ACP-973-2017

"Mass concentration, optical depth and carbon composition of particulate matter in the major Southern West Africa cities of Cotonou (Benin) and Abidjan (Côte d'Ivoire)."

By Djossou et al.

Dear Editor,

We are grateful to the reviewers for their positive reviews and for their help in improving the quality of this paper. We have answered all the comments and we have revised the paper in light of them. The structure of the paper has been changed, resulting in different figure and section numbers. Please find below our response to each reviewer's comment and the changes we have done in the manuscript following their suggestions.

Yours sincerely.

Answers to reviewers

Reviewer # 2

Black : review
Blue : answer
Red : modification of the paper

This manuscript presents aerosol (PM mass, EC/OC and AOD) measurements from two cities in West Africa, namely in Cotonou and Abidjan. These are multi-year continuous datasets for an understudied region, and are thus very valuable and provide new information. The current version of the manuscript presents the data, however is limited in analyses and interpretation of these data. Because of this, it is not clear to me what the main finding(s) are yet of this manuscript. I do believe that a manuscript that only presents aerosol data is not within the scope of ACP. However, I do believe that with further analysis and interpretation, this manuscript can be improved to the level of ACP. I would recommend major revisions and additions before it is resubmitted for review. I do believe the potential of the dataset is very relevant to ACP. The dataset is novel and very important.

I would recommend that the title is changed to avoid confusion. To me "southwestern Africa" is the region around Namibia. A suggestion is "southern West Africa..."

Correct. We have changed the title and now we now use southern West Africa (SWA) in the main text as in Knippertz et al. (2015).

Specific Comments

There is not adequate reference to previous literature, especially related to AOD measurements and previous campaigns. There is a strong AERONET network in West Africa that has been analysed in many papers. For example, Horowitz et al., (2017) provides a seasonal analysis of long-term AOD measurements; this paper and the references therein may provide a good starting point for additional literature on AOD measurements in this area.

In addition, I think that it would be helpful to include a summary of the other studies mentioned in lines 77-79. These are stated to be rural studies, but they may help to put these results in context, especially if the AERONET sites are in same region, as some sources of pollution that drive max concentrations as per the manuscript (such as dust and biomass burning) are regional. Finally, a quick google search did find some previous literature on Cotonou that, while from 2006 and earlier, could help to provide some background on the knowledge of pollution in the areas, the impacts of air pollution, and perhaps how it has changed (Fourn and Foyomi, 20o6; Fanou et al., 2006, Boko, 2003).

As you have probably noticed, Horowitz et al. (2017) is not reporting observations along the gulf of Guinea. The climate of SWA follows a strong North-South gradient and previous studies in the Northern part of our area of interest (Djougou, Banizoumbou, …) are not representative of our study. However, it is true that those site are influenced by the same seasonal phenomena involving dust and biomass burning emissions. We now explain this point in the text.

We have added the following paragraphs in the introduction:

Carbonaceous aerosols in West Africa are known to result from biomass burning, traffic and domestic fire emissions and to a lesser extent from other combustion sources such as industries, power plants and flaring (Doumbia et al., 2012; Liousse et al., 1996, 2014; and Liousse and Galy-Lacaux, 2010). According to Liousse et al., (1996, 2010), the emissions from biomass burning have an importance on the atmospheric composition in rural area of West Africa. Atmospheric aerosol in West African rural areas and typical inter-tropical ecosystems has been the subject of research programs such as DECAFE (Cachier et al., 1995 ; Lacaux et al., 1995), IDAF (Galy-Lacaux et al., 2009), EXPRESSO (Delmas et al. 1999) (1996), DECAFE program allowed to characterize the chemical composition of aerosols during savanna fires in West

Africa (Côte d'Ivoire). However, very little information exists on aerosols in West African cities. In cities of subSaharan Africa such as Cotonou (Bénin), the emissions from 2-wheeled vehicles running on mixtures of smuggled gasoline from Nigeria and motor oil are a large source of pollutants (Liousse et al., 2014). The results obtained by Doumbia et al., (2012), confirm that in West and Sub-Saharan African big cities there is a "hot spot" of emissions, particularly due to the emissions from vehicle engines, and domestic fires. Nevertheless, pollution in urban African areas and their related health impacts have been poorly studied. Therefore, observations for fine particle (PM2.5) and particulate carbon species are needed for African cities.

(...)

In cities of sub-Saharan Africa such as Cotonou (Bénin), the emissions from 2-wheeled vehicles running on mixtures of smuggled gasoline from Nigeria and motor oil are a large source of pollutants (Liousse et al., 2014). The atmosphere in the city of Cotonou is characterized by thick opaque fumes, especially at the level of major arteries and intersections (Mama et al., 2013). This phenomenon is linked to the use of two-wheeled motorcycles, especially motorcycle taxi-moto called "Zemidjan", whose number in 2005 was estimated at 96.095 according to the statistics of Cotonou City Council (Ayi Fanou et al., 2006; Mama et al., 2013). In Cotonou motorbike taxis account for 90% of the cases with intoxication symptoms 1,5 time higher than in the non-drivers of these motorbikes. The symptoms recorded on statement are intoxication disorders such as conjunctival hyperemia (18%) among which 12% of lacrimation, respiratory disorders (23%) (Fourn and Fayomi, 2006). According to Fourn and Fayomi, (2006) and Mama et al. (2013), motorcycle taxi emissions are the highest at the Dantokpa area.

(...)

In addition to measuring PM2.5 and carbonaceous species, the field experiment was also designed to acquire observations of the spectral aerosol optical depth (AOD). Indeed AOD is an indicator of the aerosol load in the atmospheric column and its spectral behavior provide information on the shape of the aerosol size distribution (O'Neil et al., 2003) and so the aerosol type. The AOD in the Sahel region has been largely investigated (Mallet et al. 2008; Léon et al., 2009; Horowitz et al., 2017) thanks to the availability of automatic sun photometer of the AERONET (Holben et al 1998). Horowitz et al. (2017) have suggested that biomass burning aerosol could make up a large fraction of the AOD in SWA during the burning season (December-Février) from observations recorded in northern Bénin (Djougou) and Nigéria (Ilorin). However, the coastal urban zone of SWA clearly lakes dedicated observations, which can be used in turns to better understand local PM2.5 variations.

Line 91, what is the cite for the large impact of 2-wheel vehicles? This difference does form the basis of some of the analysis, and thus the reference for this is critical.

See Assamoi and Liousse (2010) and Fanou et al. (2006).

Line 92, the seasonal cycle of emissions should have a reference. Is there no known seasonal-dependence of domestic fuel burning?

We don't have information about a possible seasonal cycle in domestic fuel burning.

Note that such pollution linked to domestic fires, traffic or waste burning, should occur all along the year whereas transported biomass burning and Saharan dust are expected to have an impact during dry seasons around March and April respectively (Assamoi and Liousse, 2010; Doumbia et al., 2012; Liousse et al., 2004).

I would recommend that section 1 (line 102) is moved into the Methods section.

Ok. The paragraph "site and sampling" has now been moved as a subsection of the section "Method".

Figure1, I would recommend that a box is drawn to highlight the region that was considered for the burned are (this is stated in lines 277, but it would help to see it visually). Also, I would recommend that the authors consider mapping the cities as well in a zoomed in map in figure 1. It would be helpful to see where they are relative to each other and how far apart they are. Figure 1 also needs a scale on the map to define distance and relate it to km.

Figure 1 has been redraw following your recommendations. However, we have plotted the zoom-in maps as an independent figure (now Figure 2). See below.
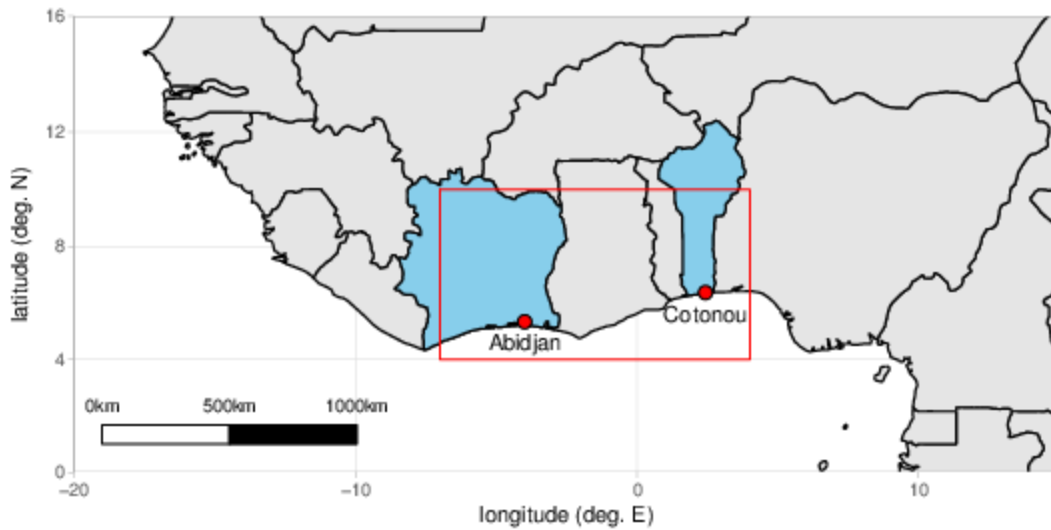
Figure 1: Geographical locations of Abidjan and Cotonou cities. The red rectangle corresponds to the geographical area between 7°W to 4°E and 4°N to 10°N (see Figure 9).
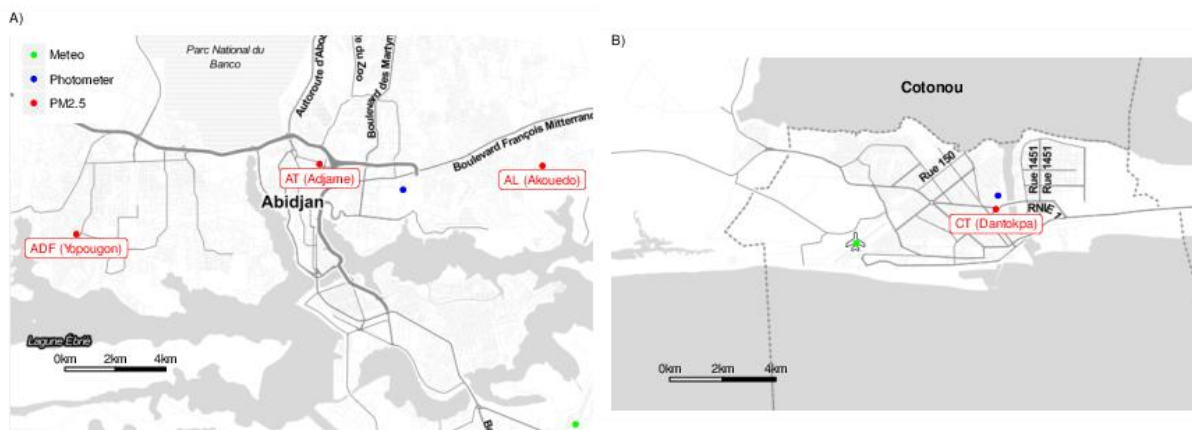

Figure 2: Maps of the cities of (A) Abidjan and (B) Cotonou reporting the location of the (red) PM2.5 sampling sites, (blue) photometer measurements and (green) meteorological station.

Line 123, was the flow measured constantly? This is an important measurement for the calculation of concentration, so it would be helpful to give more information on how it was measured, how often, was it steady, etc?

See also remarks by review #1. Sampling lines are equipped with a Cole Palmer ball flow meter with a micrometric valve (flow range adjustable from 0 to 10l/min and a Gallus G4 gas meter measuring the total volume of air sampled. The flow rate was checked each time the filters were changed by the operator. The sampling frequency (weekly) was set up

accordingly to avoid pressure loss due to filter clogging. More information has been added to the relevant section.

The particles were collected on 47mm diameter on a weekly basis. Two types of filters are used depending of analysis performed. PTFE filters were used for gravimetric measurements while quartz fiber filters were used for carbonaceous aerosol analysis. The use of different types of filter involves the installation of two filtration lines operating in parallel. The sampling system uses 2 mini Partisol sampling impactors for PM2.5 working at a flow of 5L/min. Both lines are stored in a same box standing outside at ambient temperature and humidity. Figure 2 provide a quicklook of the inside of the sampling box, which is equipped for each line with a KNF pump with a flow rate of 9 l / min (N89 KNE-K version 220v), a Cole Palmer ball flow meter with a micrometric valve (flow range adjustable from 0 to 10 l / min, accuracy 5%), a GALLUS type G4 gas meter (accuracy of 0.01 m3) giving the total volume of air sampled during the week, tubing, and a NILU online filter holder.

The concentrations of PM2.5 particles and carbonaceous aerosols (OC and EC) have been measured on a weekly time step by the ambient air pumping technique over a two-year period (February 2015 to March 2017) out of the four sites cited above. The air is sampled for 15-min every hour, leading to a total volume of sampled air of about 12.6 m_3 by week. Due to power failure, some weeks were not sampled. The samples are stored in packs before sampling and then individually in Petri dishes and covered with aluminium fold once the sample has been collected. They are then return to Toulouse, France for analysis at the Laboratoire d'Aérologie.

Line 126, how were the samples stored after collection and before analysis. Where was the analysis performed exactly?

The samples were stored in packs before sampling and then stored individually in Petri dishes wrap into aluminum film after exposure. All the analysis were performed in Toulouse, France at "Laboratoire d'Aérologie" (see affiliation of authors).

Line 142, a cite is needed for the statement that the public dump negatively affects the environment and people.

We have added those references : United Nations Environment Programme (2015) and Adjiri et al. (2015).

The public landfill of Akouedo receives the totality of waste produced in the district of Abidjan since 50 years, which is currently more than 1.000.000 tons of waste per year (Adjiri et al, 2015). It negatively affects the environment and the living environment of the populations (Adjiri et al, 2015; United Nations Environment Programme, 2015). Burning of waste in the landfill occurs mainly during the dry season either due to spontaneous ignition of burning or open burning by landfill workers. Fig. 3.d shows a combustion plume rising from the landfill as seen from our sampling site.

Line 144, how often does burning occur?
See remarks of reviewer #1. We don't have exact information on the burnt frequency in the dump. Spontaneous ignition leading to smoldering conditions occurs during the dry season. Dump workers use to burn waste for collecting material.

Line 144, at what sites exactly were the AOD measurements taken? I would include this on the zoomed in addition I recommend to Figure1. Was it close to one of the sites already explained?

The AOD measurements were taken downtown each cities. In Abidjan, it is located at the University Felix Houphouet Boigny in Cocody area, between AWB and AT. In Cotonou, it is located at Dantokpa, less than 1 km from the measurements site. We now plot this information on the new map (Figure 2). See your previous remark.

Line 147, how consistent was the time when the AOD measurements were taken? Where they at exactly 13:00 UTC every day? Is this consistent local time throughout the sampling period (i.e. no change for daylight savings time)? What is the diurnal variation of AOD expected to

be at the site? If there is a diurnal cycle, then relatively small changes in sampling time could have an impact on AOD measurements. In Line 181 it is stated that these are considered daily AOD values, but how can one point in the day capture the daily average since I assume there must be variability within the day?

The operators performed measurement at around 13 UTC. The analysis of the log file of the sun photometer shows actual measurements between 11 and 14 UTC. The diurnal cycle of the AOD is expected to be low. Using AERONET observations, Smirnov et al. (2005) give a diurnal variability between 10 and 40% with an increase during daytime and showing that measurements acquired at noon are within 5 to 10% of the daily average. This reference is now added in the text.

Additionally, the aerosol optical depth (AOD) was measured downtown Cotonou and Abidjan every day using a lightweight handheld sun photometer recording the solar irradiance at 465, 540 and 619 nm. The operators performed measurement at around 13 UTC. The analysis of the log file of the sun photometer shows actual measurements between 11 and 14 UTC. Using AERONET observations, Smirnov et al. (2005) give a diurnal variability between 10 and 40% with an increase during daytime and showing that measurements acquired at noon are within 5 to 10% of the daily average. So the diurnal cycle of the AOD is expected to be low and those measurements are considered to be representative of the daily mean AOD hereinafter. For the sake of consistency with PM measurements, the daily AOD are then weekly averaged.

Line 148, were measurements "performed" or "analysed" only for cloud-free days? If it is performed, then how in the field did you determine a cloud-free day to only take a measurement on cloud-free days? If it is analysed, what data did you use to determine a cloud-free day?

The right answer is "performed and analyzed". The operators were asked to make measurements only when the sun was not obscured by clouds. Moreover they do a sequence of 5 measurements within about 10 minutes. The presence of sub-visible cirrus of broken clouds within the field of view induce spurious variation in the atmospheric transmission (Smirnov et al., 2000) that can be easily detected by looking at the standard deviation of the small series of AOD measurements. A threshold of 0.2 on the standard deviation has been selected to remove the cloud-contaminated observations.

Measurements are performed only for cloud-free field of view. The operators were asked to make measurements only when the sun was not obscured by clouds and have proceed with a sequence of 5 measurements within about 10 minutes. The presence of sub-visible cirrus or broken clouds within the field of view induces spurious variation in the atmospheric

transmission (Smirnov et al., 2000) that can be easily detected by looking at the standard deviation of the small series of AOD measurements. An arbitrary threshold of 0.2 on the standard deviation has been selected to remove the cloud-contaminated observations.

Line 154, where did the weighing occur? At site?

The weighting was done in Toulouse, France at Laboratoire d'Aérologie. Now added in the text.

PTFE filters were weighed before and after sampling using a high precision scale (SARTORIUS MC21S) in Toulouse, France at Laboratoire d'Aérologie. Before weighing, the samples were kept for about 24-h in the weighing room at ambient relative humidity of 30 ± 15%.

Line 171, for the detection limit, what are the units (i.e. ng of what? Carbon?). What does the uncertainty (+/-) refer to?

See reviewer #1 remarks. This statement was confusing. We now report the detection limit of the DRI analyzer based on the instrument blank, which are 0.4, 0.1, 0.3 µgC/cm2 for TC, EC and OC. The accuracy estimated from our measurements is 5% for TC and 10 % for EC and OC.

The detection limit estimated of the DRI analyzer based on the instrument blank are 0.4, 0.1, 0.3 µgC/cm2 for TC, EC and OC. The accuracy estimated from our measurements is 5% for TC and 10 % for EC and OC.

Line 182, why was the AOD changed to 550nm from 540nm?

AOD is a wavelength dependant parameter. We report AOD at 550 nm as this wavelength is a reference for visibility calculation (Boers et al., 2015) and satellite mission (eg. MODIS). Now explain in the main text.

The Angström exponent (Ångström, 1961) is computed between wavelengths 465 and 540 nm. AOD measurements are reported at 550 nm because this wavelength is a reference for visibility calculation (Boers et al., 2015) and satellite mission (eg. Remer et al. 2008).

Section 2.4, the bullet list does not flow well, I would recommend that these are paragraphs, and that you include more information for each point. For the weather data, was there any validation of the NOAA measurements (either in this study or previous studies)? How well do they perform for this region? Are there any local measurements that can be used? What site is the NOAA data for (coordinates)? How close are these sites to the aerosol measurement sites? For MODIS data, how and where did you access it?

We have followed your recommendations and remove the bullet list. ISD is global database of hourly and synoptic observations (Smith et al. 2011). Data are local measurements. The description of quality analysis is available on the web site. The stations are the one for the airport of each cities, namely "CARDINAL BERNADIN GANTIN INTERNATIONAL AIRPORT" and "FELIX HOUPHOUET BOIGNY AIRPORT". Both airports are located with the city. We now report on the map (Figure 2). The MODIS data were accessed from LP DAAC (Land Processes Distributed Active Archive Center).

1.5 Ancillary Data

We have used the meteorological observations provided by the NOAA Integrated Surface database (ISD, see https://www.ncdc.noaa.gov/isd for more details) for both cities. Data are local measurements recorded at the airports of each cities, namely CARDINAL BERNADIN GANTIN INTERNATIONAL AIRPORT" and "FELIX HOUPHOUET BOIGNY AIRPORT". We used the daily data giving the rainfall, air temperature and wind. Figure 2 gives the precise location of the meteorological stations for each city.

A secondary set of ancillary data is the daily burnt surface area given by the MCD64A1 satellite product derived from MODIS on AQUA and TERRA (Roy et al., 2008; Roy and Boschetti, 2009). The burnt surface area provides a proxy for the intensity and the time occurrence of biomass burning emissions. The spatial resolution is 500 m. The data were accessed from the Land Processes Distributed Active Archive Center (LP DAAC). From those data, we have computed the weekly burnt surface in the area presented in Figure 1, from 7°W to 4°E and 4°N to 10°N, located north of our sites.

Figure 2 is small and blurry. Is the box temperature and RH controlled? This box sits outside at all sites, correct?

We have improved Figure 2. The box is located outside and is at ambient temperature and humidity. Now it's added in the text.

Figure 2 shows the inside of the box equipped with 2 sampling lines. The box is located outside and is at ambient temperature and humidity.
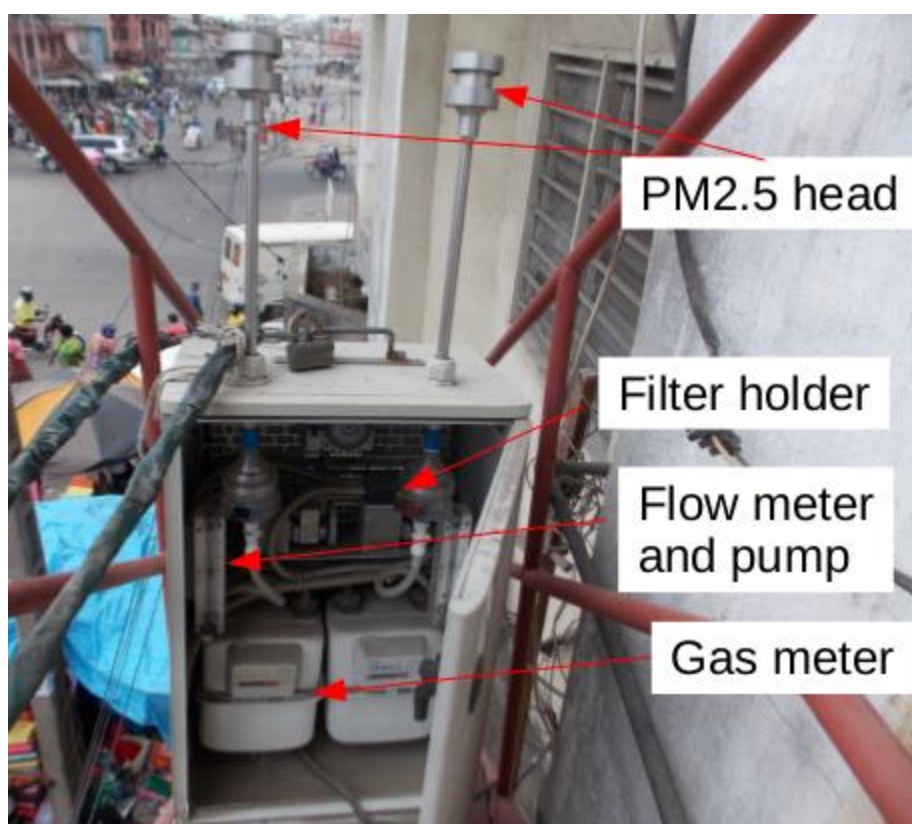

Figure 3: Picture of the sampling box standing outside at the CT site and showing the elements of the sampling lines.

What quality control and assurance procedures were applied to the measured data. How many data points were collected and how many remained after these procedures (for every measurement)?

Number of samples are now given in Table 2. Quality controls measurement procedure for sun photometer measurements are given in the text (section method) for mass and carbonaceous species.

Section 3.1, I would recommend this section is expanded. As stated above, there is a network of AERONET sites in the region, the past data could provide context for this site and a comparison point(s). The temporally coincident data during this campaign could provide additional information for the analysis of the source of the aerosols, as well as a comparison point(s). For example, what is causing the seasonality?

You are correct but this paper is really focused on the urban environment. As stated above, the other AERONET measurements are located northward of our area of interest. A comprehensive study at a regional scale accounting for all AERONET measurements and satellite data acquisition deserves a standalone paper. However we now better acknowledge previous studies in the northern part of the domain. Actually section 3.1 is not well used in the paper. The objective of AOD measurements is to bring additional information and help the analysis of surface measurements. We have removed this part and following your remark, put much more attention to the AOD/PM2.5 analysis in the subsequent section.

Also, what impact might having the measurement at 13:00 have on the analysis (i.e. impact of diurnal cycle?)?
Line 200-202 is not complete.

Thank you. We have corrected this typo. As stated above, we expect that AOD diurnal cycle has a moderate impact on our study (see your previous remark).

Line 204, is dust the only driver? What about difference in aerosols aloft? Would that be expected ?

Mineral dust transport are associated with a high AOD and a low Angstrom exponent. This is the meaning of this statement. We provide a new reference and rewrite the sentence to better emphasis this point. The analysis of the AOD time series has been rewritten as follows. Note that we now present weekly mean AOD.

Figure 7 presents the weekly AOD measurements obtained from daily measurements in Abidjan and Cotonou. The range of weekly AOD in Cotonou is [0.12 – 1.93] with a mean value of 0.63 while in Abidjan, the range is [0.16-1.18] and the mean is 0.56. Seasonal pattern is very similar for both cities with a pronounced increase during the major dry seasons, although Cotonou shows higher AOD than Abidjan. The Angstrom exponent follows almost exactly the same pattern for both cities. It ranges between [0.18 – 1.52] in Abidjan and [0.14-1.85] for Cotonou.

Mean values are 0.87 and 0.91 for Abidjan and Cotonou, respectively. The seasonal cycle of the AOD tends to be opposite in phrase with AOD, showing lower value during the major dry seasons. The observed seasonal cycle could reflect the impact of mineral dust on the atmospheric column during the Harmattan as mineral dust transport is associated with high AOD and low Angstrom exponent (Toledano et al. 2007 ; Verma et al. 2015).

The increase in the Angstrom Exponent during the major wet season (W) tends to be correlated with the start of the rainy season (Figure 5) and is associated with a decrease in the AOD, probably reflecting the impact of rainfall on aerosol scavenging. The mean Angstrom exponent during the minor dry and wet season (D' and W') is 1.2 in Abidjan and 1.3 in Cotonou, which are typical values for urban aerosols (Ben Khalifa et al., 2017). The minimum AOD is reached during W' at about 0.3 for both cities. The slight differences between both cities, ie. higher AOD for Cotonou during the dry season, could be attributed to the fact that Cotonou is more affected by dust transport. The large difference is the precipitation regime, Abidjan having more rainfall (1763 mm) than Cotonou (1084 mm), has not a clear impact on the AOD level however it can explain that less measurements are available during the wet season for Abidjan than Cotonou because of cloud cover.

Figure 4, I would recommend adding the vertical line for W1, D1', etc. as in other figures. I do not believe the "(-)" is necessary as per ACPD style rules.

Ok. Done. We have improved the figures and also followed your recommendations regarding the style rules.

Line 207, these are time series of weekly PM2.5 mass, correct? I would recommend that the authors are very precise in the use of the averaging time throughout in order to avoid confusion. This is particularly important in comparison to WHO guidelines and other studies.

Yes. Correct. We report weekly measurements. We now report averaging time in the text. The sentence is now :

Fig. 5 shows the time series of weekly PM2.5 mass (...)

Line 213, what explains the peak times at ADF?

At least 3 reasons may explain the peak time at ADF: (i) increase in smoking activities, (ii) change in fuel (wood) or (iii) change in combustion due to moisture content of the wood.

Line 218 provides an example of the need for more interpretation that I referred to in the opening comment. The PM mass concentrations are stated, however there is not then some information on what this might mean.

We perfectly understand your remark and your need for more interpretation. However it is somehow not correct. Understanding the annual average concentrations in the major cities of SWA would require a specific study assessing the apportionment between local produced particulate pollution and transported one. This is clearly the scope of ongoing studies in the frame of the DACCIWA project. We don't want to give speculative interpretation of the data. However, having a quite long time series of data gives us the opportunity to emphasize and explain the significant seasonal signal in PM2.5 concentrations.

Line 221, since the site was not downwind from the dump, and the data do not show impact from waste burning, I would recommend the authors consider changing the name of the site from the beginning. I would think it would make sense in the methods to state that this site was originally placed in hopes of capturing waste burning, but did not in the end, so it is labelled something other than waste burning. I do believe that referring to it as "waste burning" throughout the manuscript can lead to confusion.

We follow your recommendation and change the name of the station from "waste burning site" to "landfill site".

Line 224, I would recommend that the authors include the OC, EC and TC time series in a figure as it would be helpful to see the time variation in these. This could be added to figure 5.

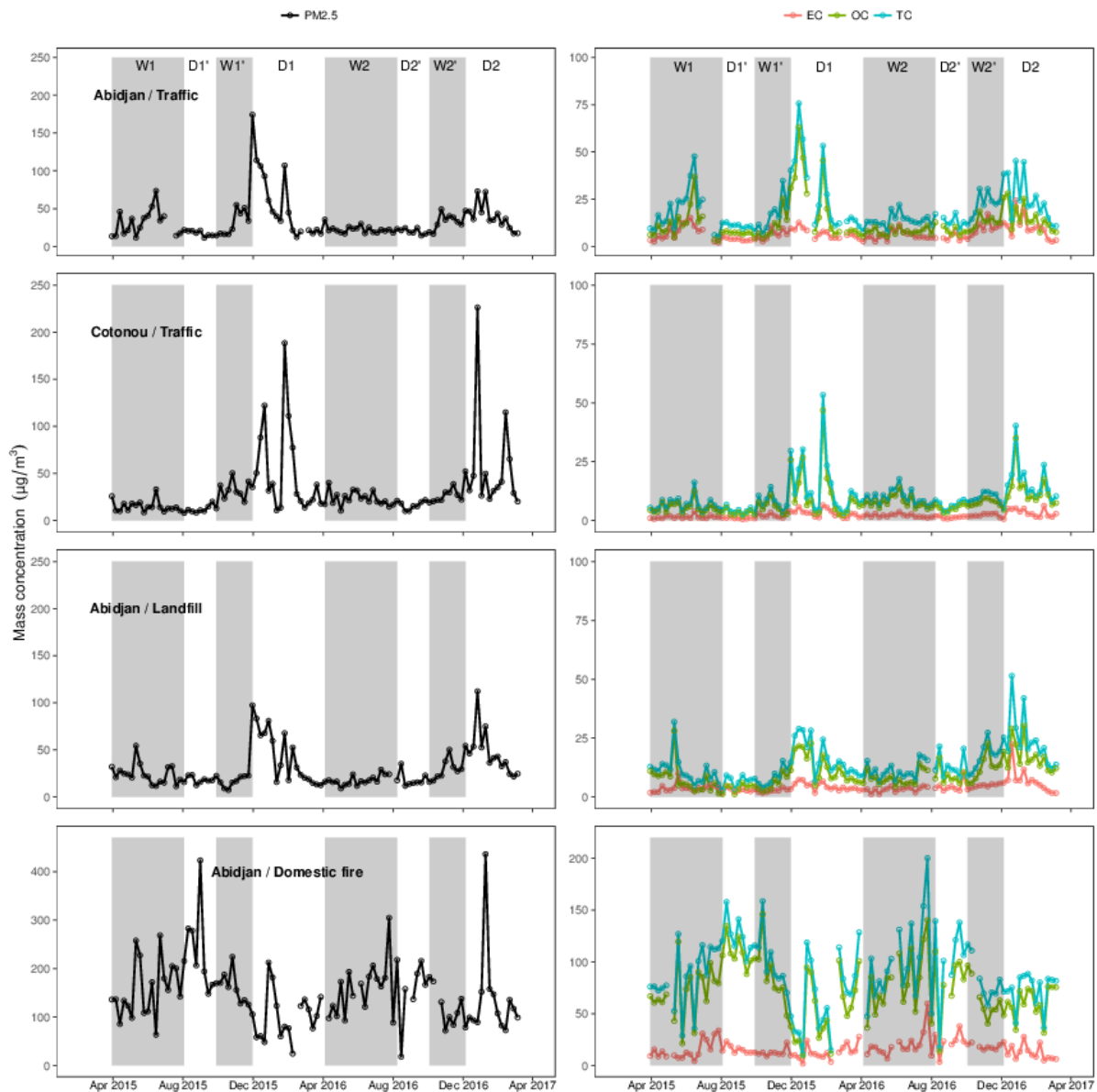We have changed Figure 5 according to your recommendation.

Figure 5: Time series of the (left) PM2.5 and (right) carbonaceous weekly concentrations at the 4 sites from February 2015 to March 2017. Shaded areas show the different seasons (see text): the long rainy seasons W1 and W2; the short dry seasons D1' and D2'; the short rainy seasons W1' and W2'; and the long dry seasons D1 and D2.

Figure 5, AT and CT are similar in PM2.5 mass but not AOD, that is interesting, why might that be? Are the spikes (i.e. ~150 ug/m3 in AT in W1' and D1 in CT etc) 1-week spikes? Or are they multiple weeks? Are they large-scale events? Why are these sites so similar even though they are impacted by different local emissions and the CT site is very far away?

Data plotted on Figure 5 are weekly data. We now clearly state in the figure legends and main text that we are dealing with weekly data. So, yes those are 1-week spikes. The similarities in the seasonal cycle are not so surprising. Indeed, we sample traffic sites in two similar urban atmosphere of coastal SWA cities. The spikes and the seasonal cycle are affected by large scale transport. Our tentative explanation is that CT is more affected by mineral dust transport that AT, as revealed by lower Angstrom exponent and higher optical depth. While some biomass burning events affects differently both sites. The text have been modified accordingly to better highlight our interpretation.

Line 252, how was the humidity of wood considered to be the largest driver of this pollution? This needs additional analyses to prove that this is the case, or citations from literature to prove this is the case.

See also our answer to your previous remark. The emission factor (EF) for PM2.5 and carbonaceous species depends on fuel type and combustion. Keita et al. (this issue) give a factor of 2 between EF between hard and soft wood. Moreover Shen et al. (2013) shows that EF for PM and OC can be a factor of 2 higher for humid wood. We can't actually verify this hypothesis as we didn't monitor smoking activity, fuel type and humidity during the experimental period.

At least 3 reasons may explain the high concentration during W, W' and D' in ADF: (i) increase in smoking activities, (ii) change in fuel (wood) or (iii) change in combustion due to moisture content of the wood. The emission factor (EF) for PM2.5 and carbonaceous species depends on fuel type and combustion. Keita et al. (this issue) give a factor of 2 between EF between hard and soft wood. Moreover Shen et al. (2013) shows that EF for PM and OC can be a factor of 2 higher for humid wood, which can be the case during season W, W' and D' as wood is stored outside. We can't actually verify those hypothesis as we didn't monitor smoking activity, fuel type and humidity during the experimental period.

Line 255-261, this is an interesting analysis. However, the relationship may be easier for the reader to understand if this is graphed (e.g. AOD vs PM2.5), as if these are linearly related or not also provides information.

AOD and PM2.5 are already graphed in Figure 5 and we think that providing a scatter plot for each of season and city individually will not bring more information. AOD and PM show rather "flat" behavior for a given season so the correlation is not significant. We have found a good correlation between AOD and PM2.5 only during the major dry season, when the concentrations and AOD are both largely fluctuating. Now we provide this result in the main

text and provide the correlation coefficients. Note that we have aggregated the data for the two urban sites in Abidjan.

AOD can also be used for a proxy of PM2.5 (Kacenelenbogen et al., 2006) as both quantities tends to be correlated. However deducing surface PM2.5 from columnar AOD is not straightforward (Wang and Christopher, 2009; Zou et al. 2016). Table 2 reports the Pearson's correlation coefficient between weekly PM2.5 and AOD for Abidjan and Cotonou for each season. The data in Abidjan are averaged between the AT and AL site. The higher correlation coefficient R are obviously obtained during the major dry season when both AOD and PM2.5 are largely fluctuating at both sites. The correlation coefficient R=0.74 in Cotonou and R=0.65 in Abidjan. Weak or even no correlation are observed in the other season. The ratio between PM2.5 and AOD is an indicator of the link between surface level pollution and the atmospheric column. A large PM2.5/AOD indicates that aerosols are confined to lower altitudes. The highest PM2.5/AOD ratio is observed during the minor wet season W' (Table 2) highlighting a possible stagnation of pollution during this period. Conversely, the lowest ratio is observed during the major wet season W, which tends to indicate aloft transport of aerosols.

Line 262, I would recommend that a more detailed analysis of wind speed (and direction, if possible; e.g. wind roses) is performed of the sites to see if these analyses provide any information that is helpful to characterize the drivers/sources of pollution.

The analysis of the wind roses shows that the prevailing wind are South-West all year-long at those coastal sites. Northerly winds appears only during the major dry season (also called Harmattan). We provide this information in the main text although we don't draw the wind roses.

The analysis of the wind roses shows that the prevailing wind are South-West all year-long at those coastal sites. Northerly winds (Harmattan winds) appears only during the major dry season.

Line 270, cites are needed for the statement on impact of dust and biomass burning. Low Angstrom exponents can also come from sea salt aerosol, and as these are coastal sites, there is a chance they may be impacted.

Line 275, the lowest AE are actually in W1 and not a dry season. Why might that be? Cites are needed on why 0.8 was defined as coarse particles.

There is a quite abundant literature about aerosol type identification with AOD and Angstrom. Following Kaufman et al. (2000), large particles (dust or maritime aerosols) are dominant in

the size distribution when the Angstrom coefficient is below 0.7, although Toledano et al. (2007) report 1.05. We wrote "typically" as 0.8 is in the range of acceptable values. Dust outbreaks are associated with high AOD, although the threshold on AOD for which dust can be identified depends on distance to dust sources and differs strongly between authors. Verma et al. (2015) gives a threshold of 0.6. Lowest AE in W1 corresponds to maritime aerosol contribution in humid environment. Now in the text.

However, the contribution of advected mineral dust and biomass burning aerosol by northerly winds is also high during season D (Balarabe et al., 2016).Following Kaufman et al. (2000), large particles (dust or maritime aerosols) are dominant in the size distribution when the Angstrom coefficient is below 0.7, although Toledano et al. (2007) have reported a threshold of 1.05. A low value, typically below 0.8, of the Angstrom exponent associated with high AOD, typically above 0.6 (Verma et al. 2015) indicates a significant contribution of coarse dust-like particles to the AOD (Balarabe et al., 2016). The presence of dust over the cities during the major dry season can be inferred by looking at the AOD and Angstrom Exponent in Figure 8. W season shows the lowest Angstrom exponent value and low AOD, which reflects the contribution of maritime aerosols (Kaskaoutis et al., 2009; Verma et al., 2015; Toledano et al., 2007).

Line 275-283, I would recommend that the EC/OC results (and possibly AOD) are used in understanding the impact of biomass burning emissions on PM.
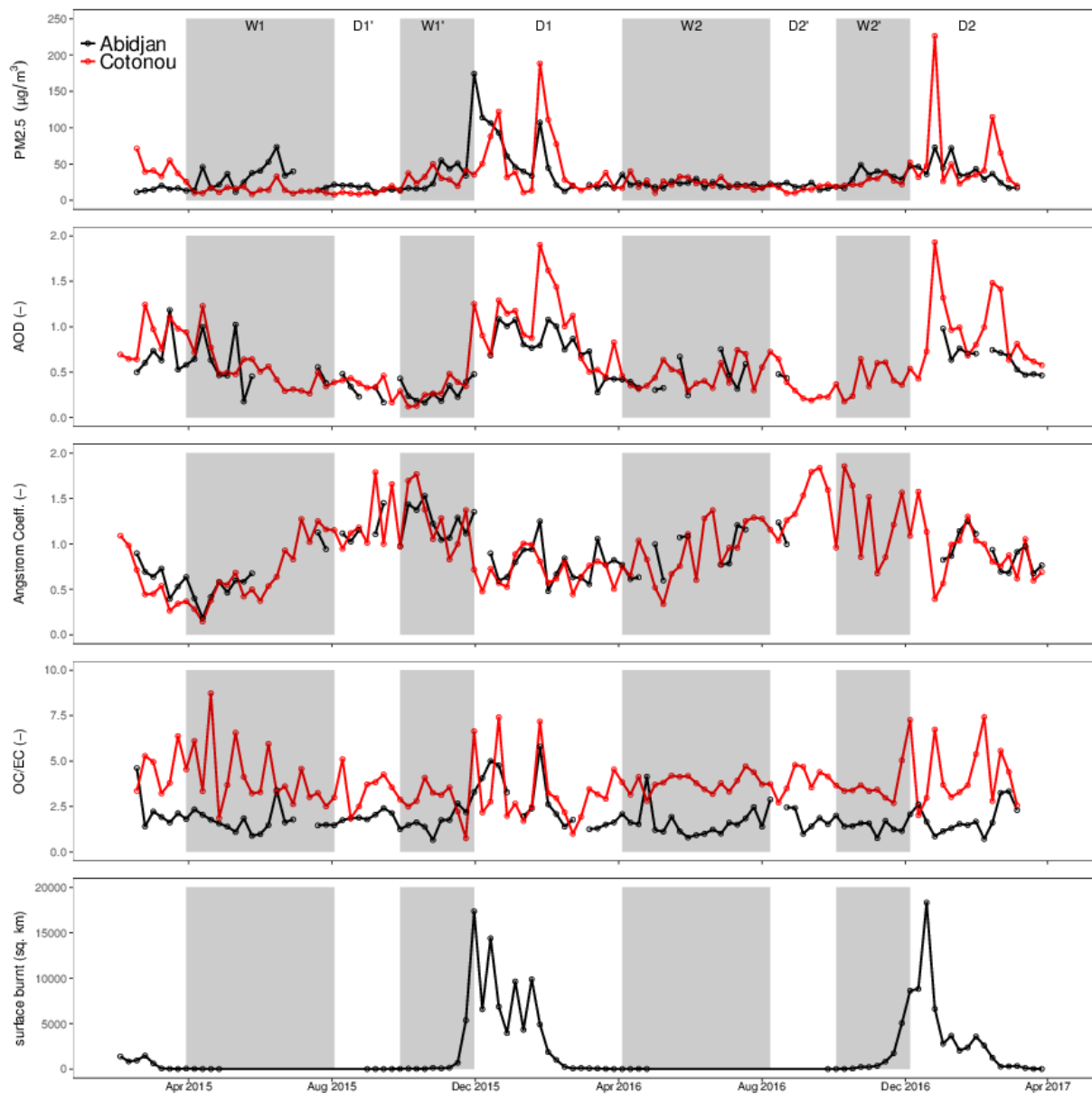
Done, See main text and new figure 7

Figure 7. Weekly mean PM2.5, AOD and Angstrom exponent, OC/EC ratio, observed at Cotonou and Abidjan traffic sites from February 2015 to March 2017. The surface burnt is the weekly total of the MODIS MCD64A1 product burnt surface areas for the region from 7°W to 4°E and 4°N to 10°N.

Line 284, the OC/EC ratio seasonal cycle is not very pronounced and there are large variations in the data per averaging period (Figure 6). In Figure 6 caption, please include an explanation of what level/percentile the boxes and lines reach to.

Correct but although the seasonal cycle is not pronounced, it is significant. We have redrawn the Figure 6 by averaging over the two years to better emphasis this point. The plot is a boxplot showing the median, the first and third quartiles (the lower and upper hinges) and the largest and lowest values (upper and upper whiskers).
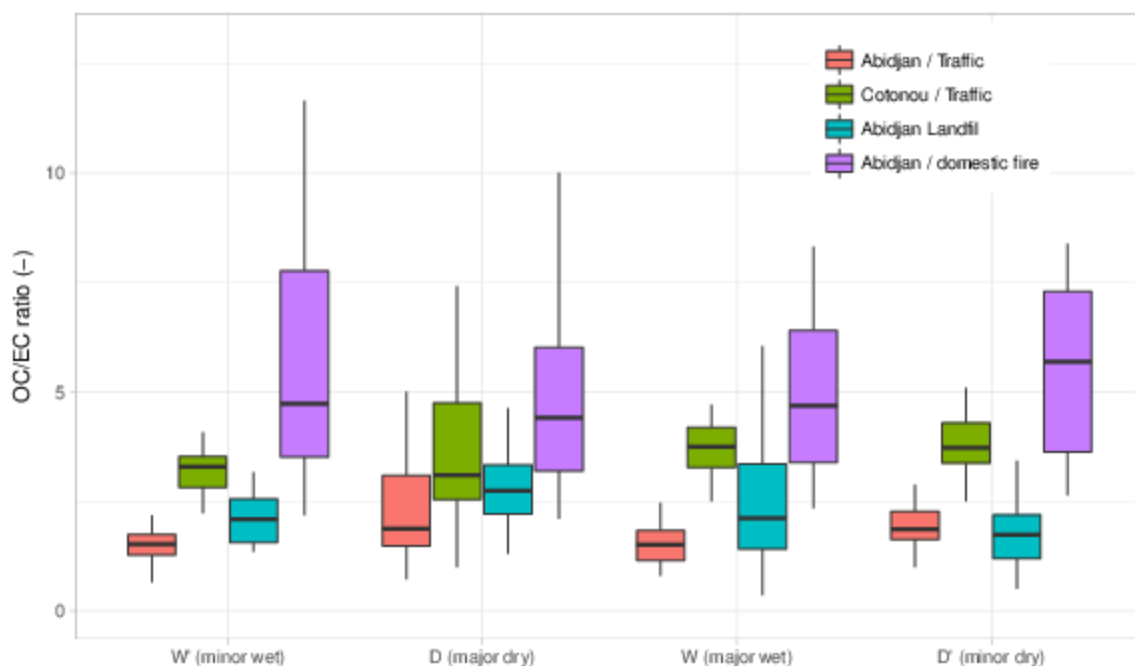
Figure 8: Mean seasonal variation of the OC/EC ratio for the different sites. Each box shows the median, the first and third quartiles (the lower and upper hinges) and the largest and lowest values (upper and upper whiskers).

Figure 8, the AOD values do not seen to the same as in Figure 4. In Figure 4, Cotonou goes above 2, but not here.

Figure 4 shows the daily variation of AOD for the two cities. Since PM2.5 is sampled weekly, we averaged weekly AOD to be do the comparison PM2.5 and AOD. Which is why there is a difference between the two figures 4 & 8.

Also, I would recommend using the same colors as in Fig 4 for Cotonou and Abidjan to avoid confusion. I also would recommend extending the W1, D1, etc lines to all figures.

See remark of reviewer #1. This figure has been suppressed. The season names and lines have been extended to all figures.

Table1, I would recommend having a column showing how many days in each season. This would help to understand the rainfall measurements as they are total per season, however the seasons (as shown on the figures) are not all the same length.

Done

Table 2, why is there no std dev reported for the ratios? I would expect this to also be reported. I would recommend showing the number of points for each measurement in each season.

We now report std for ratii.

I would imagine with the additional analysis that the discussion and conclusions would change, and thus won't comment extensively. As stated above, I would recommend that the averaging period of the measurements is always stated to avoid confusion (e.g. are all studies reporting annual averages?). Also, I do find comparison of these measurements to other sites helpful, however I would recommend that the reason for using these selected sites as comparison points be discussed (e.g. other African cities, European cities, rural areas, etc.).

The discussion section as well as the conclusion section has been rewritten (see text). Following recommendations of reviewer #1, the conclusion has been shorten and rewritten to better emphasis our findings. The references in the discussion section correspond to similar studies and have been selected to put in a broader context our findings. Exact period of time and location are not detailed here.

Line 329, "norm" should be "guideline''.

Ok. This sentence is now :

It is interesting to underline that all the average PM2.5 values that we have obtained in Abidjan and Cotonou are higher than the WHO guideline by a factor of 2 to 14.

Line 339-340, what is the link between variability and diesel use?

This sentence is awkward. We mean that we observe a significant difference between both cities.This sentence has been changed to :

The EC concentration in Cotonou and Abidjan traffic sites are significantly different, respectively 2 μg.m$_{-3}$ at CT and 7 μg.m$_{-3}$ at AT. The higher EC concentration in Abidjan reflects the large contribution of diesel engine.

Technical comments

Line 49-53 is a long sentence, I would recommend re-wording.

This sentence has been changed to:

According to Liousse et al., (2014) one is expected a tripling of anthropogenic emission in Africa between 2000 and 2030 in conjunction with exceptional population growth, massive urbanization and rapid economic growth.

Line 73, biomass burning and burning seems repetitive. I would recommend qualifying the second burning with what type of burning it refers to.

This sentence has been changed to:

The presence of carbonaceous aerosols in West Africa region are known to result from biomass burning, traffic and domestic fire emissions and to a lesser extent from other combustion sources such as industries, power plants and flaring (Doumbia et al., 2012; Liousse et al., 1996, 2014; and Liousse and Galy-Lacaux, 2010).

Line 81, I would recommend deleting "and especially the work package 2..." I think this is specific to the structure of DACCIWA and not needed in this article, as readers who are not in DACCIWA do not know the work packages.

This sentence has been changed to :

Figure 7, a legend would be helpful. The units of rainfall on the axes should be more precise. Is this total mm per week?

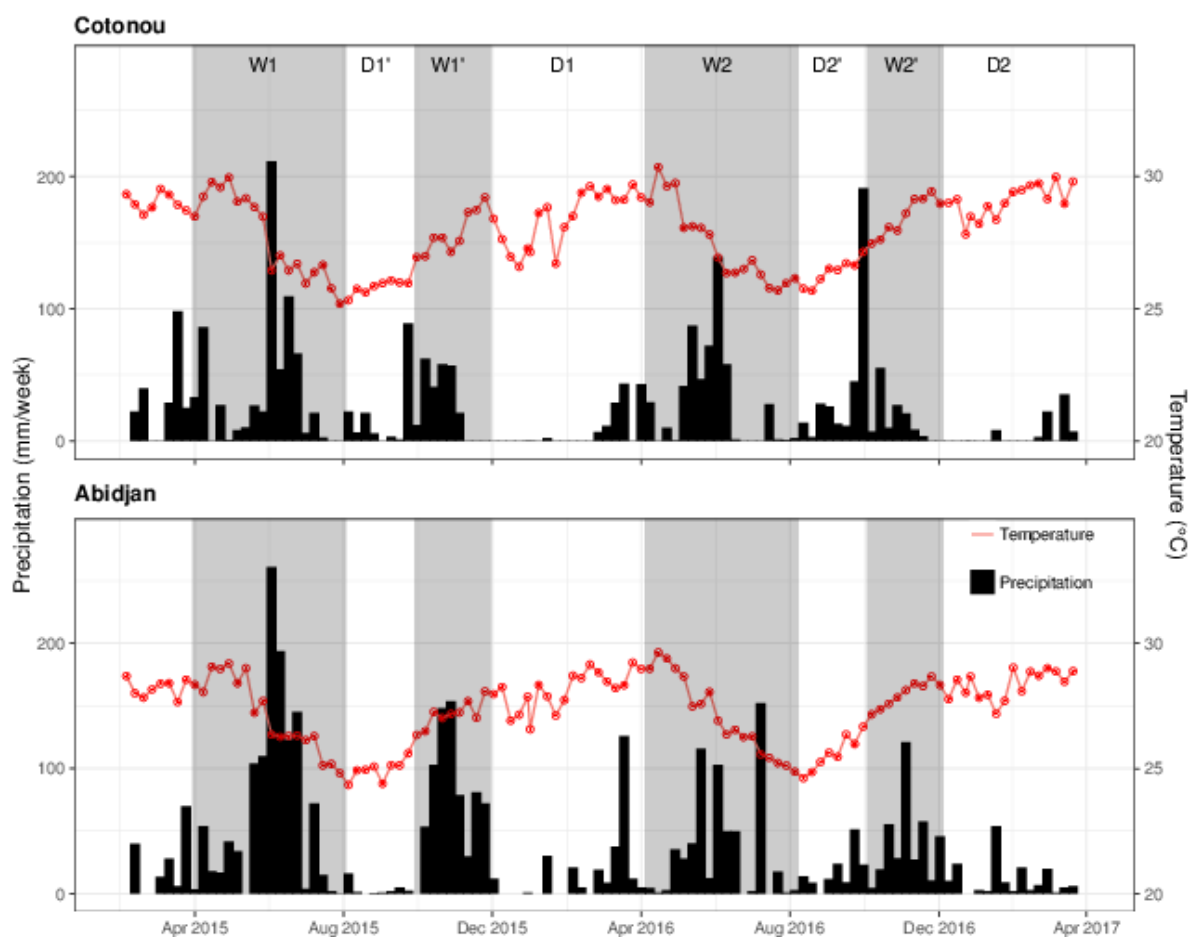The figure has been improved and now shows a legend. The units of rainfall is total mm per week.

Figure 6: total rainfall per week and weekly average temperature for Cotonou and Abidjan from February 2015 to March 2017. W1 and W2, the long rainy seasons; D1' and D2', the short dry seasons; W1' and W2'; the short rainy seasons; and D1 and D2, the long dry seasons.

Line 306, which "fuel" is this referring to?

It refers to a gasoline. As it was unclear the whole paragraph has been changed to :

These percentages of particulate carbon species obtained indicated that more carbonaceous species in PM2.5 particles. We the percentage of particulate carbon species obtained at the AT site was about 1.7 times higher than the percentages obtained at the CT site. From the percentages obtained on the traffic sites, we can say that emissions of particulate carbon species are very important at the AT. These results allow us to confirm the domination of diesel and fuel at the AT and CT site, respectively.

Line 310, "precisely" should be removed.

Ok. This sentence has been changed to :

Our results show that the average concentration of weekly PM2.5 in our urban sites in Côte d'Ivoire and Bénin is around 30 $\mu g.m_{-3}$. Whereas at the domestic fire site with smoking activities, we have found an average concentration of 145 $\mu g.m_{-3}$.