reduction of traffic flow due to school vacations and
607 meteorological influence. Higher EC concentrations are obtained at CT than at AT sites at both
608 seasons. Similar pattern is observed for OC in dry season. In contrast, lower values are obtained
609 at CT than at AT sites in wet season. Differences between OC values in wet season between
610 the two sites can be due to the influence of long-range transport of biomass burning aerosols
611 coming from Southern Africa, which could be more important in Abidjan than in Cotonou, as
612 shown by the backtrajectory patterns given in Figure 5. On the contrary, in the dry season,
613 higher OC values at Cotonou may be explained by local sources as already detailed, but also
614 by surrounding sources such as Nigerian anthropogenic and biomass burning sources (Figure
615 5).

616 In terms of WSOC concentrations, concentrations at the AT site are on average higher than
617 those recorded at the CT site in the wet season, but lower in dry season. The presence of dust
618 can produce semi-volatile organic gas scavenging and therefore WSOC and OC enhancement.
619 Such a phenomenon can explain the highest WSOC concentrations observed in dry season at
620 the CT site where dust concentrations are highest (see dust paragraph). Moreover, this can also
621 explain why the maximum WSOC are in coarse particles at CT, while at AT maximum values
622 are in ultra-fine particles.

623 Total WSI concentrations are larger at AT site in the wet than in the dry season with higher
624 values in coarse particles. At CT site, total WSI concentrations in fine particles are higher in
625 the dry than in the wet season whereas same values are obtained in coarse particles for both
626 seasons. Note that CT values are generally higher than AT values with a more important
627 contribution of fine particles in the dry season. These WSI variations can be explained by the
628 relative importance of Ca^{2+}, SO_4^{2-} and NO_3^- in both sites.

629 First, Ca^{2+} contribution to total WSI is higher in CT site than in AT site with no clear seasonal
630 variation at CT site and higher values in dry season than in wet season at AT site. Also at CT,
631 fine and coarse Ca^{2+} particles are in the same range, whereas coarse Ca^{2+} particles are
632 predominant at AT site. Such feature may be explained by the impact of dust sources including
633 long-range dust transport at Abidjan and a combination of long-range dust transport and road
634 resuspension at Cotonou.

635 Second, the relative contribution of SO_4^{2-}, NH_4^+ and NO_3^- as a percentage of total WSI in the
636 different particle modes is reduced in the wet season. During the wet season, the clean winds
637 surrounding the ocean before reaching the measurement sites could contribute to lower the

638   proportion of these species, in addition to the scavenging processes during the rainy days.

639   Unlike the wet season, a relatively good correlation of 0.87 (SO_4^{2-} versus NH_4^+), 0.73 (NO_3^-

640   versus NH_4^+) and 0.87 (SO_4^{2-} versus NO_3^-) has been found in coarse particles, indicating similar

641   sources for these three species during the dry season. In order to try to identify these sources,

642   the ratio of SO_4^{2-}/Ca^{2+} and NO_3^-/Ca^{2+} has been determined. The average SO_4^{2-}/Ca^{2+} and

643   NO_3^-/Ca^{2+} ratios in combined coarse particles (1.07 and 2.58 during the wet season and 0.33 and

644   1.60 during the dry season) are higher than the corresponding ratios for typical soil (0.026 and

645   0.003, respectively). On the other hand, the SO_4^{2-}/Ca^{2+} ratio increases in the fine particles (5.07

646   during the wet season and 2.53 during the dry season), while that of NO_3^-/Ca^{2+} remains almost

647   constant (2.86 during the wet season and 1.65 during the dry season). This implies that the

648   atmosphere at AT and CT sites is enriched by SO_4^{2-} formed as anthropogenic secondary

649   particles, possibly from sulfur containing pollution sources (Seinfield and Pandis, 1998),

650   particularly in fine particle mode, and by NO_3^- mostly coming from nitrogen containing sources

651   in all particle sizes. The higher contributions of these elements during the dry season could

652   result from a combination of several factors: 1) an atmosphere loaded with dust favoring

653   heterogeneous chemistry to obtain secondary aerosol and the rise of biomass burning emissions;

654   2) the increase of photochemical activity and higher concentrations of hydroxyl radicals in the

655   dry season, which can oxidize SO_2 from combustion (Arndt et al., 1997) to SO_4^{2-} (Li et al.,

656   2014) ; and 3) the wind transport of anthropogenic secondary particles from the industrial zone

657   located upstream from our sites. Finally, the proportion of Cl^- relative to the total mass of ions

658   is highest for coarse particles at both traffic sites especially during the wet season, suggesting

659   that Cl^- at AT and CT sites if from natural origin and probably from sea salt emissions.

660   If we focus now on dust during the two wet seasons, concentrations are higher in 2016 than in

661   2015 at CT and AT sites for coarse particles (no data of fine particles are available in WS2016).

662   This is consistent with observed aerosol optical depth (AOD) values at CT, which increased by

663   a factor of 2 between 2015 and 2016. No AOD value is given by Léon et al. (2019) at Abidjan

664   in WS2015 to allow such comparison in Abidjan. Moreover, during the wet season, an

665   Angström coefficient (AE) on the order of 1 has been found at CT site, indicating smaller

666   particles that could be due to road resuspension. It is interesting to note that during WS2016,

667   AOD and AE are respectively higher and lower at Abidjan than at Cotonou. Again, this is

668   consistent with our dust concentrations at CT site. In Abidjan, we could assume that another

669   source of Ca^{2+}, which is not taken into account in our dust calculations, may explain our dust

670   concentration data. That may be the result of anthropogenic Ca^{2+} emissions from residential

671 combustion, more important in 2016 than in 2015 as shown earlier
672 (http://naei.beis.gov.uk/overview/pollutants?pollutant_id=84).

673 The relative contribution of dust generally peaks in the coarse mode and, to a lesser extent, in
674 the fine mode, reflecting their natural origin. It is interesting to note that the dust contribution
675 observed in this study for the year 2016 at the Abidjan site is in agreement with the results of
676 Xu et al. (2019) which show a $PM_{2.5}$ dust contribution of 35-50% compared to our values of
677 18-52%.

678

4.3. Abidjan Waste Burning site

680 Concentrations measured at AWB site are slightly lower than values found in the other sites.
681 This could be explained by the distance of the site to the studied source (here waste burning
682 source) which is more important than in the other sites. However, $PM_{2.5}$ values are also higher
683 than WHO guidelines.

684 Aerosol mass, EC and OC concentrations are higher in dry than in wet season, which suggests
685 less waste burning activities during the wet season or impacts of other local anthropogenic
686 sources or long-range biomass burning sources. Highest values are found in DS2017 with the
687 lowest OC/EC ratio, as at AT site. OC/EC ratio is highly variable at AWB (1-10) which
688 confirms that AWB site may be impacted by different types of sources as well as by secondary
689 aerosol organic formation which can be detected for OC/EC higher than 2 (Turpin et al. 1990;
690 Hildermann et al. 1991; Chow et al. 1996). Note that OC/EC typical for waste burning source
691 is of the order of 8 (Keita et al., 2018).

692 It is also observed that at the AWB site, PM mass concentrations are mainly distributed in C
693 mode (30-44%) over the entire period of study, excepted during the WS2015, and to a lesser
694 extend in F mode (21-44%). EC and OC being mainly distributed in C and UF modes. Water-
695 soluble fraction of organic carbon is important (32%) and on the order of the one found at AT
696 site. Same for WSI concentrations and WSI composition. At AWB, WSI values are globally
697 slightly higher in wet than in dry season. However, it is interesting to underline that Ca^{2+} is
698 much higher in dry season than in wet season, especially in DS2017. This is in agreement with
699 dust concentrations and trace element concentrations, which have been found to be maximum
700 at AWB, reaching 35.8% of the total PM mass in the dry season. These maximum percentages
701 are due to the large contribution of both Al and Na crustal elements which account for about
702 26%. Also note that Cu/Sb of 0.08 in DS2017, which indicate an influence of re-suspended
703 particles. A Zn/Cd value of 56 is obtained for the AWB site which is in close agreement with

704 values reported for oil burning (Watson et al., 2001, Samara et al., 2003). That could indicate
705 that oil might be one of the waste burning materials.

706 Our result suggests that AWB aerosol mass is influenced by a mix of sources, including fuel
707 combustion and mineral salt from sources around the measurement site, associated to long-
708 range source impact of dust and biomass burning which will be further discussed in the next
709 paragraph.

710

711 **4.4. Interannual variability of aerosols in Abidjan and Cotonou**

712 EC and OC concentrations are generally higher in DS2017 than in DS2016 for all the sites. This
713 is not due to the meteorological condition, which is similar in both years. This is also not due
714 to biomass burning impacts. Indeed, when looking at MODIS burnt areas for our period of study
715 (http://www.aeris-data.fr/redirect/MODIS-MCD64A1), burnt areas of west African savannas
716 are higher in 2016 than in 2017. Therefore, carbonaceous aerosol concentrations should be
717 higher in 2016. Then, this could be due to a counter effect between biomass burning emission
718 strength and air mass transport efficiency. As a result, biomass burning impact could not explain
719 the difference in EC and OC during the dry season between 2016 and 2017. Rather, this is due
720 to the variability of local sources. In DS2016 in Abidjan, there was a general strike of civil
721 servants of the State with important consequences on urban activities. Lower activities were
722 observed (lower fish smoking emissions, lower traffic ..) in DS2016 compared to DS2017, thus
723 explaining the lower EC and OC concentrations at Abidjan sites. In Cotonou, highest
724 carbonaceous aerosol values in DS2017 may be explained by backtrajectory patterns: Cotonou
725 would be impacted by air masses coming from the high polluted Lagos (Nigeria) area in that
726 period whereas from less polluted northern areas in DS2016. Such an assumption is validated
727 by the AOD values at 550nm from MODIS satellite images (http://www.aeris-
728 data.fr/redirect/MODIS-MCD64A1), which show very high particulate concentrations in the
729 Guinean Golf (Figure 14).

730 This figure also shows the AOD difference between Cotonou and Abidjan for DS2017, with
731 higher values at Cotonou than in Abidjan for the campaign period, in agreement with our
732 measurements of aerosol mass, EC, OC and dust. This is confirmed by the DACCIWA
733 sunphotometer AOD and Angström coefficient (AE) measurements at Abidjan and Cotonou
734 (Léon et al., 2019; Djossou et al., 2018). Indeed, in DS2017, during our period of
735 measurements, mean AOD in Cotonou is of the order of 1.3 versus 0.9 in Abidjan for an AE of
736 0.6 for both sites, which clearly indicates the presence of coarse dust particles.

Finally, aerosol mass and dust concentrations have been seen to be higher in DS2016 than in DS2017 in Abidjan whereas values are on the same order of magnitude at Cotonou. Such high values at Abidjan in DS2016 can be explained by the back-trajectory pattern with air-masses all coming from northern dusty areas in DS2016 (Bodélé depression in Tchad, Prospero et al. (2002), Washington et al., (2003), Knippertz et al. (2011), Balarabe et al., (2016)) and/or from northern dusty countries (Mali, Niger) (Ozer, 2005), whereas in DS2017, contribution of southern marine clean air-masses may also be noted.

In the wet season, aerosol mass, EC and OC are higher in WS2015 than in WS2016. This may be due to particulate wet deposition, more efficient in WS2016 which have been seen earlier to be more rainy (4.7mm) than in WS2015 (2mm). Moreover, at AT site, dust concentrations are higher for coarse particles in WS2016 than in WS2015. Such variations may be explained by long-range dust sources and/or road dust resuspension processes. As no dust event has been noticed, local source explanation seems to be more evident.

Finally, in AT, CT and AWB, OC/EC ratios are globally on the same order for WS2015, WS2016 and DS2016, with values similar to that of gasoline emissions or old diesel vehicles. However, the ratios are lower for DS2017, with values typical of those of diesel emission (Mmari et al., 2013; Keita et al., 2018). The general strike occurring in DS2016 in Abidjan could explain such a difference. Indeed, more EC emissions occurred in DS2017 than in DS2016 for constant OC emissions. This can be the result of more diesel traffic. Similar ratio values have also been previously reported for other megacities such as Agra in India with 6.7 (Pachauri et al., 2013), Helsinki in Finland with 2.7 (Viidanoja, 2002), Cairo in Egypt with 2.9 (Favez, 2008), Paris in France with 3.5 (Favez, 2008), and Milan in Italy with 6.6 (Lonati et al., 2007).

4.5. Comparison with DACCIWA and literature measurements

Firstly, the comparison between our data and other DACCIWA results including other time sampling focuses on $PM_{2.5}$ levels, since these particle sizes are relevant for health impact studies (Xing et al., 2016). In addition to our values, Figure 7 presents data from Xu et al. (2019) using personal samplers collected in the same area and at the same dates in 2016 during 12h on women at the ADF site, students at the AWB site and drivers at the CT site, and from Djossou et al. (2018) study based on weekly measurements collected at the same areas and for the same periods as this study. We note that $PM_{2.5}$ directly measured on women are 2.3 and 0.9 times our values obtained at the ADF site in dry and wet seasons, respectively, and 3.4 and 4.9 times higher on students than at the AWB site, and 1.6 and 2.1 times higher on drivers than at the CT

site. Also, our values are on average 1.6, 3, 5 and 8 times higher than weekly values of Djossou et al. (2018) including our 3 days of measurements at the AWB, ADF, AT and CT sites respectively. As it may be seen, the lowest concentrations are observed in Djossou et al. (2018), whereas the highest concentrations are recorded in Xu. et al. (2019). This is valid for all sites, seasons and campaigns. Differences between our values and Djossou values may be explained by the sampling times of the two studies. Indeed, Djossou measurements are weekly, taking into account diurnal activities during all the week, including week-end and nights which have expected lower $PM_{2.5}$ concentrations. Our study includes only maximum pollution conditions for each site. The highest differences occur for the traffic sites. This may be clearly understood since diurnal and weekly variations of traffic sources are the most variable. Comparison between our values and Xu et al. (2019) values is also interesting. Indeed, it is at the ADF site that on-site and women $PM_{2.5}$ concentrations are the closest, which shows that this site is the most representative of the pollution exposure to women. The biggest differences are found at the AWB site. As already mentioned, distance from the site to the waste burning source is more important than for other sites, which explains why student concentrations are much higher than on-site concentrations. At the Cotonou traffic site, measurements taken from people are also higher than on site measurements. Such differences can be explained by additional pollution exposure as people move around. Note that the sampling technique may also play a role in such a comparison. In terms of seasonal variation, our results are in agreement with long-term EC measurements conducted by Djossou et al. (2018) for the same sites and period. Finally, Table 4 compares our $PM_{2.5}$ results to literature data for different traffic sites in the world including the same daily sampling time. It is interesting to note that our values are situated at the higher end of the range of $PM_{2.5}$ data observed from the other sites.

Secondly, Table 5 compares our OC and EC values to those obtained by Djossou et al. (2018) and Xu et al. (2019) as previously described for the same period and the same sites. It is interesting to note that Djossou's values are in general lower than ours. Indeed, for the wet and dry seasons, our OC measurements are 4 and 1.4 times higher than Djoussou's at the AT site, 2.1 and 5.7 times higher at the CT site, and 2.5 and 2.5 times higher at the ADF site, respectively. As for $PM_{2.5}$, this can be explained by the different sampling times between our experiments that were performed at the peak of urban activities, while Djossou's dataset represents weekly integrated values. Differences at the ADF site are largely explained by the temporal pattern of fish smoking activities which take place every day, only in the morning, as such the associated pollution is not well represented in the weekly sampling. Finally, there are less differences at the AWB site between both datasets since waste burning emissions occur

night and day throughout the week. Comparisons made between our values and those of Xu's personal data show that both OC and EC are of the same order at the ADF site, whereas Xu values are higher than ours at the CT and AWB sites. This result is in agreement with what we found with $PM_{2.5}$ concentrations as detailed above. Finally, Table 6 presents OC and EC for the $PM_{2.5}$ comparison between our values and other recent studies dealing with traffic sites in other regions of the world and with similar operational conditions. We find that our values are situated in the middle of the range observed in these different studies. Briefly, as presented in Table 7, it is interesting to compare our WSOC concentrations to literature data for different traffic sites of the world. We note that our values are on the same order as values found in Asia and higher than those found in Europe.

Thirdly, the percentages of the total WSI to PM mass (15-20%) at the three Abidjan sites (ADF, AWB and AT) are in the same order of magnitude than the data from $PM_{2.5}$ personal exposure samples collected at the same locations in 2016 by Xu et al. (2019). Our results also are very close to the ionic contribution of 9% of the PM_{10} mass found at the urban curbside site in Dar es Salaam in Tanzanie during the wet season 2005 by Mkoma (2008).

5. Conclusion

This paper presents the mass and the size-speciated chemical composition of particulate matter (PM) during the dry and wet seasons in 2015, 2016 and 2017. Measurements were performed at three sites in Abidjan, representative of domestic fire (ADF), waste burning (AWB) and traffic (AT) sources, and at one traffic site in Cotonou (CT).

It is important to underline that our results and their temporal variations are very sensitive to (1) the source activities whose pollution levels are highly linked to socio-economic status of each city; (2) the impact of imported pollution (sea-salt, biomass burning, dust, anthropogenic emissions from neighboring countries), according to air mass origins; and (3) the particle wet deposition.

The comparison between our results and literature data underlines the importance of the distance of the chosen site to the sources. At the source level (such as ADF), pollution results at the site are in agreement with exposure of people living at this site. However, at the other sites, comparison is more difficult since the sites are under the influence of a mix of transported sources. That shows the key importance of exposure studies to estimate air quality and health impacts.

The main striking feature is that $PM_{2.5}$ values are well above the annual and daily WHO guidelines of 25 and 10 $\mu g.m^{-3}$, respectively, whatever the site and the season. Also, measured

concentrations from this study are situated in the middle to the high part of the range of worldwide urban aerosol concentrations. In addition, we have stressed the importance of ultra-fine and fine particles in the studied aerosol and of species such as particulate organic matter and water soluble organic carbon, which are well known to be particularly harmful. This is again a warning signal for pollution levels in African capitals if nothing is done to reduce emissions in the future.

Our study constitutes an original database to characterize urban air pollution from specific African combustion sources. The next step will be to cross such an exhaustive aerosol chemical characterization to biological data in order to evaluate the impact of aerosol size and chemical composition on aerosol inflammatory properties.

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Author Contributions

J.A. and C.L. conceived and designed the study. J.A., C.L. and E.T.D. contributed to the literature search, data analysis/interpretation and manuscript writing. J.A., C.L., A.B. and E.T.D. contributed to manuscript revision. J.A., C.L., J.F.L, H.C, V.Y., A.A, C.G, C.Z, E.C and S.K. carried out the particulate samples collection and chemical experiments, analyzed the experimental data.

Additional Information

Figure S1 and Appendix A-D accompany this manuscript can be found in SupplementaryInformation.

Competing financial interests

The authors declare no competing financial interests

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1248 **Figure caption**

1249 Figure 1: Map of the city of Abidjan reporting the geographical location of DACCIWA urban
1250   sampling sites.

1251 Figure 2: Map of the city of Cotonou reporting the geographical location of DACCIWA urban
1252   sampling site.

1253 Figure 3: Pictures of the different sampling sites : (a) Traffic in Cotonou (Benin, CT station),
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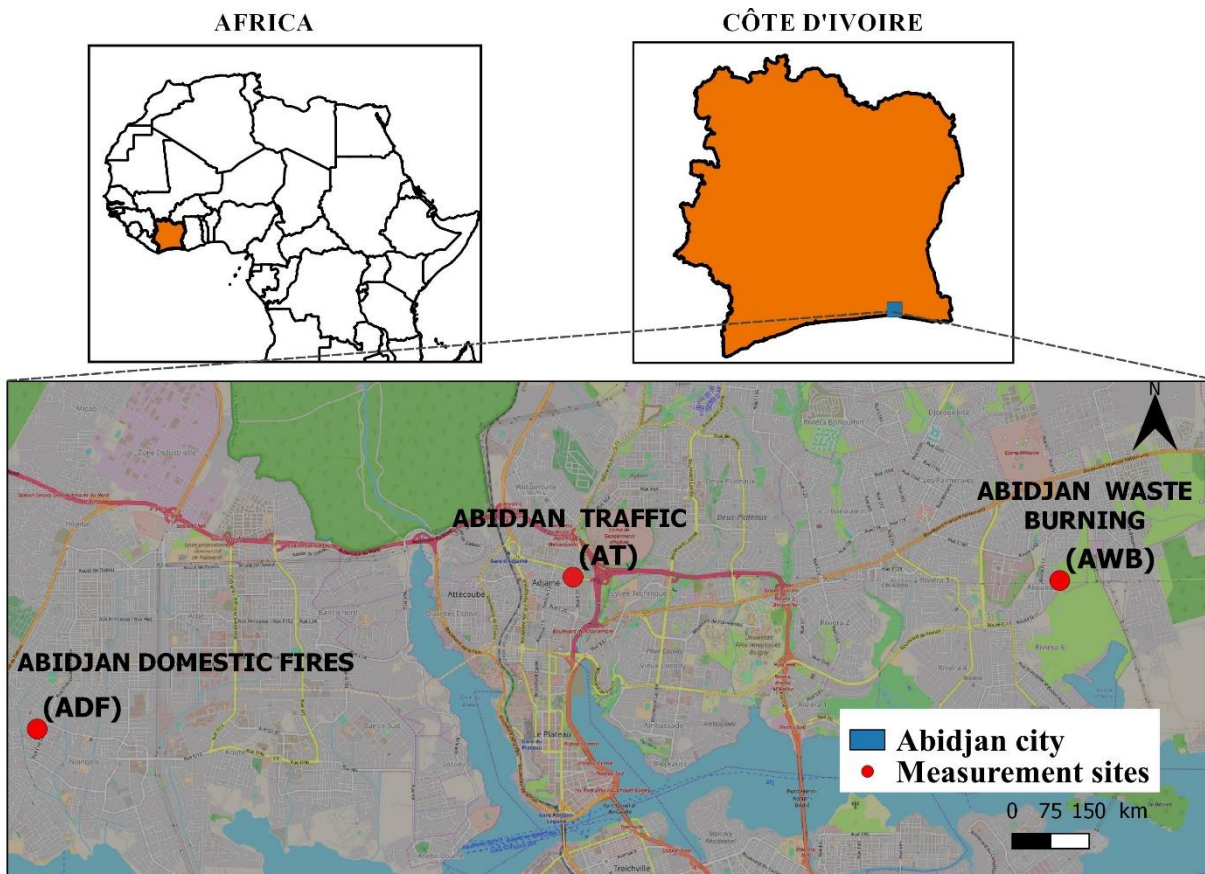
Figure 13: Size-speciated aerosol chemical composition for each site, for each campaign and each aerosol size.

Figure 14: MODIS Aerosol optical depth regional distribution over West Africa. Data are for 2017, focusing on our campaign date at Abidjan (a-c 01/11-12-left part) and Cotonou (b-d 01/6-7, right part).

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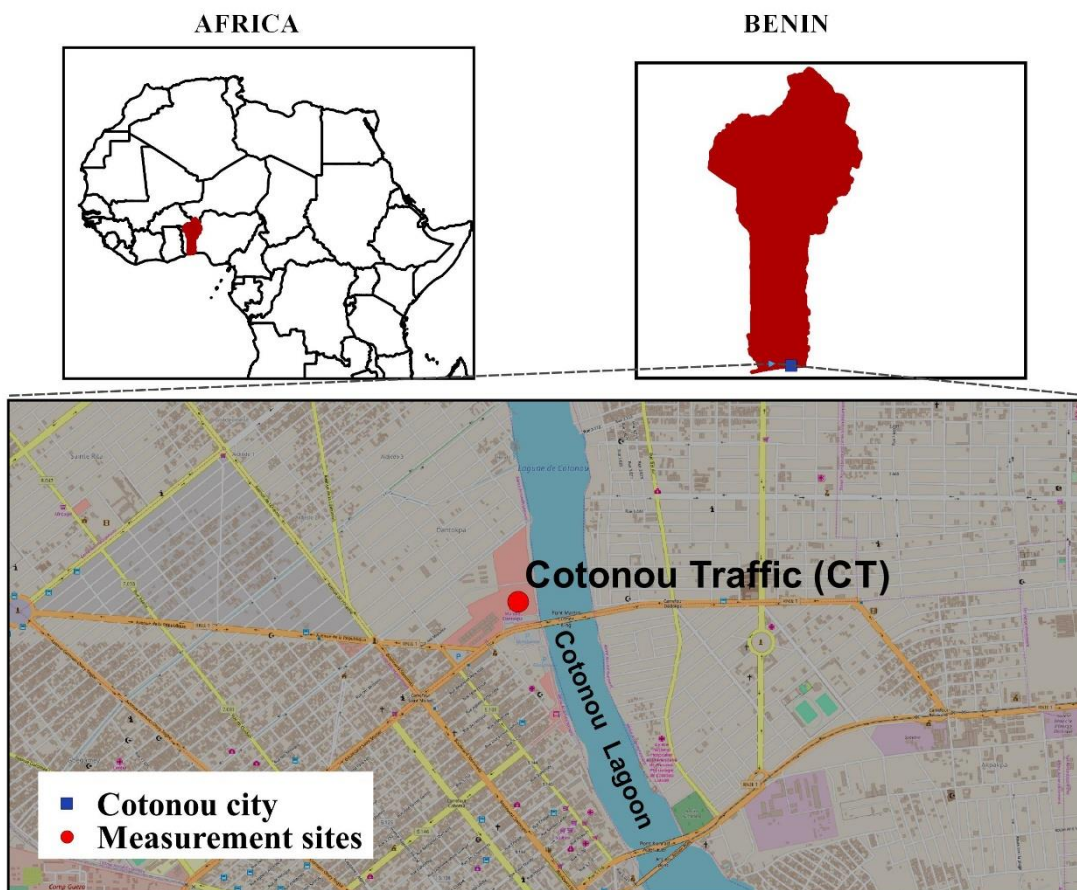
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1301   **Figure 2**

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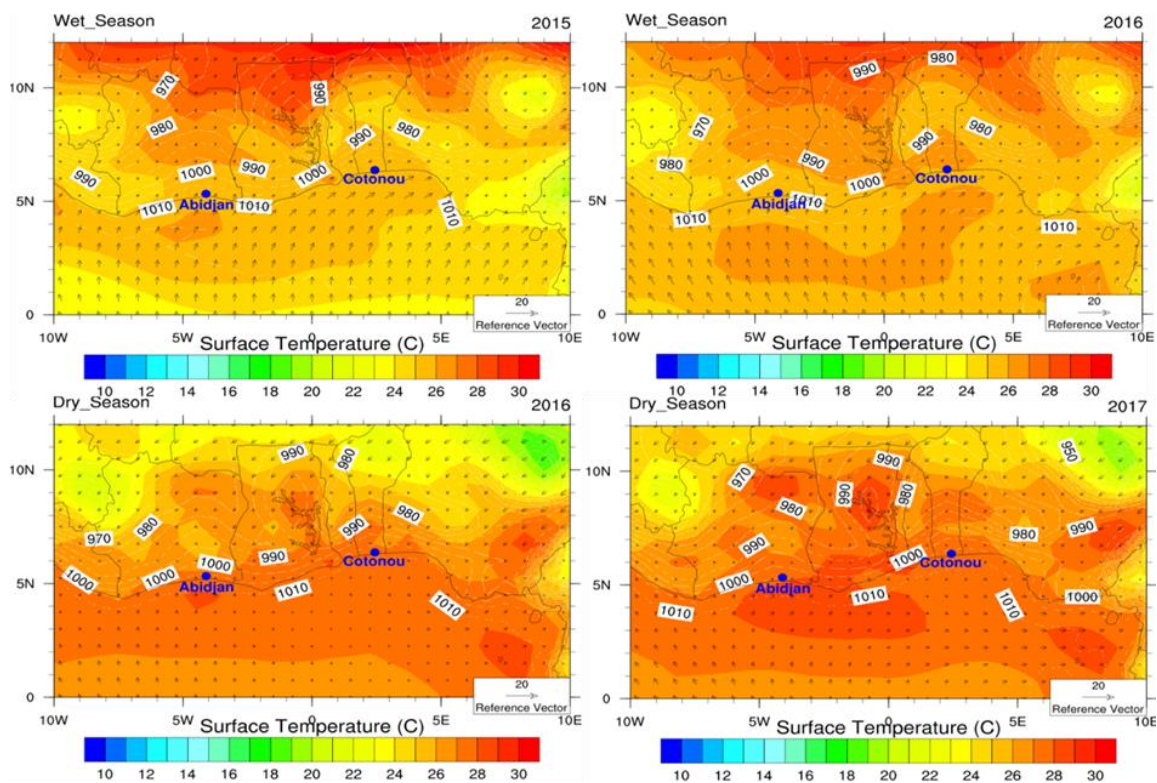
Figure 3

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1321   **Figure 4**

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Wet season 2015   Wet season 2016

Dry season 2016   Dry season 2017

Figure 5-a

Wet season 2015   Wet season 2016

Dry season 2016   Dry season 2017
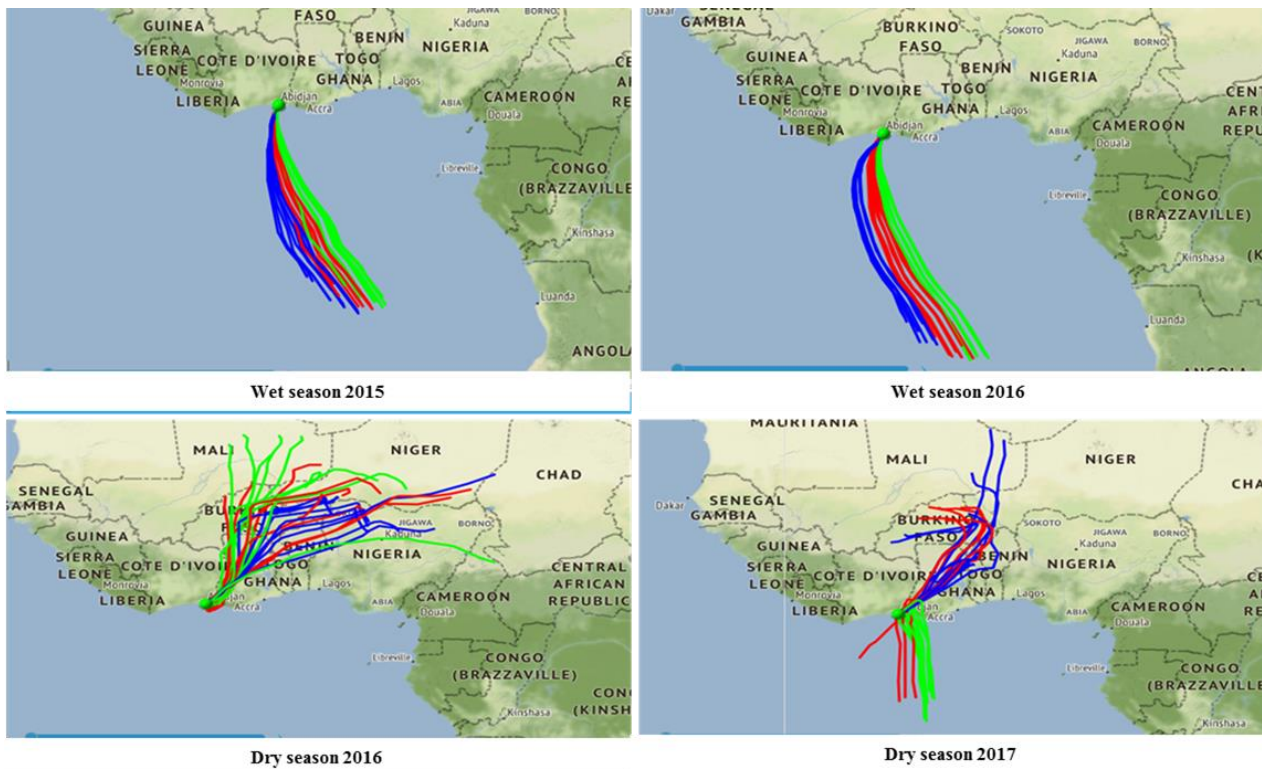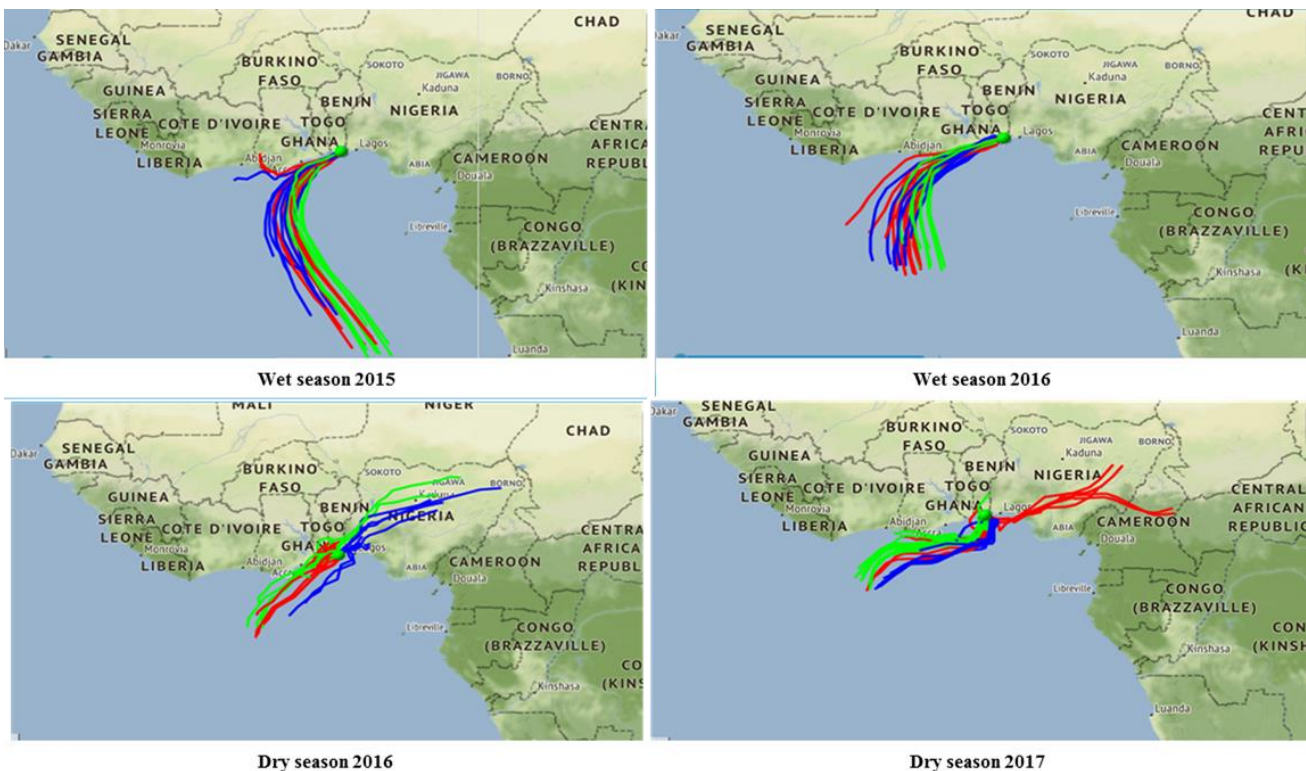
Figure 5-b

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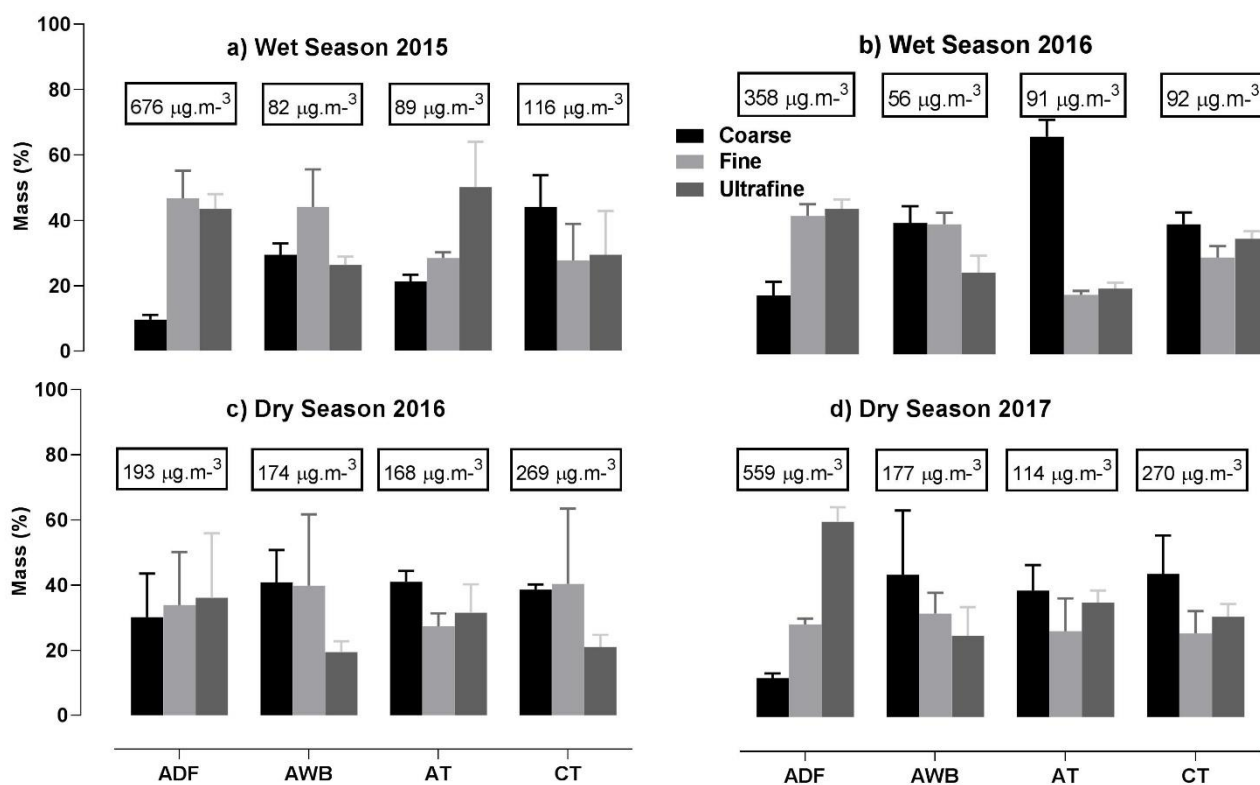
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1347   **Figure 6**

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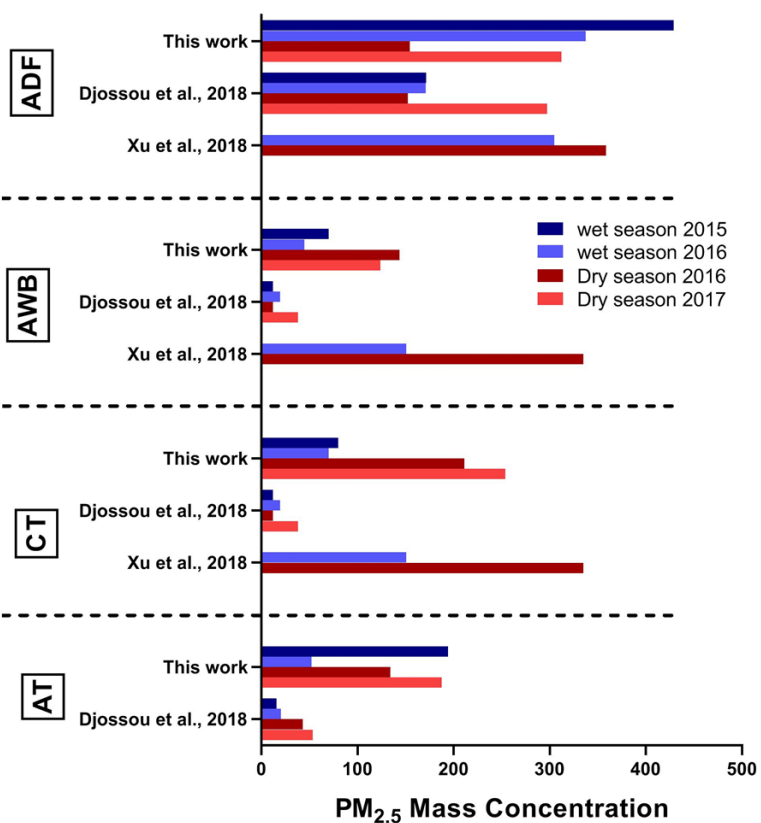
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1351 **Figure 7**

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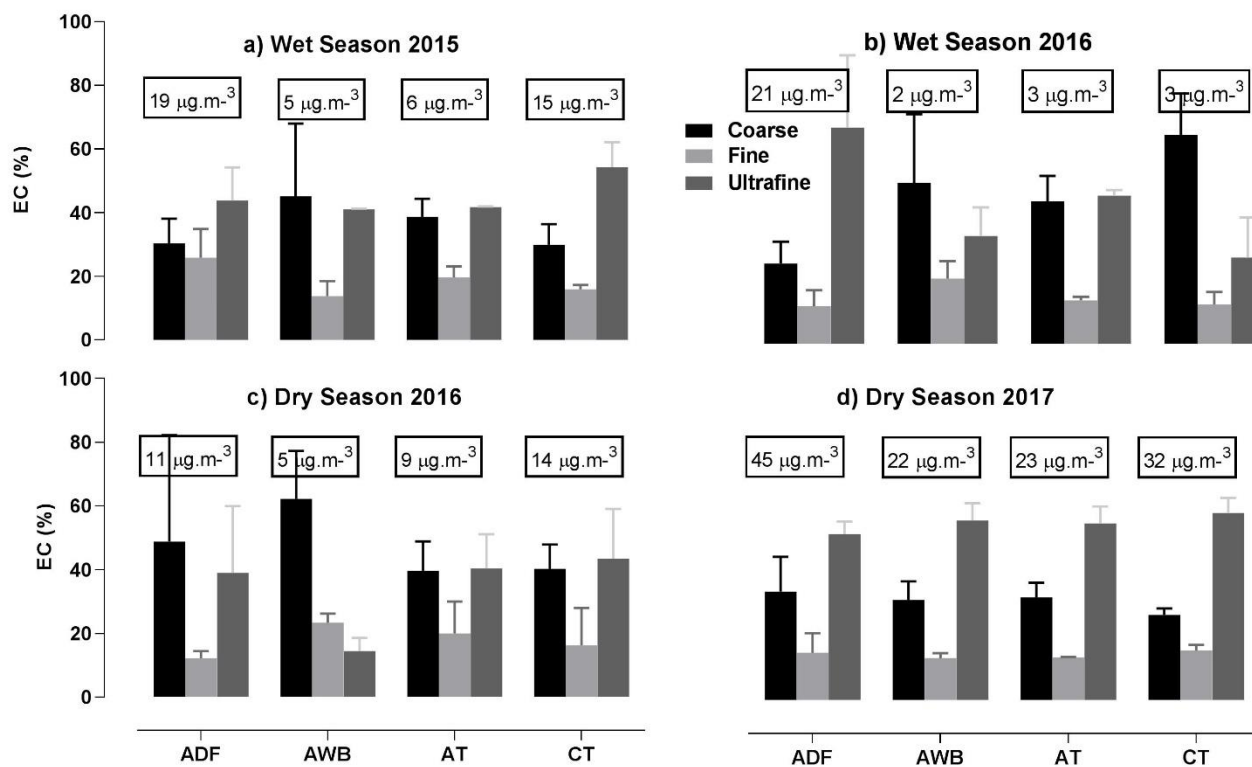
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1357 **Figure 8**

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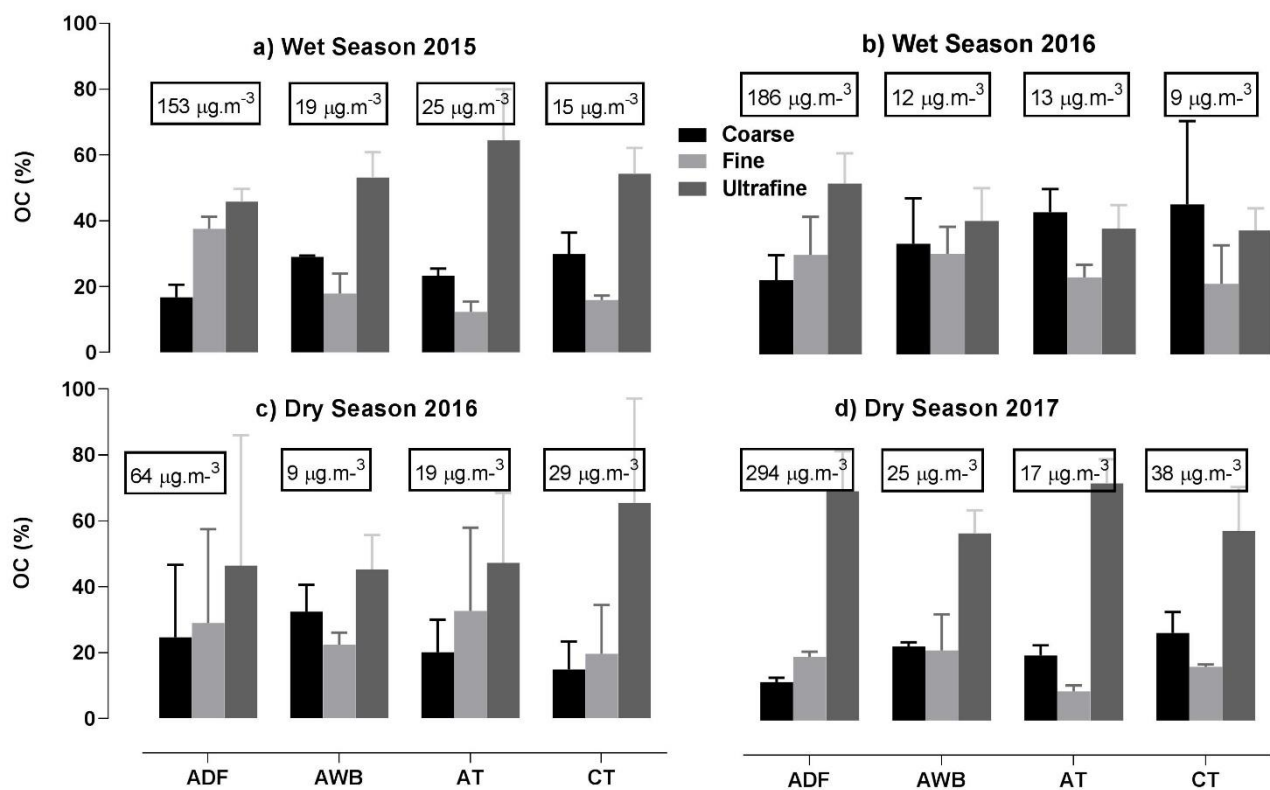
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1364   **Figure 9**

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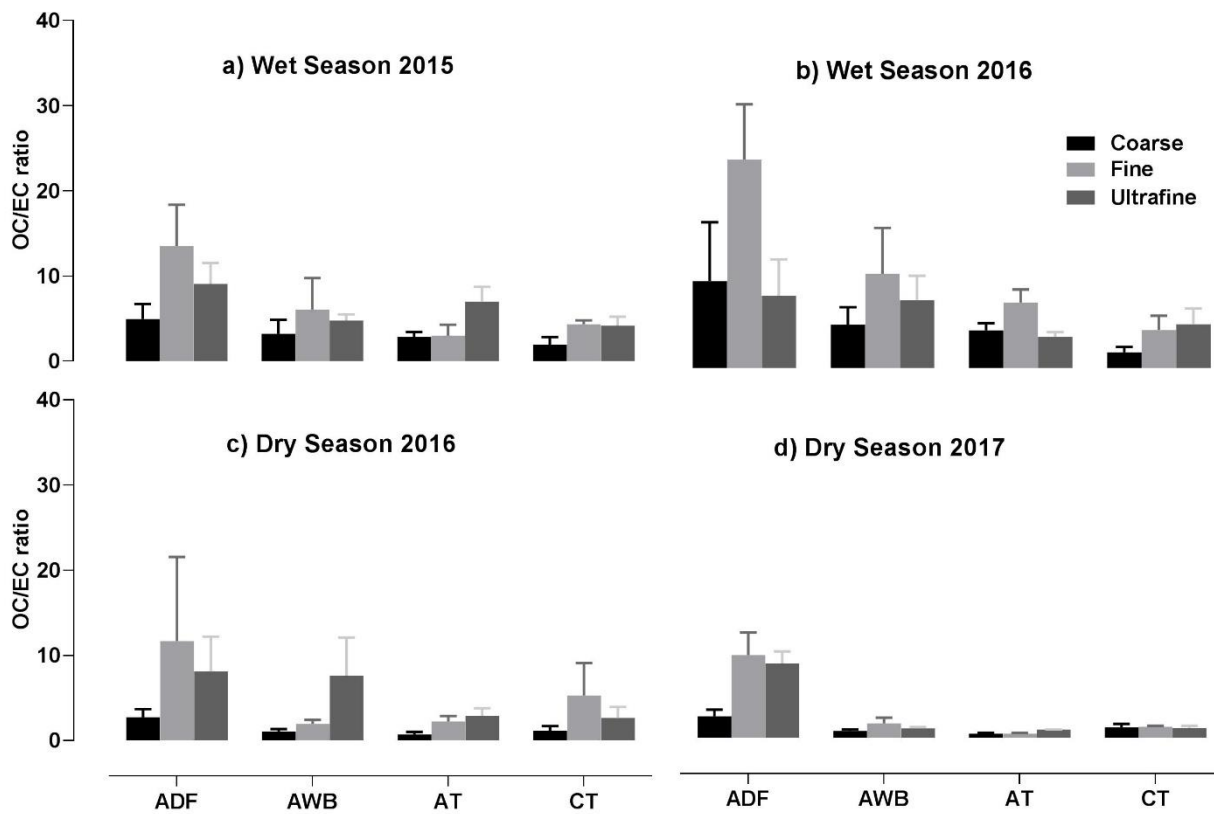
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1371   **Figure 10**

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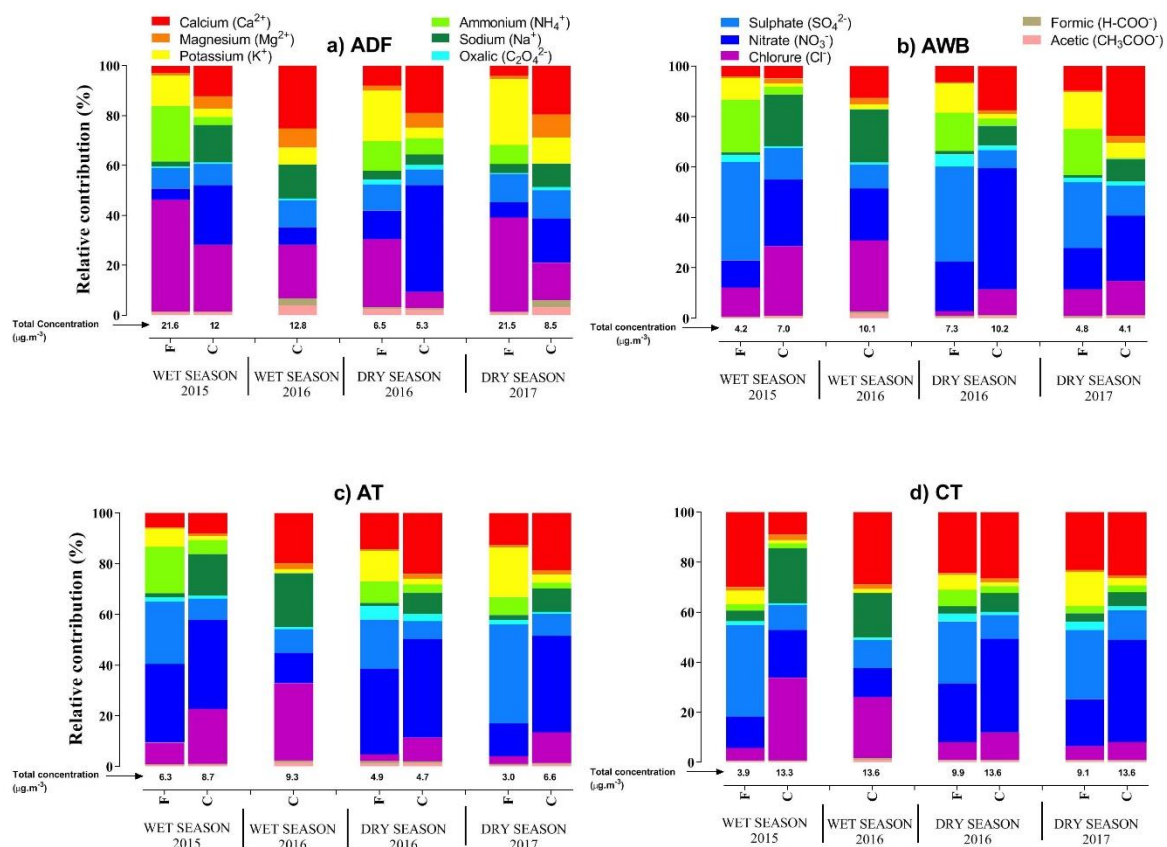
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1375 **Figure 11**

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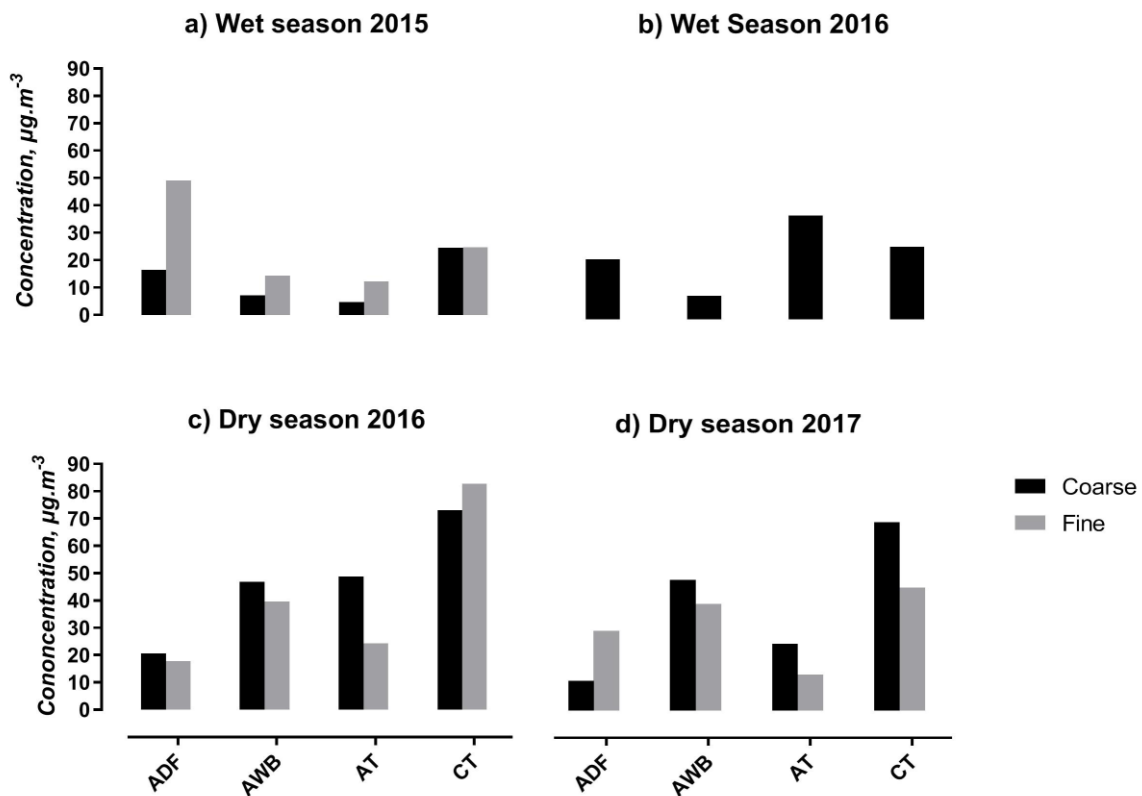
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1379   **Figure 12**

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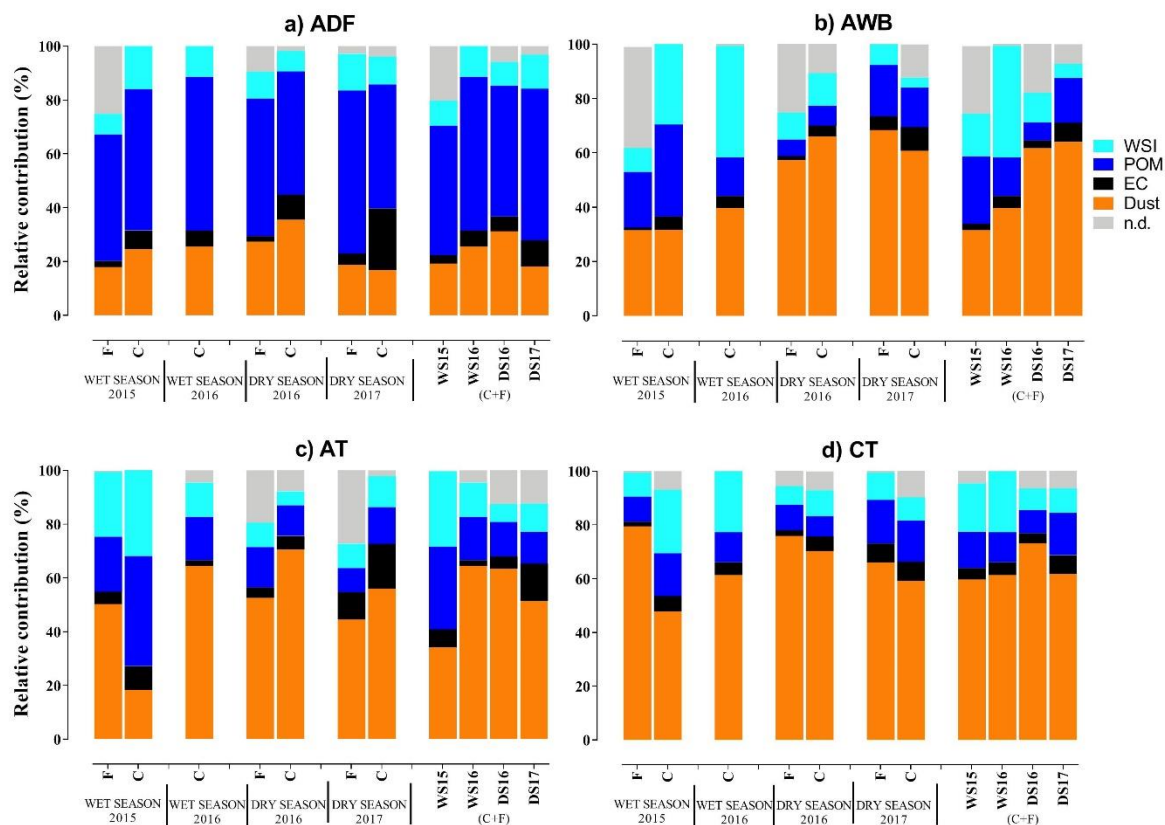
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1382 **Figure 13**

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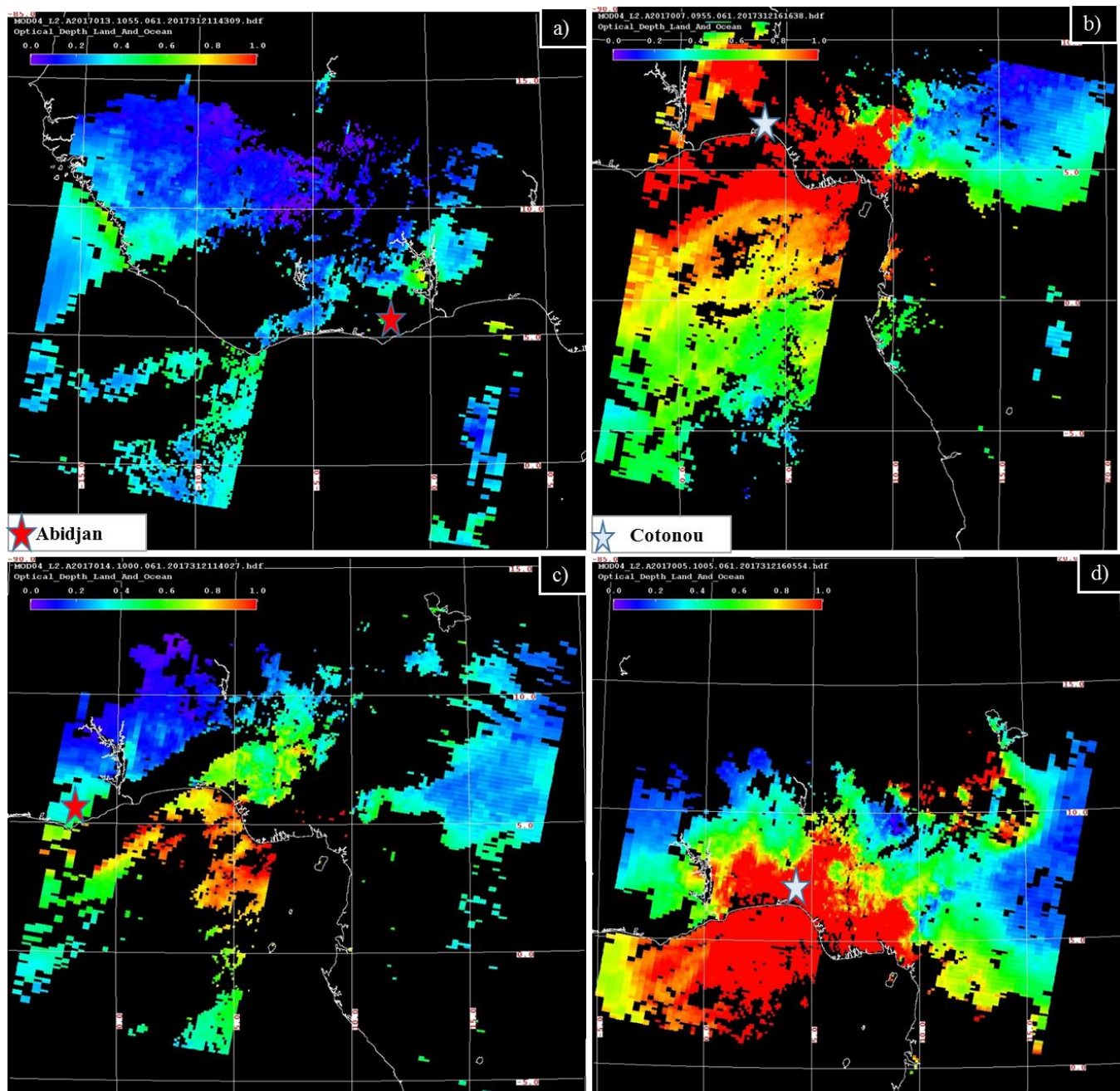
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1388 **Figure 14**

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1433   Table 1: Comparison of dust concentrations obtained from different methodologies in µg.m⁻³

Dry 2017		Sciare et al. (2005)	Guinot et al. (2007)	Terzi et al. (2010)
ADF	C	18.5	11.2	86.9
	F	9.3	29.7	22.2
	bulk	27.7	40.9	109.1
AWB	C	12.3	48.5	126.4
	F	5.2	39.7	106.4
	bulk	17.6	88.2	232.8
AT	C	16.4	24.8	98.5
	F	4.3	13.4	34.2
	bulk	20.7	38.2	132.7
CT	C	37.9	70.0	98.4
	F	23.4	45.6	55.8
	bulk	61.3	115.6	154.2

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Wet 2016		Sciare et al., 2005	Guinot et al., 2007	Terzi et al.(2010)
ADF	C	35.34	21.5	27.9
AWB	C	13.46	8.6	21.1
AT	C	19.65	37.5	21.4
CT	C	42.98	26.2	52.5
	Bulk	42.98	26.2	52.5

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1443 Table 2: WSOC concentrations (µg.m^{-3}) and WSOC/OC ratios (%) for each site, each campaign and

1444 each aerosol size

Site		Abidjan Waste Burning		Abidjan Domestic Fire	
Period	Size	WSOC	WSOC/OC	WSOC	WSOC/OC
Wet season 2015	Coarse	1.3	24,6	8.2	32.5
	Fine	0.7	19.9	12.8	22.7
	Ultra fine	4.1	43.6	51.3	72.5
	PM2.5	5.5	33.7	69.5	47.2
Dry season 2016	Coarse	0.4	12.3	4.4	18.8
	Fine	0.9	46.9	7.0	20.4
	Ultra fine	1.5	38.4	21.9	61.5
	PM2.5	2.7	32.7	31.0	32.0
Wet season 2016	Coarse	1.3	42.5	16.5	44.3
	Fine	0.8	26.3	17.1	33.0
	Ultra fine	2.0	41.2	79.7	84.5
	PM2.5	3.5	37.1	106.0	52.0
Dry season 2017	Coarse	1.9	32.9	12.1	36.0
	Fine	1.4	38.4	19.9	35.0
	Ultra fine	1.6	11.5	38.6	19.0
	PM2.5	4.0	30.0	65.8	29.0

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1447 Table 2 (suite): WSOC concentrations (µg.m^{-3}) and WSOC/OC ratios (%) for each site, each campaign

1448 and each aerosol size

Site		Abidjan Traffic		Cotonou Traffic	
Period	Size	WSOC	WSOC/OC	WSOC	WSOC/OC
Wet season 2015	Coarse	2.4	39.6	1.1	23.3
	Fine	1.3	46.7	0.5	22.1
	Ultra fine	4.7	29.0	0.4	12.7
	PM2.5	6.9	34.0	2.2	18.0
Dry season 2016	Coarse	1.4	43.0	2.3	64.1
	Fine	1.9	59.0	0.6	10.5
	Ultra fine	4.9	62.0	6.3	42.9
	PM2.5	7.5	49.4	8.0	29.0
Wet season 2016	Coarse	1.1	23.1	1.2	34.7
	Fine	0.5	16.8	0.5	32.2
	Ultra fine	1.4	34.8	0.9	23.0
	PM2.5	2.4	26.0	1.9	28.0
Dry season 2017	Coarse	0.9	24.0	3.5	37.8
	Fine	0.3	24.3	2.4	39.6
	Ultra fine	1.8	14.8	1.9	10.4
	PM2.5	2.6	16.0	6.0	18.2

1449 Table 3: Trace element concentrations for bulk aerosol for each site and for DS2017 and WS2016.

	Bulk ng.m^{-3} (%)							
	DRY 2017				WET 2016			
	ADF	AWB	AT	CT	ADF	AWB	AT	CT
Al	10050.8 (1.8)	25186.1 (13.7)	14015.8 (12.26)	15480.4 (5.7)	1370.5 (0.4)	1990.1 (3.5)	2191.4 (2.4)	4010.5 (4.4)
K	8634.3 (1.5)	6093.7 (3.3)	3677.7 (3.22)	5068.9 (1.9)	1105.0 (0.3)	472.0 (0.8)	275.9 (0.3)	1076.0 (1.2)
Na	6847.8 (1.2)	23430.5 (12.8)	15372.1 (13.44)	11529.3 (4.3)	2070.6 (0.6)	3735.4 (6.6)	2861.5 (3.1)	5310.2 (5.8)
Ca	4321.2 (0.8)	2923.7 (1.6)	4117.6 (3.60)	6233.5 (2.3)	4124.7 (1.1)	447.5 (0.8)	374.7 (0.4)	4954.02 (5.4
Mg	1940.6 (0.3)	384.0 (0.2)	410.3 (0.36)	823.2 (0.3)	1524.7 (0.4)	294.9 (0.5)	283.5 (0.3)	619.2 (0.7)
Fe	1709.9 (0.3)	3807.9 (2.1)	1628.1 (1.42)	3406.8 (1.3)	1314.0 (0.4)	709.3 (1.3)	987.3 (1.1)	1549.4 (1.7)
P	1521.9 (0.3)	696.0 (0.4)	147.8 (0.13)	207.4 (0.1)	605.4 (0.2)	8.6	13.2	81.4 (0.1)
Ti	488.9 (0.1)	2270.3 (1.2)	282.8 (0.25)	457.9 (0.17)	170.8 (0.05)	75.7 (0.13)	96.8 (0.11)	154.7 (0.17)
Zn	189.7 (0.03)	80.9 (0.04)	57.9 (0.05)	149.4 (0.06)	60.3 (0.02)	1.9	41.1 (0.04)	36.2 (0.04)
Zr	172.1 (0.03)	390.3 (0.21)	217.9 (0.19)	145.3 (0.05)	-	22.4 (0.04)	36.7 (0.04)	31.2 (0.03)
Pb	87.1 (0.02)	11.0 (0.01)	4.8	11.5	8.3	2.1	2.3	9.3 (0.01)
Sn	79.7 (0.01)	38.4 (0.02)	21.6 (0.02)	37.4 (0.01)	0.77	0.09	0.0006	9.ç (0.01)
Mn	74.2 (0.01)	35.2 (0.02)	33.7 (0.03)	160.6 (0.06)	48.9 (0.01)	12.01 (0.02)	9.1 (0.01)	41.41 (0.05)
Rb	52.4 (0.01)	8.7	5.9 (0.01)	8.5	4.47	0.71	0.85	1.9
Sb	59.9 (0.01)	201.2 (0.11)	123.6 (0.11)	149.04 (0.06)	24.4 (0.01)	0	0.0006	2.9
Ba	37.3 (0.01)	53.3 (0.03)	47.4 (0.04)	65.8 (0.02)	18.5	8.02 (0.01)	9.9 (0.01)	32.0 (0.03)
Ni	36.5 (0.01)	34.5 (0.02)	27.9 (0.02)	50.2 (0.02)	18.00)	33.1 (0.06)	9.7 (0.01)	14.9 (0.02)
Cr	29.4 (0.01)	53.8 (0.03)	35.8 (0.03)	28.6 (0.01)	41.9 (0.01)	47.7 (0.08)	24.3 (0.03)	29.7 (0.03)
Sr	28.1 (0.01)	15.5 (0.01)	21.2 (0.02)	34.02 (0.01)	17.02	0	0.19	8.1 (0.01)
Cu	24.0	12.3 (0.01)	3.6	9.6	3.99	0.26	0.87	2.8)
Sr	12.6	-	-	-	17.1	-	0.22	8.9 (0.01)
Li	7.3	15.5 (0.01)	7.8 (0.01)	7.39	0.36	0.32	0.23	0.75
Cd	6.1	1.6	1.0	0.83	1.18	0.05	0.02	0.17
V	5.5	12.4 (0.01)	5.1	10.62	2.14	1.84	2.0	3.35
Mo	5.5	8.0	4.9	3.19	4.56	6.84 (0.01)	2.04	3.2
Cs	5.4	0.9	1.2	0.94	0.11	0.12	0.01	0.17
Hf	4.5	10.8 (0.01)	6.8 (0.01)	4.63	0	0.67	1.03	0.97
As	4.2	4.5	3.1	1.22	0	0 (0)	0.05	0.60
Li	4.0	9.8	5.9 (0.01)	5.82	0.27	0.37	0.16	0.93
Co	3.8	1.1	2.1	35.67 (0.01)	0.86	0.49	0.13	0.33
Ce	3.7	6.8	6.0 (0.01)	9.85	1.06	0.50	0.42	2.03
La	1.8	3.5	2.9	4.78	0.54	0.24	0.25	0.92
Nb	1.5	2.6)	1.4	2.48	0.98	0.46	0.5	0.63
Nd	1.5	2.5	2.4	4.15	0.05	0 (0)	-	0.40
Sc	0.69	1.4	1.1)	1.31		0,00		0.02
Be	0.13	0.19	0.2	0.28	0.003	-	-	0.03
Ga	0.61	1.15	0.8	0.98	0.2	0.11	0.12	0.37
Ge	0.42	1.02	0.8	0.68	0.01	0.07	0.02	0.11
Se	0.91	-	-	0.02	0.59	-	0.20	0.18
Rh	0.02	0.02	0.00002	0.002	-	0.002		0.0002
Te	0.06	0.08	0.08	0.05	0.02	0.02	0.02	0,00
Pr	0.40	0.74	0.7	1.13	0.06	0.01	0.004	0.15
Sm	0.27	0.46	0.45	0.76	0.01	0,00	-	0.07
Eu	0.05	0.08	0.08	0.15	0.01	0.003	-	0.0
Gd	0.31	0.57	0.54	0.86	0.05	0.02	0.001	0.15
Tb	0.04	0.07	0.07	0.10	0.005	-	-	0.02
Dy	0.24	0.42	0.40	0.57	0.001	-	-	0.05
Ho	0.05	0.09	0.09	0.12	0.01	0.008	0.01	0.03
Er	0.16	0.31	0.28	0.35	0.02	0.03	0.02	0.09

Tm	0.02	0.05	0.05	0.05	0.002	0.003	0.001	0.01
Yb	0.18	0.38	0.32	0.34	0.01	0.02	0.03	0.09
Lu	0.03	0.06	0.08	0.06	0.003	0.005	0.005	0.02
Ta	0.07	0.14	0.09	0.16	0.06	0.02	0.02	0.03
W	0.80	1.63	0.69	0.54	0.26	0.41	0.4	0.3
Tl	0.22	0.01	0.03	0.06		0.009		
Bi	0.32	0.26	0.02	0.08	0.06	-	-	0.08
Th	0.41	0.88	0.79	1.29	0.15	0.09	0.09	0.24
U	0.22	0.43	0.49	0.51	0.03	0.03	0.02	0.09
Total	36459.9	65817.6	40312.2	44159.2	12562.9	7874.7	7227.2	18001.1
Mass(μg/m^3)	558.8	183.6	114.4	270.0	374.7	56.3	91.6	91.9

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1477 Table 4: Comparison of PM2.5 concentrations with literature data

Location	PM2.5 ($\mu g.m^{-3}$)	Reference
Abidjan, Côte d'Ivoire	142	This work
Cotonou, Benin	154	This work
Beijing, China	81.4	Xie et al., 2019
Christchurch, New Zealand	9.2	Tunno et al., 2019
Pune, India	98 ± 28	Pipal et al., 2019
Delhi, India	123	Guttikunda and Calori, 2013
Lahore, Pakistan	91	Colbeck et al., 2011
Ahvaz, Iran	69	Shahsavani et al., 2012
Hong Chong, Hong Kong	54.7 ± 25.6	Cheng et al., 2015
Lecce, Italia	16	Cesari et al., 2016
Libreville, Gabon	35.8	Ngo et al., 2019
Port Gentille, Gabon	60.9	
Kenitra, Morocco	51.3	Zghaid et al., 2009
Bilecik, Turkey	247	Gaga et al., 2018
Algiers, Algeria	34.8	Bouhila et al., 2015
Shobra, Egypt	216	Lowenthal et al., 2015

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1497 Table 5: PM2.5-EC and PM2.5-OC comparison with Djossou et al. (2018) and Xu et al. (2019) values.
1498 Units are $\mu gC.m^{-3}$.

Location	Period	PM2.5 OC	PM2.5 EC	References
Traffic Abidjan. Cote d'Ivoire	July 2015	22.6 ± 3.4	4.3 ± 0.2	This Work
	January 2016	15.2 ± 5.3	7.0 ± 2.6	
	July 2016	9.3 ± 1.3	2.2 ± 0.1	
	January 2017	16.1 ± 1.7	18.9 ± 1.4	
	July 2015	3.3 ± 0.2	2.3 ± 0.2	Djossou et al. 2018
	January 2016	7.7 ± 0.0	3.9 ± 0.0	
	July 2016	7.6 ± 0.2	4.9 ± 0.0	
	January 2017	19.1 ± 6.2	13.9 ± 5.5	
Traffic Cotonou. Benin	July 2015	13.1 ± 1.2	3.5 ± 0.7	This Work
	January 2016	27.8 ± 11.3	10.9 ± 2.6	
	July 2016	6.7 ± 1.9	2.0 ± 0.5	
	January 2017	33.1 ± 4.6	27.3 ± 0.9	
	July 2015	4.2 ± 0.7	1.5 ± 0.1	Djossou et al. 2018
	January 2016	3.0 ± 0.3	1.5 ± 0.2	
	July 2016	6.7 ± 0.2	1.6 ± 0.1	
	January 2017	14.5 ± 0.8	4.4 ± 0.7	
	January 2016	49.5 ± 12.5	13.6 ± 3.6	Xu et al. 2019
	July 2016	37.0 ± 3.5	9.3 ± 0.8	
Domestic fire Abidjan. Cote d'Ivoire	July 2015	147.2 ± 14.5	16.1 ± 1.6	This Work
	January 2016	56.5 ± 51.5	7.4 ± 3.1	
	July 2016	172.3 ± 39.0	17.9 ± 4.8	
	January 2017	283.9 ± 34.9	37.9 ± 4.3	
	July 2015	80.5 ± 1.1	32.2 ± 1.6	Djossou et al. 2018
	January 2016	76.3 ± 13.7	11.4 ± 0.2	
	July 2016	68.4 ± 16.5	17.4 ± 2.1	
	January 2017	66.4 ± 7.5	21.1 ± 6.6	
	January 2016	72.4 ± 24.6	19.5 ± 7.3	Xu et al. 2019
	July 2016	189.3 ± 197.8	11.5 ± 10.8	
Waste Burning Abidjan. Cote d'Ivoire	July 2015	14.8 ± 1.1	4.4 ± 0.1	This Work
	January 2016	7.7 ± 1.3	3.0 ± 0.3	
	July 2016	10.0 ± 2.4	1.5 ± 0.3	
	January 2017	21.9 ± 4.2	19.2 ± 2.4	
	July 2015	3.7 ± 2.2	4.3 ± 0.3	Djossou et al. 2018
	January 2016	13.9 ± 9.0	3.6 ± 1.8	
	July 2016	9.8 ± 4.4	2.8 ± 0.9	
	January 2017	22.4 ± 7.8	8.7 ± 3.0	
	January 2016	85 ± 57.4	15 ± 4.7	Xu et al. 2019
	July 2016	65.2 ± 65.2	12.3 ± 11.4	

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1502   Table 6: EC and OC comparison with literature values

Location	OC (µg.m^{-3})	BC (µg.m^{-3})	Reference
Abidjan (Côte d'Ivoire)	16	8.1	This study
Cotonou (Benin)	20.2	11	This study
Bilecik (Turkey)	49.6-62.8	38.8-58.1	Gaga et al., 2018
Pune (India)	30	5	Pipal et al., 2019
Shanghai (China)	4.9-13.1	1.9-5	Ding et al., 2017
Lahore (Pakistan)	85.7-152	13.8-21	Stone et al., 2010
Agra (India)	25.4-70	3.3-9.5	Satsangi et al., 2012, Pipal et al., 2014
Delhi (India)	34.1-50	5.3-10.6	Bisht et al., 2015a, Pipal et al., 2014
Ahmedabad (India)	18.3	3	Rengarajan et al., 2011
Yokohama (Japan)	4	2	Khan et al., 2010
Beijing (China)	2.9-28.2	1.2-16.3	Guinot et al., 2007

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1524   Table 7: Comparison of WSOC concentrations with literature data

Location	WSOC (μg.m^{-3})	Reference
Abidjan, Côte d'Ivoire	2-8	This work
Cotonou, Benin	2-8	This work
Beijing, China	9-27	Yu et al., 2018
Beijing, China	4-6	Xiang et al., 2017
Beijing, China	8-12	Tang et al., 2016
Beijing, China	7	Du et al., 2014
Beijing, China	6-8	Feng et al., 2006
Shanghai, China	2-7	Feng et al., 2006, Huang et al., 2012
Guangzhou, Hong Kong	2	Huang et al., 2012
Guangzhou, Hong Kong	5-10	Feng et al., 2006
Gwangju, Korea	2-3.5	Park et al., 2015
Tokyo, Japan	3-23	Sempere and Kawamura, 1994
Cairo, Egypt	3	Favez et al., 2008
Amsterdam, Netherland	1-2	Feng et al., 2007
Barcelone, Spain	1-2	Viana et al., 2007 and 2008
Brindisi, Italy	1.5	Genga et al., 2017
Saint Jean de Maurienne, France	1-5	Sullivan et al., 2004, Jaffrezo et al., 2005a

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