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Atmospheric Chemistry and Physics Discussions

Interactive comment on "The biomass burning aerosol influence on precipitation over the Central Amazon: an observational study" *by* W. A. Gonçalves et al.

W. A. Gonçalves et al.

goncalves.weber@gmail.com

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Comments and answers to the Referee #1

Thank you for your careful review and comments to improve the quality of the manuscript. We really appreciated all yours relevant comments. All suggestions are commented bellow, the paper now is more complete and the main subject is better addressed.

I) Comments from Referees

1) The effect of aerosol absorption should be considered seriously as an important

player. They briefly mention references considering the aerosol absorption effect in the data analysis part and never discuss it more. Aerosol absorption was shown in many studies to play an important role during the dry season. It can explain many of the results by simply suggest that when the conditions are more stable and cloud fraction is relatively low, the interaction of the smoke with EM radiation is larger and therefore warming by absorption can further stabilize the atmosphere. They can find many references for such process. The fact that there is a competition between microphysical and radiative effects is very important in the amazon. It'll change the papers interpretation.

2) The authors use the Manaus sounding measurements as a key part of the data. Therefore all results are gathered within +/- 2hrs around the measurements. This is a major problem of the analysis in my opinion. Manaus is 4 hrs after GMT. It means that all measurements are around 8am or 8pm. These times are probably the worst to study convection in the Amazon. I suspect that whatever is studied here might be the tail of the distribution. The Amazonian convection develops slowly from the morning and peaks in the afternoon. After the afternoon strong rain the whole atmosphere is getting more stable

3) In this article the statistic is based on observations of one El NINO year. Although it is based on a large number of rain observations the conclusions made about the difference between the wet and dry season are weak. In EL-NINO year we expect the rain characteristics in that area to be significantly different than the average. This again suggests that the study is on a very specific subset of the whole data.

4) The introduction is sparse. The authors do not use the known terminology for the aerosol effects and cite the wrong papers for the discussed effects. This is true for the entire paper. Parts that should be in the introduction appear in other places in a partial form. The paper should be reedited.

5) Abstract – there are many good reasons for understanding aerosol cloud interactions not only deforestation fires.

6) Specify better the months of the wet and dry season throughout the paper. I think that the use of the word "semester" here is strange.

7) P 5 L 20-26: I didn't understand why the explanation of the Z-R relation is important? The results afterwards are only based on Z and not R.

8) P 8 L 1: It is not clear what the described process is in this case. It could sound like the intensity of the rain increase due to the decrease in the RF. If so, why is it true?

(I) Author's Response

1) The manuscript now discusses the effect of aerosol absorption in several parts of the text introducing new references and clarifying this aspect. There is a competition effect between microphysics and radiative effect reducing precipitation, however, the quantification of each effect in the rainfall is not possible with this database. We also discuss the effect of the radiative effect during the unstable situation. In these situations the radiative effect does not seem to be predominant, as there is a significant amount of polluted periods with high CAPE values (Figure 1), there are unstable cases for high black carbon concentration. The thermodynamics effect has a smaller time scale than the radiative effect and in the convective scale the instability acts faster increasing updrafts and developing a mesoscale circulation that maintain the cloud lifecycle.

2) This is a question we had raised when we decided to evaluate the CAPE in this paper. We were expecting to have only very few large value of CAPE, but the detailed analysis of CAPE distributions showed this dataset appropriated to be used in this study. Actually, even at 8am we have a reasonable range of CAPE values (see the distribution in Fig. 2). At 8pm the amount of higher values is larger (see Figure 2). The more stable and unstable values are the tails of the distribution and these days corresponds to more extreme population of thermodynamics condition that we would like to evaluate. We do agree that convection in the Amazon peaks in the afternoon and soundings around noon would be more representative. Unfortunately, there is no historical dataset of sounding in Manaus in this period because it is regularly launched

at synoptic time. In the future, with the GoAmazon campaign we will have, during a specific period, 4 radiosondes per day and a specific correlation between the other sounding times will be possible to stablish. Figure 2 presents histograms for the CAPE values used at 00 and 12 UTC in this research. It is observed that the 00 UTC histogram presents an elevated occurrence of high CAPE values (>2600 J/kg). It is also noted that even less frequent, high CAPE values also occurs in the morning (12 UTC). This behavior could be explained by the fact that we observed from our soundings that more than 70% of the days which presented CAPE values higher than 2600 J/kg at 00 UTC high values were also identified in the next morning. We added this discussion in the text to highlight this feature.

3) We do agree that convection in the Amazon is affected by El Niño configurations. Rolpelewsky and Halbet (1987) and Peel et al. (2002) commented that the Amazon is one of the most important regions in the tropics where precipitation is influenced by El Niño occurrences. Ropelewski and Halbet (1987) commented that during El Niño periods, less precipitation is observed in the Amazon. However, less rainfall is not necessarily linked to weaker precipitating systems, but to the quantity of these systems. So, as the El Niño configuration was observed in the second semester of the year, the quantity of precipitating systems was probably inferior than in a regular dry season. Therefore, the El Nino effect acts to reduce the number of rainfall events and not the characteristics of the convective event. For the evaluation of stable and unstable atmosphere and the relationship between aerosol-rainfall we have enough cases to have statistical significance in our results. Also, for the study of size and aerosol loading, however, we agree that we had a non-significant number of rain cell lifecycle to study the effect of aerosol in the lifecycle duration. These points were clarified in the manuscript. References for this question: PEEL, M.; MCMAHON, T. A.; FINLAYSON, B. L. Variability of annual precipitation and its relationship to El Niño Southern Oscilation. Notes and Correspondence, v. 15, p. 445-451, 2002. ROPELEWSKI, C. F.; HALBERT, M. S. Global and regional scale precipitation patterns associated with El Niño/Southern Oscillation. Monthly Weather Review,v. 115, p. 1606-1626, 1987.

4) We changed the Introduction and several parts of the manuscript. We hope now have addressed the right references to the study.

5) Yes, we do agree that there are many other reasons for understanding the aerosol cloud interactions. Nevertheless, we just cited the deforestation fires because BBA predominates in the mean annual aerosol optical thickness in the Amazon, which is our study region. Also, because in this study we used black carbon, which is a byproduct of a partial combustion of fossil or wild fires, as an aerosol tracer. However, as the first sentence of the abstract is not clear that we focused on the Amazon region, this sentence was changed.

6) We do agree that the months of wet and dry seasons were not well specified in the paper. Then, we added a new sentence in Section 3, in order to clarify this aspect. We also agree that the word "semester" is not appropriate. Thus, this word was substituted for the word "season" and for the specific months throughout the text.

7) We agree that after the VPR explanation all results are based on Z, not in R. The explanation of the Z-R relation could lead to misinterpretations regarding to the data which we used. Then, in the actual version of the manuscript we eliminated the Z-R explanation. We have added more details from other important aspects related to the VPR technique. The text was modified.

8) We agree that this explanation is confusing in the manuscript. The results indicate that in the dry period, when the large scale precipitation decreases in the study area, most of precipitation in the area is related to intense convection. However, the increase of IRF is not due to the decrease of RF. The high IRF frequency observed is linked to the fact that most of intense convection occurs over elevated areas during the dry period, as shown in Fig. 2 in the manuscript. The sentence was modified in the manuscript.

(III) Author's Changes in Manuscript

1) Bellow some paragraphs discussing this subject in the manuscript:

"Two main effects are well documented: radiative or direct, and microphysical or indirect. The first effect is related to the BBA high capacity of absorption in the visible portion of the electromagnetic spectrum (Ramanathan et al. 2001, Wake, 2012). This absorption could warm the atmosphere (Koren et al., 2004; Randles and Ramaswamy, 2010; Koch and Del Genio, 2010; Jacobson, 2014) and produce atmospheric stabilization (Koren et al. 2008). The indirect or microphysical effect is linked to the possibility of BBA particles becoming cloud condensation nuclei (Roberts et al. 2001). As a result, it is expected that the amount of cloud droplets would increase with the particle concentration (Rosenfeld, 1999; Ramanathan et al., 2001; Nober et al., 2003; Andreae et al., 2004; Qian et al., 2009)."

"One of the most important issues regarding the aerosol-cloud interactions is the determination of the predominant effect, radiative or microphysical. In warm rain suppression, both effects seem to act together. However, quantifying their respective contribution is still an important issue. Warm rain suppression evidence was firstly documented by Rosenfeld (1999), and then similar results were also obtained and presented in the literature by Nober et al., (2003), Koren et al., (2004) and Qian et al., (2009). The suggested indirect effect mechanism for warm rain suppression is related to the fact that BBA could act as cloud condensation nuclei. A high concentration of small cloud droplets occurs in polluted environments (Rosenfeld, 1999; Ramanathan et al., 2001; Nober et al., 2003; Andreae et al., 2004; Qian et al., 2009), which compromises the coalescence process (Kaufman et al., 2005). These droplets do not reach the required size in order to precipitate and can rapidly evaporate (Artaxo et al., 2006)."

"The radiative effect that acts to stabilize the atmosphere is of a second order because even with high BBA the atmosphere is highly unstable, and thermodynamics, on this time scale, dominates over the radiative process. Also, the feedback effect due to the radiative effect, which increases droplet evaporation, does not seem to be the predominant mechanism. Probably, the high instability (high updraft) and the large number of droplets inside the cloud ascend very fast, thereby reducing the evaporation. Although impossible to quantify, the wet scavenging also seems to be of second order, and would act in the opposite direction through the fact that precipitation did not decrease BC concentration at any point of the curve (Fig. 4b). During the dry season only the upslope regions trigger convection and in the highly unstable cases it appears that BBA helps to increase ice nucleus, increasing precipitation."

"This could be associated to the warm rain suppression mechanism or the direct radiative effect, or an association of the radiative and microphysical effects together. During the dry season in an unstable atmosphere, the convective invigoration for elevated concentrations of BBA seems to be a very significant result, because all other features act to reduce precipitation in polluted atmospheres, such as wet scavenging. The probable physical mechanism is related to stronger updrafts inside the rain cells initiated over upslope regions, which could increase ice nucleus and strengthen convection. It is true that the vertical velocity within the precipitating systems was not available in the database used."

2) Bellow the paragraph discussing this subject in the manuscript:

"Atmospheric soundings, which were collected twice a day, at 00 and 12 UTC. The atmospheric soundings were used to calculate the Convective Available Potential Energy (CAPE), an important atmospheric index used as an intense convective activity predictor (Wallace and Hobs, 2006). As Manaus radiosondes were released by an operational station, only soundings at 00 and 12 UTC, 08 and 20 local time, were available. The best time for a sounding in this study would be sometime around noon when convection starts to develop. However, the CAPE dataset was evaluated and shown to have very useful information and capture the daily instability feature even though it was not recorded at the most appropriate time. In an evaluation of the sounding dataset we observed at 00 UTC a considerable population of high CAPE values, but less frequently then at 12 UTC."

3) Bellow the paragraph discussing this subject in the manuscript:

"The El Niño configuration, as was observed during the dry season, is associated to less precipitation due to a decrease in the occurrence of rain cells. Even if this situation decreases the rain cell population in order to study the lifetime duration, a significant number of samples were analyzed for the evaluation of the aerosol-rainfall interaction, and this did not compromise the main results of this study that are associated to the convective scale."

4) Following is the new introduction of the manuscript.

"Every year the Amazon Forest faces a large amount of aerosol from pasture and forest fires, and the pollution plumes generated can spread over large areas (Martin et al., 2010). The Amazon Biomass Burning Aerosol (BBA) alters the atmospheric particulate material composition (Ryu et al., 2007) and can influence cloud formation, precipitation and the radiation budget (Artaxo et al., 2002; Lin et al., 2006; Tao et al., 2012; Camponogara et al., 2014). Accordingly to Tegen et al. (1997), BBA predominates in the mean annual aerosol optical thickness in the Amazon. The dry season, which occurs between July and December, is the period that faces greater biomass burning emissions (Artaxo et al., 2002; Altaratz et al., 2010; Martin et al., 2010; Camponogara et al., 2014). However, from January to June (wet period), BBA is also observed in the Amazon Basin (Martin et al., 2010). In recent years, the scientific community has made great efforts to understand the effect of aerosols on cloud and precipitation in order to reduce uncertainties in climate prediction (Tao et al., 2012). Two main effects are well documented: radiative or direct, and microphysical or indirect. The first effect is related to the BBA high capacity of absorption in the visible portion of the electromagnetic spectrum (Ramanathan et al. 2001, Wake, 2012). This absorption could warm the atmosphere (Koren et al., 2004; Randles and Ramaswamy, 2010; Koch and Del Genio, 2010; Jacobson, 2014) and produce atmospheric stabilization (Koren et al. 2008). The indirect or microphysical effect is linked to the possibility of BBA particles becoming cloud condensation nuclei (Roberts et al. 2001). As a result, it is expected that the amount of cloud droplets would increase with the particle concentration (Rosenfeld, 1999; Ramanathan et al., 2001; Nober et al., 2003; Andreae et al., 2004; Qian et al., 2009). One of the most important issues regarding the aerosol-cloud interactions is the determination of the predominant effect, radiative or microphysical. In warm rain suppression, both effects seem to act together. However, quantifying their respective contribution is still an important issue. Warm rain suppression evidence was firstly documented by Rosenfeld (1999), and then similar results were also obtained and presented in the literature by Nober et al., (2003), Korenet al., (2004) and Qian et al., (2009). The suggested indirect effect mechanism for warm rain suppression is related to the fact that BBA could act as cloud condensation nuclei. A high concentration of small cloud droplets occurs in polluted environments (Rosenfeld, 1999; Ramanathan et al., 2001; Nober et al., 2003; Andreae et al., 2004; Qian et al., 2009), which compromises the coalescence process (Kaufman et al., 2005). These droplets do not reach the required size in order to precipitate and can rapidly evaporate (Artaxo et al., 2006). Based on the observations of warm rain suppression over regions with forest fires, Diehl et al. (2007) suggested that the ice phase could be an important factor in the rain process. In fact, laboratory measurements indicate the high capacity of ice nucleation by BBA (Petters et al., 2009). In recent years, some studies have suggested that ice phase clouds are invigorated by the presence of aerosols from vegetation fires (Andreae et al., 2004; Lin et al., 2006; Rosenfeld et al., 2008; Altaratz et al., 2010; Koren et al., 2012; Storer and Heever, 2013). Rosenfeld et al. (2008) propose a conceptual model based on the effect of aerosols on deep convective cells, which is mainly associated to the microphysical effect. Accordingly to the authors, due to the high concentration of aerosols in polluted environments, the raindrop nucleation process would be slower than in unpolluted areas. Besides, in atmospheres which favor deep convective activity, these droplets and aerosols could ascend into the atmosphere, reaching the frozen layer, acting as ice nuclei and releasing more latent heat, which in turn increase the updrafts and strength convection (Lin et al. 2006; Rosenfeld et al. 2008). Over a certain time, the cloud accumulates higher liquid water and ice

contents, favoring more intense rainfall rates and increasing electrical activity (Graf, 2004). However, even with this evidence, the cloud invigoration process by aerosols still needs to be better understood (Altaratz et al., 2014). Although well documented, especially in recent years, the BBA effect on clouds and precipitation is still a source of debate in the scientific community. One of the most important issues is related to filtering the aerosol-precipitation relationship from other dominant atmospheric components. In order to reach this goal, this study presents a new methodology which is based on the atmospheric degree of instability. The possibility of using ground based measurements has the potential to contribute to the present scientific knowledge of the BBA influence on precipitating cells in the Amazon region. Rain, ice content, size and duration of precipitating systems retrieved from a S-band radar were evaluated as function of black carbon concentration over the largest Amazon City (Manaus, Amazonas state, Brazil)."

5) "Understanding the influence of biomass burning aerosols on clouds and precipitation in the Amazon is an important key in order to reduce uncertainties in simulations of climate change scenarios with regards to deforestation fires."

6) Explanation of the rainy and dry periods in Section 3:

"The Manaus precipitation characteristics were obtained from the calculation RF and IRF. The RF and IRF were normalized by their annual mean and standard deviation in order to compare both annual cycles. The result (Fig. 1a) was useful in determining two distinct periods to perform the analysis. Months during which the normalized RF was greater/smaller than zero were considered rainy/dry seasons. Then, the period of the year between January and June was considered the rainy season and the months from July to December, the dry season."

- Sentences which the word "semester" was substituted throughout the manuscript:

"The most important results were obtained during the dry season (July-December)." "The dry season, which occurs between July and December, is the period that faces greater biomass burning emissions (Artaxo et al., 2002; Altaratz et al., 2010; Martin et al., 2010; Camponogara et al., 2014)." "However, from January to June (wet period), BBA is also observed in the Amazon Basin (Martin et al., 2010)." "In other words, even with a high peak of reflectivity being observed over elevated regions, during the rainy season precipitation occurs nearly homogeneously." "This characteristic observed during the dry season lead us to try filtering the possible aerosol influence on precipitation from an atmospheric feature in which could modulate the effect."

7) "The S-band radar data were processed following the TRADHy strategy (Delrieu et al. 2009), briefly described hereafter. A preliminary quality control of the radar data was performed, and the radar calibration was checked throughout the year of 2009. The area actually sampled by the radar was determined for each elevation angle with characterizing partial or complete beam blockage and ground clutters. Rain types and the corresponding vertical profiles of reflectivity (VPR) were dynamically identified. Regarding the VPR identification, the initial method used in TRADHy performs a numerical identification of the VPR from the comparison of the radar data at different distances and altitudes to account for sampling effects (Kirstetter et al., 2010). In the present study the physically-based approach described by Kirstetter et al. (2013) was used for enhanced robustness to identify a representative VPR over the radar domain for a given precipitation type. Corrections for both clutter and beam blockage were performed along with a projection of measured reflectivities onto the ground level using rain-typed VPRs. At a given pixel, reflectivities from all available elevation angles were used for the projection. The projected radar reflectivity to a constant altitude plan at the same elevation as the radar was called the Constant Altitude Plan Position Indicator-Ground (CAPPI-Ground). The Vertical Ice Content (VIC) for each pixel of the radar images was also calculated. The method described in Kirstetter et al. (2013) is based on a modeling of the physical properties of the hydrometeors (size distribution, shape, phase, electromagnetic properties, etc.) contributing to the VPR features. In particular the model for the ice phase above the freezing level allows for the computation of the Vertical Ice Content (VIC). The identified VPR is then associated to a model for the

ice phase, which is used to compute the VIC at each pixel alongside the projection of reflectivity at the surface."

8) "This result indicates that in the dry period, when large scale precipitation decreases in the study area, most of the precipitation is linked to intense convection, which mainly occurs over elevated areas."

Interactive comment on Atmos. Chem. Phys. Discuss., 14, 18879, 2014.

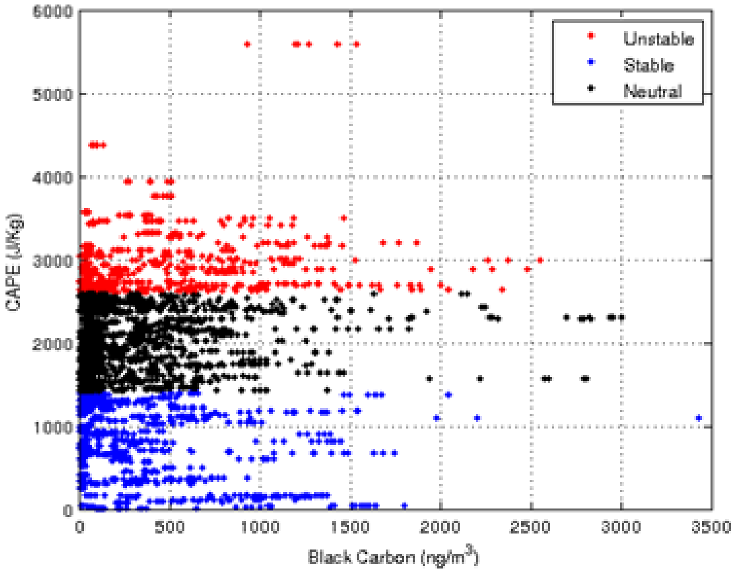

Fig. 1. Scatter plot diagram for CAPE versus Black Carbon Concentrations for the entire year of 2009 collected by EUCAARI.

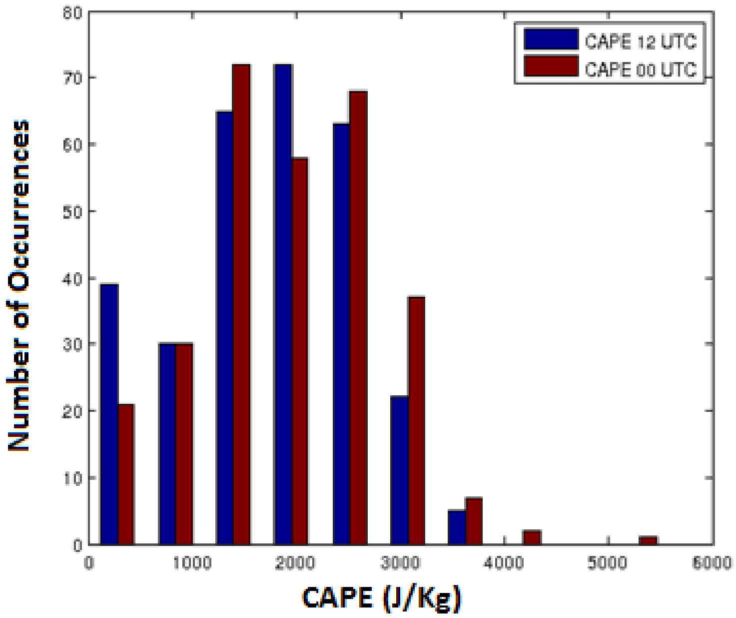

Fig. 2. CAPE histograms for 00 and 12 UTC in Manaus in 2009.