Atmos. Chem. Phys. Discuss.,
https://doi.org/10.5194/acp-2019-43-RC2, 2019

Atmospheric Chemistry and Physics Discussions
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Interactive comment on "Above Cloud Aerosol Optical Depth from airborne observations in the South-East Atlantic" *by* Samuel E. LeBlanc et al.

Anonymous Referee #2

Received and published: 14 March 2019

The paper written by Samuel LeBlanc et al. is focused on the Aerosol Above Cloud (AAC) properties measured by the 4STAR instrument during the ORACLES 2016 airborne campaign. The magnitude and spatial variability, as well as the vertical distribution of above-cloud aerosol optical depth (ACAOD) and Ångström Exponent (AE) are discussed. A comparison of 4STAR ACAOD with satellite retrievals from MODIS of clear-sky fine mode AOD and ACAOD is also made. The authors also show a hyperspectral ACAOD profile case-study and a comparison of the 4STAR measurements with other in-situ instruments on-board of the P-3 aircraft. The final section is focused on the vertical distance between the aerosol layer and the underlying cloud. Their results show that during the ORACLES 2016 campaign the aerosol properties sampled above the clouds are consistent with previous studies, which show high elevated thick

layers of fine particles, typical to biomass burning aerosols. They also found that the largest ACAOD is found in the northern part of the sampling region, and that high AOD variability coincides with high AE variability. Both the satellite climatology over August and September and MODIS ACAOD retrievals collocated along the flight tracks consistently overestimate the 4STAR ACAOD. The final results show that the gap between the aerosol layers and the cloud tops is larger further away from the coast (0-4000 m) compared to near-coast samples (0-2500 m). The extent of the gap between aerosol and cloud peaks at a longitude of 7.5E, unlike the expected gradual decrease of the gap from the coast westwards.

Overall, the paper is well documented and generally well written, however there are several issues that should be further discussed in the paper. I would recommend it for publication if the following remarks are addressed.

General remarks:

While the authors have focused on the ACAOD retrievals with 4STAR, I was expecting a broader and more detailed analysis of aerosol properties, using other instruments onboard of the aircraft. For example, the aerosol absorption is not exploited even though the PSAP instrument has been used to compute the in-situ extinction. The in-situ aerosol extinction could have been compared for the entire sample set with the 4STAR derived extinction, since they seem to show some differences for one study case (Figure 12). It would had been interesting to see the difference in AOD from the 2 instruments. Also, the vertical aerosol profiles, and especially the distance between the aerosol layers and clouds could be further emphasized by showing a lidar profile, either from satellite retrievals or from the ER-2 aircraft. This could also give more confidence in the in-situ extinction measurements showed in Figure 2 and could support the "gap" definition for detached or attached situations.

I am not convinced of the statistical representability of the AOD full-column (and AE full column) from 4STAR, since there are so few samples, and if a comparison with the

ACAOD is bringing new insights. In most cases it is expected that a full-column AOD in this region should be higher than the ACAOD counterpart, due to the presence of sea salt aerosols. However, I am curious if the authors have considered the presence of POCs (pockets of open cells - Stevens et al., 2005; Wood et al., 2011) where the air is very clean and could had been possible that some of the full-column measurements were made within such a cell? That could perhaps add an explanation for the larger standard deviation observed.

In my opinion, there is a missing discussion regarding the variability in ACAOD around 8-10E and 18-22S and the larger variability of AE in the same region (page 10). Could it be possible that because the measurements were made at the southern region of the aerosol plume, the AOD during some measurements is small enough to impact the AE computation? We can clearly see how low AOT affects AE values in figure 12. Also, I am curious what could lead to such high standard deviation in the AOD retrievals (Figure 4), around 14S? It would be useful if the authors would add a color bar plot that would show the number of measurements averaged over each grid box of 0.6 x 0.65 deg, for both AOD and AE (if they are not the same).

While I appreciate the authors approach to compare with MODIS data, I found this section poorly explained. There are confusions related to the label of the MODIS products used for different comparisons; occasionally it is difficult to follow which comparison has been made. I suggest a rephrasing or a better description of these products. Also, it is not clear to me if the MODIS data were collocated along the flight track. What is the native resolution of the MODIS products? Have they been aggregated onto the grid box explained in section 3.1? From the description it appears that there is a subset of the MOD06ACAERO that has been temporally and spatially collocated with the flights, another subset that has been only spatially collocated (over the month of September), but the MODIS climatology dataset seems to be representative for the entire region. Is that right? I am also curious if the authors have investigated what happened on the date of 12/09, that shows anomalous values of the MODIS data? This is important,

since this high value seems to skew the mean AOD of that longitude bin in Fig. 8, and implicitly affect the analysis and conclusions of the paper.

Another concern is related to the analysis presented in section 3.5. It is not clear to me if this analysis was made along the routine flight track or using the entire dataset of measurements. If the samples are averaged along longitude bins from all the measurements, wouldn't that bias the results due to temporal and spatial variations of the vertical profile of the aerosol layer? The measurements were made on the extent of several days, in which the meteorological state or even diurnal cycle could have impacted the aerosols transport and their altitude. The authors should be more careful in making a statement on the expected aerosol layer transport and distance to cloud, particularly because of the meteorological uncertainty.

In my opinion, the paper could benefit from a little restructuration. Firstly, I consider that the study case can be presented as a methodology case, that leads further to the AE computation. The method of computing AE should also be presented in the methodology. I would also gather the AOD and AE sample statistics in one section, and the averaged spatial distribution of AOD and AE in another section. From my standpoint, this structure would make the paper easier to follow and clearer in its scientific message.

I suggest here a new plan, that the authors could consider.

1. Introduction

2. Data and instrumentation

2.1. ORACLES (Fig 1)

2.2. 4STAR

2.3. In-situ instruments

2.4. AERONET

2.5. Satellite retrievals

3. Methodology

3.1. AOD above cloud determination (Fig 13 + Fig 2)

3.2. Spectral AOD above cloud and AE

3.2.1. Hyperspectral AOD study-case (Fig 11 + Fig 12)

3.2.2. AE estimation (Fig 5)

4. Results

4.1. Statistics of sampled AOD and AE (Fig 3 + Fig 6)

4.2. Spatial distribution of AOD and AE (Fig 4 + Fig 7 + figure with number of measurements / grid box)

4.3. Airborne AOD in context of climatology and satellite measurements (Fig 8)

4.4. Aerosol vertical profiles and distance to clouds

4.4.1. Spatial variability in AOD profiles (Fig 9)

4.4.2. AE vertical dependence (Fig 10)

4.4.3. AOD distance to cloud (Fig 14)

5. Summary and discussion

Specific remarks:

Page 5, lines 5-10: The absorption coefficient is taken in dry conditions, while the scattering coefficient is measured at different relative humidity conditions. How does that impact the computation of the extinction coefficient and what is the resulted uncertainty?

Line 43: What is the minimum cloud optical thickness for which the MODIS product

can retrieve AOD above cloud? Do you know what are the uncertainties of the MODIS ACAOD product for optically thin clouds (e.g. COT < 5)?

Page 6, line 5: "two aerosol model assumptions. . ." What are those assumptions? Lines 16-20: Maybe move Page 14, lines 8-11 here for better clarification. Do you know how the measurement uncertainty (60 m) for "no gap" situations affect the ACAOD retrieval?

Page 7, lines 13-15: "Considered together, the ACAOD and full column AOD (denoted by the total extent of the histogram bars in Fig. 3) represent what a satellite remote sensor would retrieve in the region, if it were spatially and temporally co-located to the NASA P-3 aircraft." I understand this sentence, but I don't understand its relevance to the paper.

Page 9, line 3: Why are you fitting the AE up to 1650 nm, since you have showed that for wavelengths larger than 1000 nm, the AOD has higher uncertainties (Fig. 5)?

Lines 25 – 27: You mention the negative difference of above cloud AE500 -AE470/865 of -0.26 as representative to biomass burning sources, as defined by Yoon et al., 2012. I do not understand why the full column difference is positive? Aren't you subtracting AE470/865 (=1.25) from AE500 (=1.08) which would result in -0.17? I am confused of your conclusion for this analysis. Could you please clarify it in the text?

Page 10, line 33: Why are you using August in the MODIS AOD climatology? As shown is Adebiyi et al., (2015) there is a shift in meteorological condition between August and September, and this would result in a change in aerosol transport – hence climatology.

Page 12, Section 3.4.1: - Figure 9 c): how come there are profiles that begin almost at 0 m? Shouldn't these be measurements above the cloud? Are these all column AODs or ACAODs?

- "[. . .] the variability of the AOD profile in these different regions, we observed at 2000 m AOD ranges between 0.17 to 0.6 for 25 profiles along the routine diagonal, and 0.3 to

0.58 for coastal profiles." Are you discussing only figures 9c) and 9d)? If you consider all the plots, then at 2000 m I observe larger values of AOD closer to the coast.

Page 12, Section 3.4.2.: I do not understand how there are more data at 3000-4000 m for "all data" situations in Figure 10 compared to "above cloud" situations. Wouldn't the measurements at that altitude include only above-cloud measurements? Why is the AE above cloud profile stopping at 4000 m, when the ACAOD goes up to 6000 m (Fig. 9)? All the AOD above 4000 m is < 0.1, and thus you have filtered these data?

Figure 1: Add the latitude and longitude coordinates

Figure 14 is confusing. You talk about profiles in the text, but show days on the plot. You should mention one or the other in the text or on the plot.

Technical corrections:

General observation: I observed missing commas in many places, which makes the text difficult to follow in some cases.

Page 2, line 41: Wen et al., (2017) reference is missing. I also suggest Cornet et al., (2018) that looked at POLDER 3-D cloud radiative effects.

Page 3, Line 1: You could also mention Hu et al., (2007) for the CALIOP Depolarization Ratio Method, since you mention Chand et al., (2009) for CALIOP Color-Ratio Method.

Line 1: Matus et al. 2015 reference is missing

Lines 11-15: Maybe split this sentence, as it is hard to follow: "Past work has shown that the elevated aerosol layers in this region are frequently separated from the underlying cloud top, e.g., Devasthale and Thomas (2011) found that 90-95

Page 5, line 1-3: Rephrase: "with paired single-wavelength nephelometers (Radiance Research M903 measuring at 540 nm, with air in one humidified to 80

Line 31: You have already mentioned Gobabeb and Henties Bay in line 26. Maybe

rephrase a bit so you don't repeat the same information.

Page 6, Line 3: "...uses reflectance ..."

Lines 40-42: Change "[. . .] including the biomass burning layer of aerosol above clouds as well as any lower-level aerosol near the sea surface." to "including the elevated biomass burning layer as well as any lower-level aerosol near the sea surface."

Page 9, Line 11: Kaufman 1993, missing reference

Line 42: "[. . .] in the southern part of the sampling" should be correct

Page 11: lines 11-13: "The peak August and September mean ACAOD from MOD06ACAERO at the most western edge of the region, near 0°E, is shifted to the east in the subsampled MOD06ACAERO." – unclear of which product you are referring to

Lines 15-18: this sentence is too long "The largest [. . .] monthly statistics"

Page 12, line 20-22: "[. . .] large variability is noticeable, especially when contrasting the far-from-coast versus profiles along the routine diagonal". High variability of? Also, I thought far-from-coast is along the routine diagonal, thus this sentence is not clear.

Page 14, line 5: there is no Section 3.2.3

Line 12: Sakaeda et al., 2011: This study does not analyses the aerosol-cloud distance (longitudinal gap) from spaceborne lidar. Could you replace your reference with the right one?

Page 15, line 15: add reference for the MODIS AOD 12 years climatology

Line 23: "For the full column AOD, the AE470/865 is much lower than its above cloud counterpart". It is not much lower, since the value of the mean difference between ACAOD and AOD equals 0.4, which is within the uncertainty range (standard deviation of ACAOD is up to 0.4 – Figure 7).

Line 32: You could add a discussion of the following sentence: “The ACAOD from 4STAR also has a peak closer to shore than the MODIS AOD climatology mean and median (both fine and coarse mode), with differences near coast between 4STAR ACAOD measurements and MOD06ACAERO retrievals.”

Page 16, lines 10-12: “From these airborne measurements, we have seen that the ACAOD is lower than expected from current MODIS satellite retrievals during the measurement period (by 0.05-0.08) and from a 12-year climatology (by 0.04).” Unclear sentence. Do you mean “. . .compared to current MODIS satellite retrievals. . .”?

References:

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