Journal: AMT
Title: Consistency of aerosols above clouds characterisation from A-Train active and passive measurements
Author(s): Lucia T. Deaconu et al.
MS No.: amt-2017-42

Authors want to thank Referee #1, Hiren Jethva, for his contribution and interactive comments. The answers to specific questions (in red) are addressed below in blue, while the modifications made in the manuscript are in green.

Q1. The first thing that struck me while reviewing the paper was that authors didn't include the CALIOP-based "color ratio" retrievals, which have been shown to perform best in the smoke-above-cloud environment (Chand et al., 2007, 2008, Jethva et al., 2014), in the present analysis. This product is currently not available in the public domain. However, I strongly recommend authors to take Duli Chand (PNNL), the developer of color ratio based ACAOT retrieval, on board and include the results at least for the Southeastern Atlantic region where smoke particles above the cloud decks are observed during biomass burning period (July-Aug-Sep). We, the OMI aerosol group at NASA Goddard, have also developed a near-UV based method to detect and retrieve ACAOT on a global scale [Torres et al., 2012; Jethva et al, 2016]. The method has been applied to the entire record of OMI on board Aura platform (Oct 2004 to present). The resultant OMACA (OMI above cloud aerosols) product was made available freely to public in July 2016 and can be accessed at the Aura validation web portal: https://avdc.gsfc.nasa.gov/pub/data/satellite/Aura/OMI/V03/L2/OMACA/
The paper is already length and full of POLDER-CALIOP results. However, if space and time permit, I would suggest the author carry out a comparison between POLDER and OMI on a monthly scale for the Southeastern (smoke) and North Atlantic Ocean (dust) regions in order to check the consistency between the two passive retrieval techniques. Regional maps of ACAOT from POLDER/OMI for a season (say July-Aug-Sep) would be sufficient.

Author's response: The main objective of this paper was to assess the consistency of the POLDER polarisation method developed at LOA laboratory (the data are available now on ICARE Data Center site: http://www.icare.univ-lille1.fr/archive?dir=PARASOL/PM-L2.v3.01/). We chose to check the consistency between the retrievals of POLDER polarisation method and DRM because both methods are retrieving AAC properties above the same type of cloudy scenes (optically thick and homogeneous liquid water clouds) and, most of all, they are sensitive to all types of particles (scattering or absorbing aerosols, fine or coarse ones). This is not the case for CRM, which can operate mostly for absorbing aerosols.
The aim of this paper was to analyse the two methods in more detail (from regional to global comparisons, relationships between AAC AOT retrievals and cloud properties), in order to better understand their limitations and sensitivities to different situations. We do not attempt to make an assessment of other available AAC products and methods because the time and space do not permit to make a more detailed evaluation.
Nonetheless, as both CRM and OMACA products are now available, we would be very interested in a future collaboration with Mr. Duli Chand and the OMI aerosol group, that will allow a detailed assessment and inter-comparison of the methods developed for retrieving absorbing aerosol properties above clouds. It would be

likely that such work would have a very different focus than this one and it would be more fruitful to conduct such a work in a follow on paper.

Modifications: No modifications have been added to the manuscript.

Q2. While the paper presents the results of the comparison in detail and also investigates the causes of differences between different techniques, a discussion on how to actually 'validate' the satellite-based ACAOT against the airborne 'truth' is completely missing. I am sure the authors are aware of the ongoing ORACLES (https://espo.nasa.gov/oracles) and CLARIFY-2016 field campaigns that are specifically aimed to provide us in situ and remote sensing measurements of the optical and microphysical properties of aerosols above cloud over the Southeastern Atlantic Ocean. These datasets will be extremely valuable in validating not just the satellite based ACAOT retrievals but also for verifying and improving the aerosol and cloud models assumed in the inversion. A paragraph or two is needed that describes the validation plan for the CALIOP and POLDER above-cloud aerosol products.

Author's response: These data will be indeed extremely valuable. The authors are well informed on the completed and ongoing field campaigns focused on understanding the aerosol-cloud-radiation interaction off the coast of African continent, especially the field measurements located in the South Atlantic Ocean. In fact, AEROCLO-SA (AErosol RadiatiOn and CLOuds in Southern Africa) is the French contribution to an international project that reunites researchers from other campaigns, called COLA: CLARIFY-ORACLES-LASIC-AEROCLO, which will attempt to characterize smoke properties from in situ and remote sensing. The AEROCLO-SA campaign is scheduled for August-September 2017 and will be based in Walvis Bay, Namibia. The LOA laboratory will deploy the OSIRIS instrument, which is the airborne prototype of the 3MI instrument (Multi-viewing, Multi-channel, Multi-polarisation) that is currently developed by ESA and EUMETSAT and will be launched on a Post-EPS platform in 2022. OSIRIS and 3MI instruments are based on the concept of the POLDER instrument; therefore a validation of POLDER polarisation method used for aerosol above cloud retrievals is envisioned. The aircraft is also expected to follow the satellite CALIOP/CALIPSO and simultaneously measure AAC properties. This will allow the validation of the DRM retrievals. Moreover, an airborne sun-photometer PLASMA and a lidar will also be onboard the aircraft that will provide useful information on aerosols above clouds properties. Therefore, the authors have already envisaged the validation plan for the CALIOP DRM and POLDER above-cloud aerosol products, by using the combined retrievals from the AEROCLO-SA.

Modifications: Page 21, Line 23 – 26: Airborne measurements are extremely useful in providing information on aerosols above cloud properties. Several ongoing and planned airborne field campaigns will attempt to characterize the properties of biomass burning aerosols over the Southern Atlantic Ocean (Zuidema et al., 2016). Planned measurements from the French Falcon 20 aircraft, equipped with a high-resolution lidar, an airborne sun-photometer and a POLDER-like sensor, will notably be considered for a future validation of CALIOP DRM and POLDER above-cloud aerosol products.

Specific comments:

1. Page 1 Line 11: CALIOP/CALIPSO (in order to be consistent with POLDER/PARASOL)

Author's response: Thank you. We added your observation in the text.

Modifications: Page 1, Line 11: A-Train sensors CALIOP/CALIPSO and POLDER/PARASOL

2. Page 1, Line 12: "We compare" would be the better word. "...between the results derived from the active and passive measurements"

Author's response: Thank you for the contribution.

Modifications: Page 1, Line 12: The main objective is to analyse the consistency between the results derived from the active and the passive measurements. We compare the Aerosol Optical Thickness (AOT) of above optically thick clouds (Cloud Optical Thickness (COT) larger than 3) and their Ångström Exponent (AE).

3. Page 1, Line 19: "Four and a half year of data..."

Author's response: We modified the text

Modifications: Page 1, Line 19: Four and a half years of data are studied over the entire globe […]

4. Page 1, Line 27: "...between the CALIOP operational method and POLDER is found to be low"

Author's response: We modified the text

Modifications: Page 1, Line 27: [...] between the CALIOP operational method and POLDER is found to be low

5. Page 2, Line 7: "...by modifying the cloud reflectivity and micro-physics"

Author's response: We modified the text

Modifications: Page 2, Line 7: […] by modifying the cloud reflectivity and microphysics, […]

6. Page 2, Line 11: "..but also on the reflective properties of underlying surface"

Author's response: Thank you. We added the observations in the text

Modifications: Page 2, Line 11: but also on the reflective properties of underlying surface

7. Page 2, Line 20: "..as a source of uncertainty for the estimation of all-sky DRE of aerosols"

Author's response: Thank you.

Modifications: Page 2, Line 20: […] of all-sky DRE of aerosols.

8. Page 2, Line 21: Sundar Christopher's group at UAH has published a paper on measurements based estimation of DRE. Here is the citation. Please include it. Feng, N., and S. A. Christopher (2015), Measurement-based estimates of direct radiative effects of absorbing aerosols above clouds. J. Geophys. Res. Atmos., 120, 6908–6921. doi: 10.1002/2015JD023252.

Author's response: We added the new reference

Modifications: Page 8, Line 21: […] using satellite observations (Chand et al., 2009; Feng and Christopher, 2015; Meyer et al., 2013).

9. Page 2, Line 24: "...remains a subject of large uncertainty"

Author's response: We modified the text, thanks.

Modifications: Page 2, Line 24: […] remains a subject of large uncertainty.

10. Page 2, Line 30: "...when aerosol layers are in contact with the top layers of cloud deck"

Author's response: We modified the text

Modifications: Page 2, Line 30: […] when the aerosol layers are in contact with the top altitude of the cloud deck.

11. Page 3, Line 4: "Passive imagers offer larger spatial coverage"

Author's response: Thank you. We modified the text.

Modifications: Page 3, Line 4: We changed "Passive techniques have large spatial coverage" into "Passive imagers offer larger spatial coverage […]"

12. Page 3, Line 7-8: These claims are referred to the cloud-free aerosol retrievals. Torres et al. (2012) paper introduced the near-UV technique to quantify the AOD above cloud, not SSA.

Author's response: We corrected in the text

Modifications: Page 3, Line 7-9: The main retrieved optical properties for aerosols, in "clear-sky" conditions, are the Aerosol Optical Thickness (AOT) and the Ångström Exponent (AE), which is a parameter indicative of the particles size (Kaufman et al., 2002). Recent methods also allow retrieving the aerosol Single Scattering Albedo (SSA) over clear-sky ocean scenes (Torres et al., 2013; Waquet et al., 2016).

We added Kaufman et al., 2002 in the list of reference.

13. Page 3, Line 23: "..situated underneath the aerosol layer as the background"?

Author's response: Both POLDER polarisation method and DRM consider the cloud as background for retrieving the AAC properties. The word "target" for the water clouds situated underneath an aerosol layer was previously used by Hu et al., (2006); Jethva et al., (2014); Waquet et al., (2013b).

Modifications: Page 3, Line 23: No modifications have been made

14. Page 4, Line 24: "...with an aim of assessing the consistency (and lack thereof) between the two independently derived ACAOTs.

Author's response: Thank you.

Modifications: Page 4, Line 24: Jethva et al. (2014) performed an intercomparative analysis of the ACAOT retrieved with the aforementioned methods in order to assess the consistency (or lack of) between the two independently derived ACAOTs.

15. Page 4, Line 32: Chand et al. (2008, 2009) and Jethva et al. (2014) have shown that the CALIOP-based CRM works best for fine mode absorbing particles. Two of the regions selected in this study, i.e., Southeastern Atlantic Ocean and Siberian wildfire areas are known for the presence of strongly absorbing biomass burning aerosols. The CRM retrieval owing to its suitability in these environments would give a better estimate of aerosol loading above clouds. Note that CRM, similar to the DRM, does not require to assume specific aerosol and cloud microphysical model. I strongly recommend the author to take Duli Chand, the developer of CRM, on board and include the ACAOT retrievals for the inter-comparison.

Author's response: Please refer to the answer addressed at question Q1.

Modifications: Page 4, Line 32: No modifications have been made in the manuscript.

16. Page 6, Line 1-2: "Lastly, AOT retrieved at 6 km spatial resolution are aggregated to 18 km x 18 km spatial grid."

Author's response: We modified the text

Modifications: Page 6, Line 1-2: Lastly, the AOT retrievals at the 6 km × 6 km spatial resolution are aggregated to 18 km × 18 km spatial grid.

17. Page 6, Line 2-3: Restricting the standard deviation in AOT to 0.1 would likely mask the actual spatial inhomogeneity in the above-cloud aerosol field.

Author's response: Indeed, we assume that the aerosol layer is homogeneous under the 18x18 km^2 pixel. Please see Waquet et al., (2013b) for more details regarding the POLDER algorithm and the filters used to improve the quality of the products.

Modifications: Page 6, Line 2-3: No modifications have been made

18. Page 8, Line 6: "the developers of"

Author's response: We modified the text

Modifications: Page 8, Line 6: […] the developers of the Synergized Optical Depth of Aerosols and ICE clouds […]

19. Page 10, Line 8: "The A-train satellite pass through close orbits within several minutes"

Author's response: We added A-Train in the phrase

Modifications: Page 10, Line 8: The A-train satellite pass […]

20. Page 10, Last paragraph: CALIOP Aerosol Layer Product ALay uses the signal at 532 nm to locate the layers of aerosols. In the presence of heavy loading of absorbing aerosols, such as observed over the Southeastern Atlantic Ocean, the signal at 532 attenuates rapidly due to aerosol absorption effects within the top layers of aerosols. This results in diminished magnitudes of backscatter as the lidar light penetrates further into the aerosol layer. After some depth of penetration, the signal falls within the noise levels and therefore rejected for any meaningful interpretation. This is precisely the reason why standard CALIOP above-cloud AOD product at least over the Southeastern Atlantic Ocean is underestimated compared to other A-train based above-cloud AOD retrievals [Jethva et al., 2014]. I believe in such cases, the CALIOP ALay product would show a greater number of separated ("detached") layers than mixed layers.

Author's response: The authors considered the limitations of CALIOP layer detection products and agree with the reviewer's observations, as we have already highlighted in the manuscript at Page 12, Line 25. The choice of 500 m between the cloud top altitude and aerosol base altitude was made as a compromise between keeping enough data to be statistically meaningful and choosing a large enough distance to minimize the possible contact between the layers.

As a future perspective, the lidar signal measured at 1064 nm could be use to refine our classification of « attached » and « detached » cases. « Apparent » false detached cases (due to strong attenuation at 532 nm)

could be identified by controlling the attenuated backscattering coefficient measured at 1064 nm between the aerosol layer base and the cloud top.

Modifications: We added in the text at Page 20, Line 23: Nevertheless, some of the *detached* cases considered in our study, mainly the ones associated with optically thick smoke layers, are likely to be incorrectly classified as *detached*. As a future perspective, these misclassified detached cases (due to strong attenuation of the CALIOP 532 nm signal) could be detected by controlling the CALIOP 1064 nm signal, which was shown to provide more sensitivity to the entire vertical extent of these absorbing aerosol layers.

21. Page 12, Line 3-4: It would be extremely useful to also show the CALIOP 1064-nm backscatter curtain plot for these events. I expect the 1064-nm results would show deeper extent aerosols in the vertical column.

Author's response: Figure 1.R1 presents the attenuated backscatter profiles for 1064 nm and 532 nm for the three case studies presented in the article. We observe a larger geometrical thickness of the aerosol layer situated above the clouds for Namibian biomass burning, when we consider the CALIOP 1064 nm retrievals. Also, the aerosol layer appears mostly detached from the underlying cloud at 532 nm, while at 1064 nm we notice more contact area. Nonetheless, for this peculiar case (13 August 2006), we still have a very good agreement between DRM and POLDER (see Table 1 in the manuscript). The Saharan desert dust and the Siberian biomass-burning cases present small differences of backscatter profile between the 532 nm and 1064 nm.

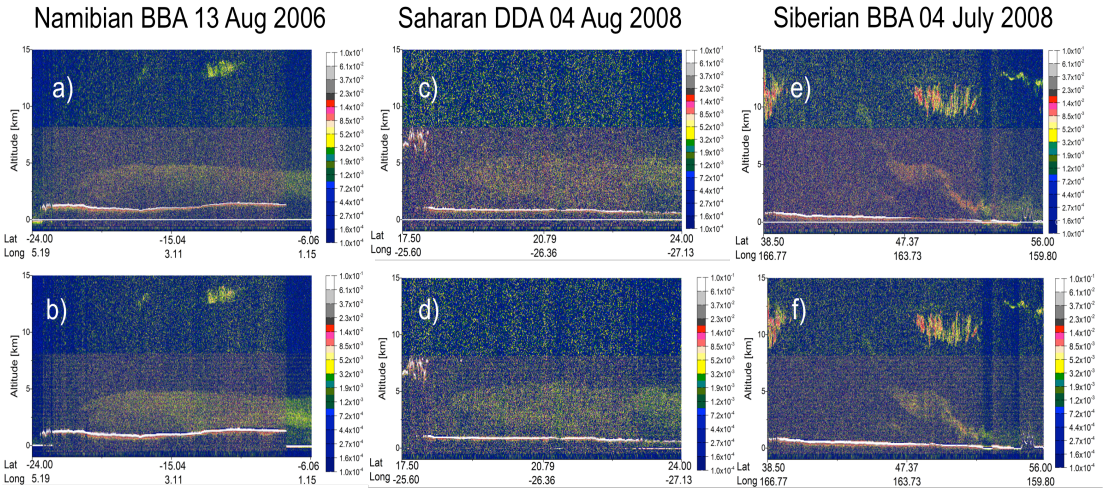


Figure 1.R1: The first row of the panel shows the CALIOP attenuated backscatter coefficients at 532 nm, while the second row presents the CALIOP attenuated backscatter coefficients at 1064 nm for three case studies: a), b) African Biomass-Burning (BBA) aerosols above clouds on 13 August 2006; c), d) Saharan dust (DDA) on 4 August 2008 and e), f) Siberian biomass-burning aerosols over the Okhotsk Sea on 3 July 2008.

Modifications: Figure 1 from the manuscript was modified in order to include the CALIOP attenuated backscatter coefficients at 1064 nm.

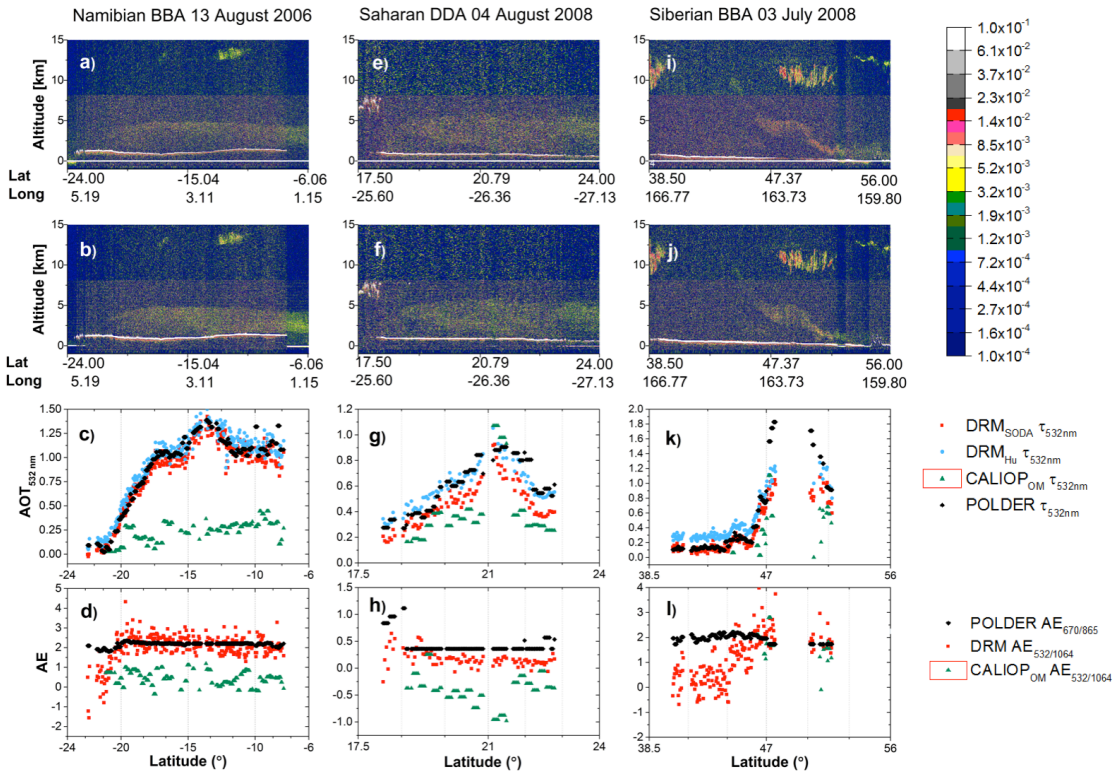


Figure 1. The first row of the panel shows the lidar CALIOP attenuated backscatter coefficients at 532 nm (km-1 sr-1) and the second row presents the CALIOP attenuated backscatter coefficients at 1064 nm for three case studies: African biomass-burning (BBA) aerosols above clouds on 13 August 2006 ((a), (b), (c), (d)), Saharan dust (DDA) on 4 August 2008 ((e), (f), (g), (h)) and Siberian biomass-burning aerosols over the Okhotsk Sea on 3 July 2008 ((i), (j), (k), (l)). For these cases, the above-cloud AOT at 532 nm and the Ångström exponent (AE) as a function of latitude, measured with several techniques are displayed.

Page 12, Line 16-18: According to the CALIOP vertical profile at 532 nm of the biomass-burning case (Fig. 1a), the cloud top is at around 1.5 km and the aerosol layer is located between 3 and 5 km. The 1064 nm backscatter profile (Fig. 1b) exhibits an aerosol layer with a larger vertical extent, showing up more potential contact area with the underlying cloud.

22. Page 17, Line 9: Please refer to Meyer et al. [2015] paper which documents the uncertainty in the cloud effective radius retrievals due to the presence of absorbing aerosols over cloud. I guess it is <5%.

Here is the citation: Meyer, K., S. Platnick, and Z. Zhang (2015), Simultaneously inferring above-cloud absorbing aerosol optical thickness and underlying liquid phase cloud optical and microphysical properties using MODIS. J. Geophys. Res. Atmos., 120, 5524–5547. doi: 10.1002/2015JD023128.

Author's response: Thank you for the new reference.

Modifications: Page 17, Line 10-13: For example, Haywood et al. (2004) found biases of ± 2 µm for r_{eff} in case of strong dust events above clouds and Meyer et al., (2015) found an increase in the r_{eff} monthly mean of 2% in case of above-cloud absorbing aerosols.

23. Page 17, Line 10-14: The effect of cloud effective radius on DRM(SODA) could be larger for moderate to high aerosol loading ("detached" cases).

Author's response: Thank you. We modified the following in the text.

Modifications: Page 17, Line 10-11: […] 2% in case of above-cloud absorbing aerosols. We expect that large biases on r_{eff} could be possible in case of high aerosol loading for *detached* cases.

24. Page 20, Line 7: "Aerosols as a solution within the cloud droplets..."

Author's response: We have corrected the text

Modifications: Page 20, Line 7: Aerosols as a solution within the cloud droplets […]

25. Page 20, Line 13-14: What is the overall uncertainty in DRM-retrieved AOT when lidar ratio changed from say 19 sr to 25 sr or 29 sr.

Author's response: By modifying the lidar ratio from 19 sr (corresponding to DRM_{Hu}) to 25 sr, the retrieved AOT values decreases by around 0.1 In order to illustrate this, we computed the AOT at 25 sr for the Namibia biomass-burning study case from 4 August 2008 in Figure. 2.R1.

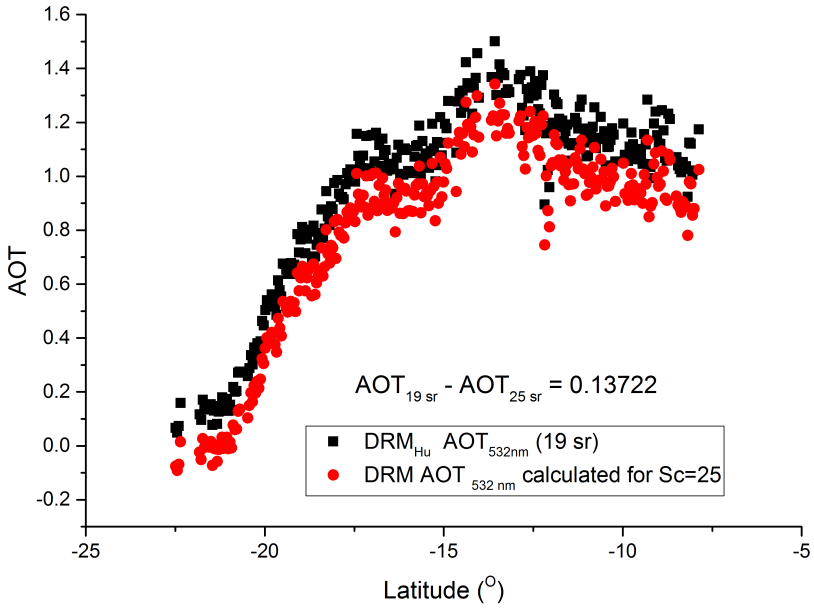


Figure 2.R1 presents the above-cloud AOT at 532 nm for DRM_{Hu} (19 sr) and DRM at 25 sr in function of latitude for 4 August 2008, for a case of biomass-burning off-coast of Namibia.

Modifications: No changes were made in the manuscript.

26. Page 20, Line 28: "...with respect to other methods."; Line 32: "impacts"

Author's response: Thank you. We corrected the text

Modifications: Page 20, Line 28: […] with respect to other methods.[…] impacts the AOT […]

27. Page 21, Line 23: Do author think that the imaginary part of the refractive index is also important and can affect the retrieval accuracy?

Author's response: Yes, as demonstrated in Figure 2.R1, the inclusion of soot within the droplets may significantly modify their imaginary refractive index and impact the DRM method. The polarisation method is primary sensitive to the scattering property of the aerosols and the operational method (Waquet et al., 2013)

retrieves the scattering AOT. The assumption made for the imaginary part of the refractive index does not much perturb the retrieval of the AOT. Please see the sensitivity study in Peers et al. (2015) for more details.

Modifications: No modifications have been added.

28. Figure 9. Aerosols above cloud is a regional phenomenon. The global plot of attenuated backscatter shown in Figure 9 is not a representative of what is happening over the prominent region of AAC i.e., over the Southeastern Atlantic Ocean, the tropical Atlantic Ocean off the coast of Sahara, South-East Asia (springtime agricultural fires), and northern Arabian Sea (dust above cloud). The author should focus on these regions and create similar plots, particularly for the Southeastern Atlantic Ocean, tropical Atlantic Ocean.

Author's response: The authors agree with the reviewer's observations. Nonetheless, as the global number of *attached* situations in our database is quite low compared to the *detached* cases (1277, respectively 21866 at 5 km resolution at a global scale – see Figure 9), in the manuscript we have decided to present the global result for statistical reasons. In order to address the review's question, we generated the median and average backscatter coefficients for the South Atlantic Ocean region, for a period of six months (May to October) during 4.5 years (2006-2010). Figure 3.R1 presents the results. As in the global situation, we notice that for *detached* cases the aerosol and cloud backscattering profiles can be easily distinguished in both the median and mean profiles. For the attached cases the continuous transition in the backscatter signal between the cloud top and the above atmosphere is still present (like in the global case). The results confirm our previous analysis made for global observations.

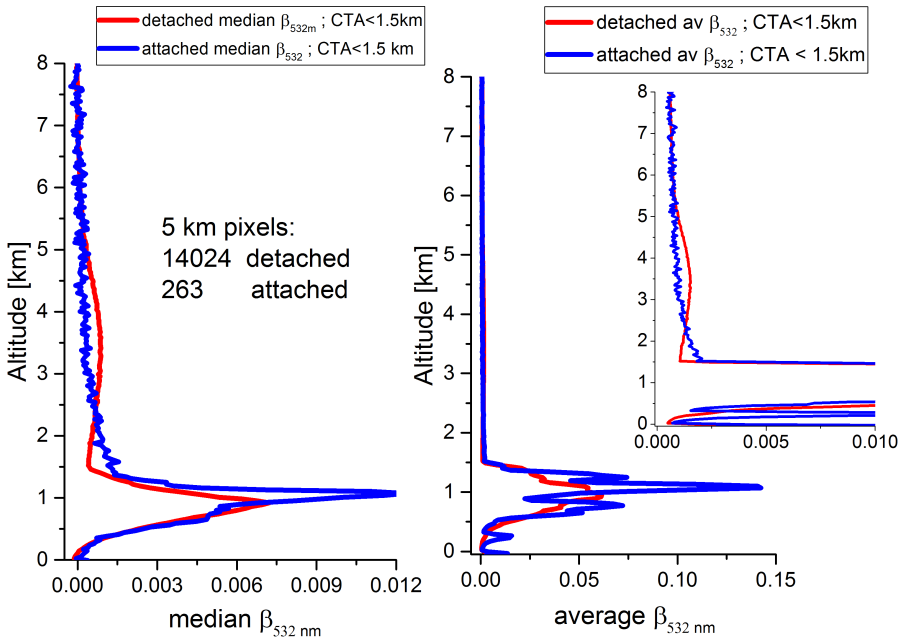


Figure 3.R1. Median (a) and averaged (b) backscatter profiles ($km^{-1}sr^{-1}$) for aerosol layer detached from the cloud layer (red) and aerosols attached to the top of the cloud (blue), for the period May-October from 2006 to 2010, over the South Atlantic Ocean region. The data was filtered for a cloud top altitude lower than 1.5 km.

Modifications: No changes were added in the manuscript.

29. Figure 10 should be recomputed in accordance with the CALIOP backscatter results for above regions. Figure 10. This simulation is a bit confusing. The cloud layer is located between 0 and 1 km and two of four aerosol simulation cases (blue and red) locate aerosols within the clouds. The third case (orange) has an aerosol layer with half the depth merged into the clouds and the half on top of the cloud. The fourth one is truly a detached case.

Author's response: There is no need to recompute the simulation for different aerosol and cloud altitudes, because the polarised radiance computed at 865 nm is not affected neither by the vertical position of the aerosol, nor by the vertical position of the cloud layer (i.e. no difference in the AOT retrievals), as long a there is no contact between the aerosol and cloud.

For a cloud top altitude of 1 km and an aerosol layer of AOT = 0.25, we considered three different situations:

1. Aerosol layer detached from the cloud top (between 1.25 and 1.75 km): The retrieved AOT corresponds to the simulated AOT; the polarised signal is well simulated.
2. Aerosol layer attached to the cloud top (between 0.75 and 1.25): The polarised signal coming the aerosols located within the cloud layers is partially attenuated due to cloud multiple scattering.
3. Aerosol layer located in the upper part of the cloud (between 0.5 and 1km): We would expect complete attenuation of the polarised signal coming from the aerosols. However, Figure 10 shows that there is still a remaining polarized signal observed at forward scattering angles coming from the aerosols located in the upper part of the cloud. An additional signal coming from the aerosol located within the cloud would lead to an overestimation of the POLDER above cloud AOT. This signal could explain the situations where POLDER polarisation method retrieves nonzero AOT values whereas DRM method retrieves an AOT close to 0.

Modifications: We added at Page 19, Line 22: Note that the polarised radiance at 865 nm is not affected by the vertical position of the aerosol layer as long as there is no contact between the aerosol and the cloud.

Authors want to thank Referee #2 for his contribution and interactive comments. The answers to specific questions (in red) are addressed below in blue, while the modifications made in the manuscript are in green.

In this study, the authors compare and analyse the consistency of the AOT and AE retrievals above clouds from different passive and active remote sensing instruments (namely CALIOP and POLDER). Comparisons are conducted in the framework of a) three case studies corresponding to an African biomass-burning event, a Saharan dust event and a Siberian biomass-burning event; b) a regional scale analysis, over South Atlantic Ocean, North Atlantic Ocean and North Pacific Ocean for a period of six
months in 2008 and c) a global scale analysis for different vertical layer distributions for the period 2006−2010.
The paper is well written and well structured which makes it enjoyable to read in spite of the very complex methodological concepts and tidious analyses it conveys. The paper is well suited for AMT and certainly deserves publication, after addressing a minor point. I am aware that the authors only claim to check the consistency between the products, but a comparison of the products to actual airborne measurements made during field experiments off the coast of the Africa continent would be very good. Since the mid 2000s, a large number of airborne campaigns have attempted to characterize
aerosols properties off-shore of West Africa (SAMUM 1 & 2, DODO, DABEX, AMMA, NAMMA, ICE-D, SALTRACE, DACCIWA) and southern Africa (SAFARI, and recently ORACLES). At least the authors should explain why they have not attempted to do so.

Author's response: Thank you. As you mentioned in the comment, this paper is focused on assessing the consistency between the two methods: POLDER and DRM methods developed for aerosols above clouds. As explained in the first part of this review (see responses to reviewer #1, Q2), the comparison of these methods with non-collocated measurements from different previous field campaigns would have a small contribution for the purpose of this paper. Nonetheless, we added few sentences in the manuscript mentioning the existence of ongoing field campaigns (please see the responses to reviewer 1) that includes dedicated validation flights.

Modifications: Page 21, Line 23 – 26: Airborne measurements are extremely useful in providing information on aerosols above cloud properties. Several ongoing and planned airborne field campaigns will attempt to characterize the properties of biomass burning aerosols over the Southern Atlantic Ocean (Zuidema et al., 2016). Planned measurements from the French Falcon 20 aircraft, equipped with a high-resolution lidar, an airborne sun-photometer and a POLDER-like sensor, will notably be considered for a future validation of CALIOP DRM and POLDER above-cloud aerosol products.

We added Zuidema et al., 2016 in the list of references.

Authors want to thank Referee #3 for his contribution and interactive comments. The answers to specific questions (in red) are addressed below in blue, while the modifications made in the manuscript are in green.

1. Page 9, lines 3 and 4: "This ensures a minimum level of attenuation of the signal from the surface." I believe the authors want an adequate level of attenuation of the surface return, rather than a minimum (i.e.low) level of attenuation, otherwise the following statement that "The intent of this threshold is the same as the previous criteria" is not coherent.

Author's response: Indeed, we made a mistake. Thank you.

Modifications: We wrote: adequate level of attenuation of the surface return.

2. Page 9, Line 20: The calibration of SODA is not very well explained. Presumably η_c comes from Eq. (3) and provides a way to estimate η_{calibr} when there are aerosols above clouds using the layer integrated depol. The implication of Eq. (8), that the global mean value of Sc is assumed to be 19 sr should be stated. How the binning by latitude is done should also be stated since otherwise substituting equation (8) into (9), at face value, suggests that Sc,lat =19.

Author's response: We added several clarifications.

Modifications: Page 9, Line 20-28: As a first step, SODA calibrates the multiple scattering to depolarization relationship for nighttime data on a monthly basis. The data of interest are based on Eq. (2) and can be written as

$$\eta_{geo} = \frac{1}{2\times 19\times \gamma'_{water,parallel}} \quad (7)$$

where $\gamma'_{water,parallel}$ is the parallel-integrated backscatter coefficient. This equation provides a direct measurement of the multiple scattering coefficient of liquid water clouds (η_{geo}) when their lidar ratio is constant. The constant value of 19 sr used in the SODA algorithm is based on Hu et al. (2006) who found a lidar ratio equal to 19.1 ± 0.21 sr when the 41 droplet size distributions of Miles et al. (2000) are used as inputs of a Mie scattering code.

For all opaque liquid water clouds defined with the above criteria, SODA then compares the direct measurement of the multiple scattering coefficient (η_{geo}) and the theory (η_c) to find the second order polynomial that best fit the data in the least square fit sense. This defines the calibrated multiple scattering coefficient (η_{calibr}):

$$\eta_{calibr} = fit\left[\eta_{geo}(\eta_c)\right] = A\eta_c + B\eta_c^2 \quad (8)$$

As a second step, SODA calculates the apparent lidar ratio $S_{c,lat}$ of all opaque liquid water clouds as a function of each degree of latitude and for both 532 and 1064 nm. This procedure is done separately for daytime and nighttime data.

3. Page 9, Line 24: Providing ranges for A, B and $S_{c,lat}$ if not figures, would be helpful to the reader to understand how much the data is being corrected for potential calibration and other issues.

Author's response: We provided the median value of $S_{c,lat}$ to give the reader a sense of the correction. As the SODA algorithm saves this value, it should be at the same time statistically correct and easy for the reader to grasp, even if more than 4 years of data are considered.

Concerning A and B, as they compensate each other, providing their value and their variations would probably confuse the reader. For the 4.5 years considered here, the median is 1.39 for A and -0.66 for B so the reader

could easily be lead to believe that the correction is in the order of 30 to 40%. For a typical range of multiple scattering coefficient between 0.3 to 0.5 (see Hu et al. 2007), the values become 0.35 to 0.52, respectively.

Following your comment and a similar comment by M. Vaughan, we agree that it is important to improve the reader understanding and we added modified the text accordingly.

Modifications:

Page 9, Line 26: This procedure allows us to use a relationship between depolarization and multiple scattering that fits the observation. Using Eq. 3 instead of Eq. 8 would create an aerosol optical depth bias that would typically range between 0.02 and 0.08. Although this is not always significant, this correction is necessary as the resulting ACAOD bias does correlate with the clouds microphysical properties. This is particularly undesirable as the link between aerosol and cloud microphysical properties is an active topic of research

Page 10, line 2: For the 4.5 years of data we considered in this study, the median of $S_{c,lat}$ for the nighttime data is 19.36 sr, which is interestingly close from the theoretical value determined by (Hu et al. 2006). For daytime data, $S_{c,lat}$ is systematically higher and with a median of 20.64 sr. The systematic daytime/nighttime difference could be geophysical. However, it is premature to reach such conclusion until all nighttime/daytime differences in the CALIPSO data have been addressed.

4. This is also relevant to p.16 lines 25,26 where it is stated that "The DRM algorithm assumes a constant lidar ratio of 19 sr, independent of the cloud droplet effective radius." It was previously stated that the latitudinal dependence in $S_{c,lat}$ allowed for calibration and actual variations in S_c. What is true?

Author's response: You are correct, this statement is partially true only for the original DRM_{Hu} and when no further calibration is performed which is not how this methodology should be used. In order to improve clarity, we modified this sentence:

The DRM algorithm assumes a constant lidar ratio of 19 sr, whatever the cloud droplets effective radius is. In order to evaluate the accuracy of this approximation, we recalculated the DRM_{SODA} AOT_{532nm} taking into account the dependence of S_c on r_{eff}.

Modifications: Page 16, Line 25-30: The DRM algorithm does not use an explicit parameterization of the lidar ratio as a function of the cloud droplets effective radius. An implicit dependence will arise from the latitudinal correction (Eq. 9) when clouds at different latitudes will exhibit different microphysical properties. In order to understand the usefulness of adding an explicit parameterization, we recalculated the DRM_{SODA} AOT_{532nm} taking into account the dependence of S_c on r_{eff}. This calculation assumes a simplified and unique droplet size distribution and is based on MODIS r_{eff} retrieval. We expect that even if the cloud droplet size distribution is variable (Miles et al. 2000) and that the ACAOD creates a bias in r_{eff}, the results will still provide guidance for future algorithm development.

5. Page.18, Line 20: "The background reaches 0.09 in AOT at 532 nm." Is this the extrapolated POLDER optical depth for the undetermined cases? If so, say so.

Author's response: Yes, it is the extrapolated AOT at 532 nm.

Modifications: Page 18, Line 20: The background of the extrapolated POLDER AOT at 532 nm for the undetermined cases reaches 0.09.

6. Page 20, Line 9, 10: "imaginary part of 0.0001", the authors should really provide an estimate of the volume mixing ratio of black carbon needed to provide such an imaginary index. It seems unlikely that such an imaginary index is plausible for droplets of 10 μm or more given the required mass of carbon.

Author's response: Erlick (2006) calculated the range of visible refractive indices and single-scattering albedos at 550 nm in case of water with soot inclusion for different droplets size. In this study, the complex refractive indices are considered equal to $1.333+i1.96\times10^{-9}$ for water and $1.750 + i0.440$ for soot, respectively. The volume fractions of soot, f, varies for different dilute solutions $f=10^{-4}$, $f=0.01$ and $f=0.1$. In case of water with soot inclusion, the refractive index for $f=10^{-4}$ is around $1.33 + i4.5\times10^{-5}$, while for $f=0.01$ the water/soot refractive index is around $1.34 + i3.8\times10^{-3}$. In our study, we made the choice to use an intermediate value of complex refractive index, equal to $1.337+i10^{-4}$, which roughly corresponds to an intermediate volume fraction of $f=10^{-3}$. Therefore, we consider our choice to be realistic and in agreement with bibliography.

Modifications: Page 20, Line 9: We used an imaginary part of 0.0001 for the complex refractive index of the droplets. This might simulate, for instance, the properties of brown clouds contaminated by absorbing aerosols. The chosen value is in agreement with the refractive indices given for water containing soot inclusions with volume fractions ranging between 10^{-4} and 10^{-2} (Elrick, 2006).

We added the reference in the list of references:

Authors want to thank Mark Vaughan for his contribution and interactive comments. The answers to specific questions (in red) are addressed below in blue, while the modifications made in the manuscript are in green.

1. Page 3, Line 11 referring to (Winker et al., 2003): this is gray literature; suggest citing Winter et al., 2010, BAMS instead (doi:10.1175/2010BAMS3009.1)

Author's response: Thank you. We added the new reference

Modifications: Page 3, Line 11: […] satellite provides high-resolution vertical profiles of aerosols and clouds (Chand et al., 2008; Winker et al., 2010).

2. Page 3, Line 14 referring to (Vaughan et al., 2009; Winker et al., 2009): more appropriate references would be Omar et al., 2009 (doi:10.1175/2009-JTECHA1231.1) and Young and Vaughan et al., 2009 (doi:10.1175/2009JTECHA1228.1)

Author's response: We added the new reference

Modifications: Page 3, Line 14: […] assuming an aerosol lidar ratio (extinction to backscatter) (Omar et al., 2009; Young and Vaughan, 2009).

3. Page 3, Line 16 referring to (Winker et al., 2007): Hunt et al., 2009 (doi:10.1175/2009JTECHA1223.1)

Author's response: We added the new reference

Modifications: Page 3, Line 16: […](i.e. the ratio of the two orthogonal polarization signals) (Hunt et al., 2009)

4. Page 6, Line 9 referring to (Winker et al., 2003): this is gray literature; suggest using Winker et al., 2009 (doi:10.1175/2009JTECHA1281.1) or Winker et al., 2010 (doi:10.1175/2010BAMS3009.1) instead

Author's response: We added the new reference

Modifications: Page 6, Line 9: The CALIPSO lidar (CALIOP) is a frequency-doubled Nd:YAG laser, dual-wavelength, dual-polarization, elastic backscatter lidar (Winker et al., 2009).

5. Page 6, Line 12 referring to (Winker et al., 2009): CALIOP layer detection reference is Vaughan et al., 2009 (doi:10.1175/2009JTECHA1228.1)

Author's response: Thank you. We added the new reference

Modifications: Page 6, Line 12: […] the feature and layer detection scheme (Vaughan et al., 2009).

6. Page 6, Line 21: cite references or reword (e.g., 'can be' a substantial source, rather than 'is')

Author's response: We modified the text.

Modifications: Page 6, Line 21: It should be noted that an incorrect assumption for the lidar ratio could be a source of substantial errors in the AOT retrieved with this method.

7. Page 7, Line 11, Eq. (1): incomplete; see feature finder ATBD (https://www-calipso.larc.nasa.gov/resources/project_documentation.php) or Vaughan et al., 2010 (doi:10.1029/2009JD013086) the equation given here will overestimate the integrated backscatter at 532 nm

Author's response: This is a reference to (Eq. 1) of (Hu et al., 2007). We agree with your comment and we understand you call it incomplete, as it does not contain as much detailed information as an ATBD would, however this pioneering paper defined the science basis of the depolarization method. Note that SODA does not contain an explicit correction of the Rayleigh scattering contribution because of the high scattering ratio of liquid water clouds. The underlying philosophy of this first version of the AOD over liquid water cloud dataset is to keep the algorithm simple. This helps for error tractability and it reduces potential algorithm artefacts that could end up creating a higher uncertainty that the second order error they are aimed at correcting (i.e. the amount of bugs scales non-linearly with algorithm complexity).

Modifications: Page 7, Line 10: When Rayleigh scattering contribution has been corrected for, the definition of γ'_{water} is given by the following equation:

Page 9, Line 2: Note that SODA corrects the molecular attenuation above the cloud, but does not contain an explicit correction of it within the cloud because of the high scattering ratio of liquid water clouds. Nonetheless, the molecular contribution is statistically taken into account by the calibration procedure.

8. Page 7. Line 16, Eq. (2): reference Platt, 1973 (doi:10.1175/1520-0469(1973)030<1191:LAROOC>2.0.CO;2) or Platt, 1979 (doi:10.1175/1520-0450(1979)018<1130:RSOHCI>2.0.CO;2)

Author's response: Thank you. We added the reference in the text.

Modifications: Page 7, Line 14: […] the lidar equation simplifies to the following definition, expressed as a function of the lidar ratio (S_c) and layer effective multiple scattering factor (η_c) (Platt, 1979):

9. Page 7, Line 21, Eq. (3): add definition for integrated depolarization ratio

Author's response: We added the definition in the text.

Modifications: Page 7, Line 19: η_c, […] is strongly related to the cloud depolarization ratio δ' (defined as the ratio of the parallel and perpendicular polarization signals), since multiple scattering processes tend to depolarize light.

10. Page 7, Line 22: should be either "molecular and gaseous attenuation" or "molecular attenuation and gaseous absorption"

Author's response: We modified the text.

Modifications: Page 7, Line 22: After γ'_{water} is corrected for molecular and gaseous attenuation […]

11. Page 8, Line 1: also does not require accurate (any!) layer detection for the overlying aerosol layer

Author's response: Thank you for the contribution. We modified the text accordingly.

Modifications: Page 8, Line 2: […] and does not require accurate layer detection for the overlying aerosol layer in order to estimate the AOT integrated over the atmospheric column.

12. Page 8, Line 14: what does 'significant' mean in this context? 1%? 10%? 100%?

Author's response: Sassen and Zhu (2009)found a bias in the linear depolarization of cirrus clouds of around 30% (0.1/0.34).

Modifications: we modified this sentence accordingly: […] a significant source of uncertainty. Previous research (Sassen and Zhu, 2009) found a bias in the linear depolarization of cirrus clouds of around 30%.

13. Page 9, Line 5: can you translate this into an effective overlying optical depth (e.g., if the surface integrated attenuated backscatter in clear air is X, what optical depth does it take to reduce it to 7.5e-6?)

Author's response: The reflectance of the ocean surface return is depending on wind strength so the corresponding COD that can be detected above threshold is variable. It's typically between an optical depth 4 to 5 during nighttime and 1.5 and 2.2 during daytime. Because of the increased noise, this filter has a limited usefulness during daytime but it is not deemed critical because of the redundancy between the different filters used here.

Modifications: Page 9, Line 6: We added the following sentence in the text: This corresponds to a cloud optical thickness of around 2 during daytime and 4-5 during nighttime, which is when this filter is the most useful.

14. Page 9, Line 16, Eq. (6): should use different threshold for day and night in order to account for very different contributions from solar background noise also, to mitigate noise effects and guard against the inclusion of poorly calibrated or otherwise unsuitable data, some minimum value of the integrated backscatter should also be imposed.

Author's response: In general, we avoided to introduce a day/night dissymmetry in the algorithm. The filter discussed in Page 9, Line 5 is an exception because the filter redundancy (one among three) is built to avoid algorithm artifacts.

Future prototypes of SODA would probably rely more on the CALIPSO products instead of developing independent custom thresholds. However, as in general it is interesting to introduce some redundancy, it could be a consideration to keep this filter with the modifications you suggested: a different day/night threshold along with a minimal value. To not overwhelmed the reader with detail of future releases but still clarify the matter, we completed the text.

Modifications: Page 9, Line 16: As this filter introduces more aerosol contamination during daytime (similar to Josset et al. 2010, Fig. 4), it could be desirable to consider the shot-to-shot CALIOP cloud mask for future version of the algorithm as SODA already uses this information for the scene classification flag.

15. Page 9, Line 18: why not use the molecular lidar ratio given in the CALIPSO L1 ATBD?

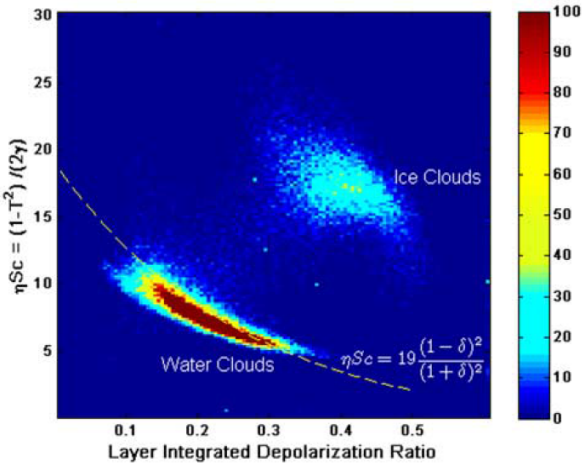
Author's response: It is mostly to simplify the algorithm. It avoids the use of a number with more significant figures (and adjust the threshold factor, i.e modify the 1.5 factor). This reduces the likelihood of a bug due to a typo when several people are involved in the development of the algorithm. SODA uses the same numbers than CALIPSO for the algorithm over the ocean so it could be a consideration to use the same number here.

Modifications: No modifications have been added in the text.

16. Page 9, Lines 20-26: this approach seems to homogenize the eta-delta relation, and I'm not sure that's valid. for example, I've seen (unpublished!) simulations suggesting that eta can change as a function of droplet size distribution (though perhaps the CALIOP FOV is too large to effectively resolve these differences?)

Some more discussion on the rationale for taking this approach and the possible pitfalls involved would be helpful here.

Author's response: The multiple scattering relationship used in SODA is indeed calibrated on the observed properties of dense liquid water clouds. This procedure avoids the issue visible in Hu, 2007 (GRL), Fig. 2 (see below) where the theoretical relationship given in Hu, 2007 (white line) does not exactly fit the data centroid. Using the proposed modified relationship avoids to create an aerosol optical depth bias which would correlate with the clouds microphysical properties. It would be particularly undesirable because we would knowingly keep an error in the dataset, which would look like a geophysical feature that interest researchers (i.e. the effect of aerosols on cloud microphysical properties).



There are alternative ways to implement this correction that we mentioned in the manuscript (Hu et al. 2007a) but it assumes a specific underlying cause (transient response) whereas the approach used in SODA is more general.

The published papers do not point towards a clear reason for the discrepancy between theory and data so we cite the different possibilities and the associated (limited) references. If the issue is linked to a variability of the eta/delta relationship as a function of the microphysical properties of the cloud, our approach would statistically address it but as it is inconsistent with the published results of Cao et al. (2009), it would be premature to include such a discussion. However we can clarify the consequences of not using this approach and we added and replaced lines 20 in the manuscript:

Modifications: As previously mentioned, even if the multiple scattering–depolarization relationship has been confirmed by laboratory experiments (Cao et al., 2009), the relationship between the multiple scattering factor and the depolarization by the cloud shows a systematic deviation from the theory. It has to be corrected, as it would introduce a bias in aerosol optical depth with the particularly undesirable trait to correlate with cloud microphysical properties. As a first step, SODA calibrates the multiple scattering to depolarization relationship for nighttime data on a monthly basis. The data of interest are based on Eq. (2) and can be written as:

$$\eta_{\text{geo}} = \frac{1}{2\times 19\times \gamma'_{\text{water,parallel}}} \qquad (7)$$

where $\gamma'_{\text{water,parallel}}$ is the parallel-integrated backscatter coefficient. This equation provides a direct measurement of the multiple scattering coefficient of liquid water clouds (ηgeo) when their lidar ratio is constant. The constant value of 19 sr used in the SODA algorithm is based on (Hu et al., (2006) who found a lidar ratio equal

to 19.1 ± 0.21 sr when the 41 droplet size distributions of (Miles et al., (2000) are used as inputs of a Mie scattering code.

For all opaque liquid water clouds defined with the above criteria, SODA then compares the direct measurement of the multiple scattering coefficient (η_{geo}) and the theory (η_c) to find the second order polynomial that best fit the data in the least square fit sense. This defines the calibrated multiple scattering coefficient (η_{calibr}):

$$\eta_{calibr} = fit\left[\eta_{geo}(\eta_c)\right] = A\eta_c + B\eta_c^2 \quad (8)$$

This procedure allows us to use a relationship between depolarization and multiple scattering that fits the observation. Using Eq. (3) instead of Eq. (8) would create an aerosol optical depth bias that would typically range between 0.02 and 0.08. Although this is not always significant, this correction is necessary as the resulting ACAOD bias does correlate with the clouds microphysical properties. This is particularly undesirable as the link between aerosol and cloud microphysical properties is an active topic of research.

As a second step, SODA calculates the apparent lidar ratio $S_{c,lat}$ of all opaque liquid water clouds as a function of each degree of latitude.

17. Page 9, Line 28: a very good idea for the V3 data, especially during daytime (but unnecessary for V4). Was a SODA recalibration also done at 1064 mm?

Author's response: Yes, SODA was recalibrated for both 532 and 1064 nm.

Modifications: To clarify we added the following sentence Page 9, Line 28: […] as a function of each degree of latitude and for both 532 and 1064 nm.

18. Page 10, Line 9: what is this 'nearest pixel approximation' based on? footprint location? is cloud altitude considered in the collocation scheme?

Author's response: For the *nearest pixel approximation* in CALTRACK product, the center of MODIS and POLDER pixels at different resolutions (1x1 km^2 for MODIS, 6x6 km^2 and 18x18 km^2 for POLDER) is collocated; with the closest CALIOP 5 km midpoint footprint. Within the algorithm, the cloud altitude is corrected for high-resolution pixels (such as MODIS 1x1 km^2), but in the case of POLDER 18x18 km^2 pixels, the effect of parallax can be neglected as the distance of a parallax correction falls within the POLDER pixel.

Modifications: No modifications have been added.

19. Page 10, Line 13: this is retrieve then average vs. average then retrieve. why? in general, more stable and more accurate results are achieved with the latter approach. Please justify your choice of the former.

Author's response: The authors agree with your comment. As mentioned in answer to reviewer #1, comment 7, we assume that the aerosol layer is homogeneous under the 18x18 km^2 pixel. Please see Waquet et al., (2013b) for more details regarding the POLDER algorithm and the filters used to improve the quality of the products. For the moment, the SODA product is only available at 333 m. An algorithm is under development at ICARE data center, which will allow retrieving an average SODA product at 5 km with a homogeneity flag.

Modifications: No modifications have been added.

20. Page 10, Line 15: how is this accomplished? how do you estimate attenuation between 30 km and 10 km? or do you assume it's effectively zero? please clarify.

Author's response: Thank you for this question. The explanation was not clear enough in the text. In fact we eliminate data related to aerosol altitudes higher than 10 km (single-layer and multi-layer situations), in order to confine as much as possible the possible cirrus contamination. Also, high aerosol altitudes can suggest extreme events, which do not make in the aim of this paper. Therefore, we don't need to make any assumption of the attenuation above 10 km. Likewise for the cloud altitude limit of 5 km.

Modifications: Likewise, we eliminated from our data analysis all situations in which the aerosol top altitude exceeds 10 km. This maximal value should be sufficient, since most of the biomass burning and dust aerosol layers are typically observed between 0.5 and 4.0 km over ocean (Torres et al., 2013).

21. Page 10, Line 24: line 26 on page 6 says that you're using aerosol base and top heights from the CALIOP level 2 layer products. however, for highly absorbing aerosols the base detections are clearly in error. This can be seen by comparing the attenuated backscatter images to the vertical feature mask images for cases of dense smoke over opaque stratus. In these cases, the CALIOP layer detection algorithm frequently fails to detect the full vertical extent of the layer. (this has been noted in several prior publications.). How does this failure influence the partitioning of the aerosol layers into attached, detached, and undetermined? My guess is that optically thick smoke layers will largely (but incorrectly) be classified as detached (or maybe get excluded all together).

Here's a nighttime example (and note that the problem is much worse for daytime data, when the background noise further degrades the CALIOP detection efficiency). Between ~6°S and ~16°S, the depolarization and 1064 nm attenuated backscatter plots clearly indicate that the aerosol layer is in contact everywhere with the cloud. However, according to the layer detection results, the aerosol layer is only intermittently in contact with the cloud.

https://www-calipso.larc.nasa.gov/products/lidar/browse_images/show_detail.php?s=production&v=V4-10&browse_date=2013-08-28&orbit_time=01-29-00&page=2&granule_name=CAL_LID_L1-Standard-V4-10.2013-08-28T01-29-00ZN.hdf

the above URL shows version 4 results. version 3 results are here:

https://www-calipso.larc.nasa.gov/products/lidar/browse_images/show_detail.php?s=production&v=V3-30&browse_date=2013-08-28&orbit_time=01-29-00&page=2&granule_name=CAL_LID_L1-Standard-V4-10.2013-08-28T01-29-00ZN.hdf

Author's response: We are aware of the limitations of CALIOP layer detection products. In the detached cases, the choice of 500 m between the cloud top altitude and aerosol base altitude was made as a compromise between keeping enough data to be statistically meaningful and choosing a large enough distance to minimize the possible contact between the layers. Nonetheless, we agree that our «detached» cases indeed include some remaining contact situations.

"How does this failure influence the partitioning of the aerosol layers into attached, detached, and undetermined?"

That will impact the results of our linear regression in terms of slope, correlation coefficient (R^2) and offset. But, that will not change our main conclusion: a good agreement is found between the DRM_{SODA} and POLDER above cloud AOTs when we remove the attached cases from our analysis, whereas the correlation between the two products largely decreases when we keep the attached cases.

In order to strengthen this conclusion, we compared the DRM_{SODA} and POLDER AOTs at 532 nm over a period of 4.5 years (June 2006 to December 2010) for two other situations:

a) all « valid » AAC measurements, which includes attached, detached and intermediate cases (aerosol base altitude between 100 and 500 m above the cloud top)

b) detached cases, same as in the manuscript (see figure 4 in the manuscript), but the minimal distance between the aerosol base altitude and the cloud top height must be larger than 1.5 km instead of 500 meters.

When taking into account all the "valid" situations (attached, detached and intermediate cases), the correlation between the two methods is low (R^2 = 0.48, see Fig. 1.SC-a). When we consider the detached scenario with a minimal "cloud-top-aerosol-base" distance of 500 meters, a broader agreement is found (R^2 = 0.68, slope = 0.84, intercept = -0.03 - see figure 4 in the manuscript). When we consider the detached scenario with a minimal "cloud-top-aerosol-base" distance of 1.5 km instead of 500 meters (as shown in Fig. 1.SC-b), the agreement between the two methods further improves: the slope is closer to 1. (0.86 instead of 0.84, intercept = -0.03) and the correlation coefficient increases (R^2 = 0.70 instead of 0.68). These results show that the agreement between the DRM and POLDER AOTs progressively improves as the apparent distance found by CALIOP between the cloud top height and the aerosol base height increases.

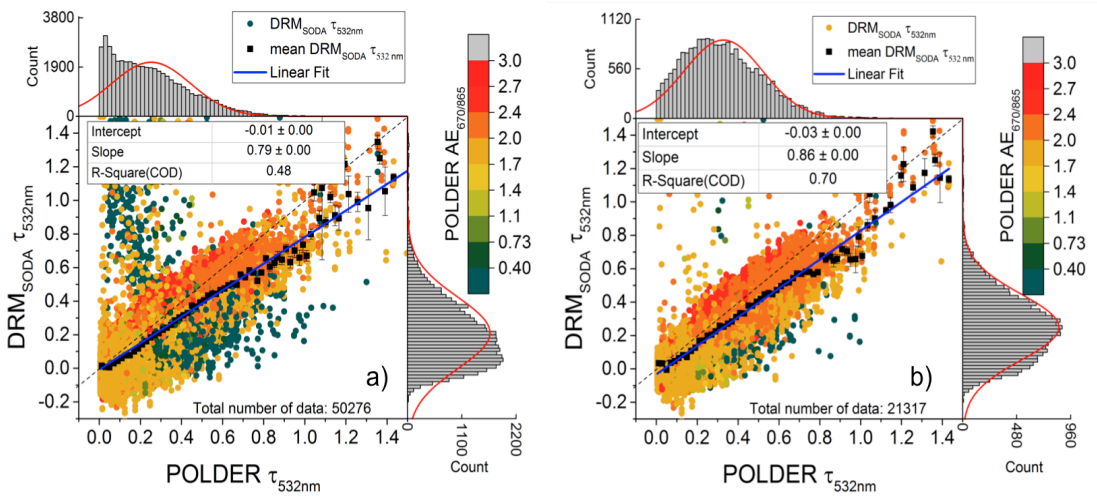


Figure 1.SC. Global comparison over a period of 4.5 years (June 2006 to December 2010) for (a) all valid AAC situations (in which the base of the aerosol layer penetrates the cloud maximum 50 m) and (b) situations where the aerosol layer is well separated from the cloud top with a minimum distance of 1.5 km between the two layers The color scale represents the corresponding POLDER AE computed between 670 and 865 nm. The histograms present the data distribution. The error bars in figures (a), (c) and (e) represent the standard error of the mean (SEM).

As a future perspective, the lidar signal measured at 1064 nm could be use to refine our classification of « attached » and « detached » cases. « Apparent » false detached cases (due to strong attenuation at 532 nm) could be identified by controlling the attenuated backscattering coefficient measured at 1064 nm between the aerosol layer base and the cloud top.

Modifications: We added in the text at Page 20, Line 23: Nevertheless, some of the *detached* cases considered in our study, mainly the ones associated with optically thick smoke layers, are likely to be incorrectly classified as

detached. As a future perspective, these misclassified detached cases (due to strong attenuation of the CALIOP 532 nm signal) could be detected by controlling the CALIOP 1064 nm signal, which was shown to provide more sensitivity to the entire vertical extent of these absorbing aerosol layers.

22. Page 10, Line 27: not sure what this means? if the cloud is truly opaque, what possible evidence could you have for the presence of aerosols underneath? Likewise, what criteria are used to distinguish 'aerosol touching ' from 'aerosol within'?

Author's response: The authors do not claim to have any evidence of aerosols within or under the cloud. Nonetheless, after the collocation process (nearest pixel approximation), we can encounter situations where we have AAC AOT retrieved with POLDER that corresponds to CALIOP aerosol altitudes (top and/or base) lower than the cloud top altitude. This can be explained by the presence of fractional cloud cover within the super-pixel POLDER and different resolutions used in the CALTRACK product. Therefore, we classify these cases as "within" or "under" and they are eliminated from the study.

When the base altitude of the aerosol layer is situated between 100 m above the cloud top and 50 m below the cloud top, the data falls under the "attached" category.

When the base of the aerosol layer is below 50 m from the cloud top, the data falls into the "within" category.

There are no selection criteria for the aerosol top altitude, except that it has to be higher than the cloud top altitude in all cases.

Modifications: The so-called "attached cases" correspond to situations where the aerosol layer touches the top of the beneath cloud layer. For these cases, we assume that the vertical distance of the aerosol bottom altitude from cloud top altitude must be lower than 100 meters, without penetrating the cloud layer for more than 50 meters. […] Aerosol layers with the base altitude within a distance between 100 and 500 meters above the cloud layer are considered too uncertain and are excluded from our study. We also removed the situations for which the detected CALIOP aerosol top and/or bottom altitudes are located below the cloud top, assuming that these data are highly uncertain.

23. Page 11, Line 1: this needs more explanation. For example, suppose the CALIOP layer detection algorithm fails to detect an aerosol layer that is readily visible in the CALIPSO images. Would this be an example of an 'undetermined' layer? Also, what is meant by 'missing data'?

Author's response: As for the previous question, the answer rests upon the different resolutions of CALTRACK products. If we retrieve valid POLDER AAC AOTs, but CALIOP layer detection algorithm fails to identify the aerosol or cloud altitude for the midpoint footprint used to collocate the data (even if the aerosol layer is readily visible in the CALIPSO images), then we treat the data as undetermined. We chose to keep these data in our analysis as they cover the majority of POLDER AAC detected cases, even if CALIOP classifies them as invalid. In these situations, the fill values of -9999 used for the aerosol or cloud altitudes in the ALay and CLay products are the "missing data" referred to in the manuscript.

Modifications: The third category, "undetermined", corresponds to situations for which the vertical position of the aerosol or cloud layer is not identified by the CALIOP layer detection algorithm (i.e. missing data), even though POLDER AAC AOT retrievals are valid. We chose to keep these data in our analysis as they cover the majority of POLDER AAC detected cases with a non-negligible AOT (even if CALIOP classifies them as invalid or noise), as the purpose of the paper is to better understand the differences between the methods.

24. Page 11, Line 7: a map showing the boundaries of these three regions would be very helpful

Author's response: Figure 2.SC presents the global map on which the regions used in the manuscript are emphasized with a rectangle of different color.

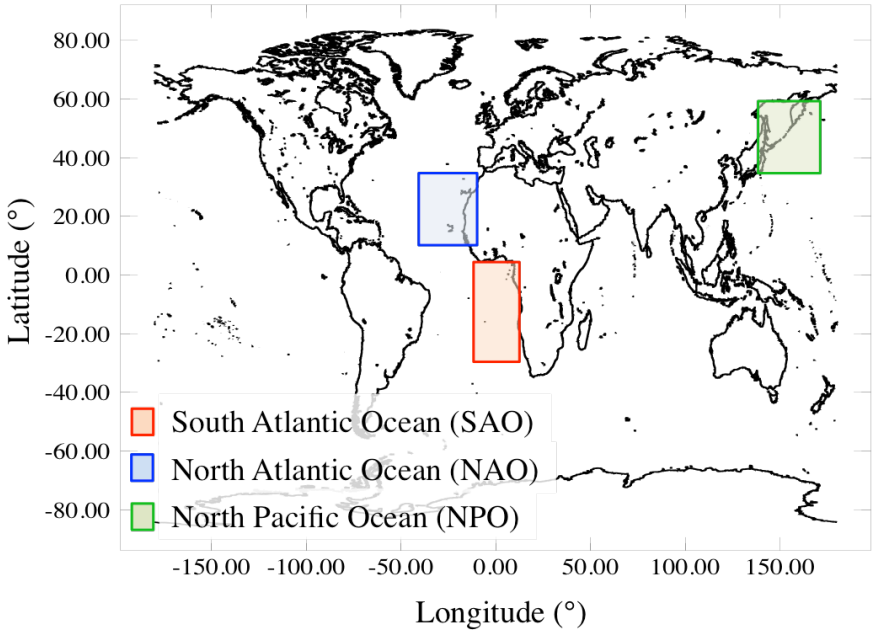


Figure 2.SC: The map presents the latitudinal and longitudinal boundaries of the three regions used in the regional study (Sect. 3): South Atlantic Ocean (SAO) extends from 30° S to 5° N and 12° W to 14° E, North Atlantic Ocean (NAO) is situated between 10 to 35° N and 10 to 40° W and North Pacific Ocean (NPO) is located between 35 to 60° N and 140 to 170° E.

Modifications: We added this new figure in the manuscript.

25. Page 11, Line 21: based on the text in this paragraph, you're partitioning the retrievals by cloud type and not necessarily by cloud properties (e.g., optical depth)

Author's response: Thank you for the observation.

Modifications: Cloud types and their associated optical and microphysical properties are expected to be different in these three regions (Warren et al. 1988).

26. Page 12, Line 21: add references

Author's response: We added the new reference

Modifications: […] which is characteristic for fine mode particles (Dubovik et al., 2002).

27. Page 12, Line 23: techniques

Author's response: Thank you for the correction.

Modifications: […] three other techniques.

28. Page 12, Line 27: when using V3 data, this is more likely to be 1064 calibration error; 1064 calibration is much improved in V4

Author's response: Thank you for this contribution.

Modifications: The selection of an inappropriate aerosol model (i.e. aerosol lidar ratio S_a for biomass burning, varies between 70 ± 28 at 532 nm and 40 ± 24 sr at 1064 nm (Cattrall et al., 2005; Omar et al., 2005)) or the significant biases found in the V3.01 CALIOP 1064 nm calibration, might also contribute to the underestimation of the AOT for this case study.

29. Page 13, Lines 15-18. I suspect this is due to a combination of a bad model (for dust in CALIOP V3.x analyses, S = 40 @ 532, S = 55 @ 1064) and maybe bad calibration.

Author's response: Thank you for this contribution. We added the following in the text.

Modifications: […] two other algorithms. These low values of AOT and AE may be explained once more by a biased CALIOP calibration at 1064 nm combined with an unfitted model selection (i.e. for desert dust, S_a is equal to 40 ± 20 sr at 532 nm and 55 ± 17 sr at 1064 nm (Cattrall et al., 2005; Omar et al., 2005)).

30. Page 13. Line 26: add references

Author's response: We added the new reference

Modifications: which indicates that coarse mode particles are predominant (Dubovik et al., 2002).

31. Page 15, Line 4: I'd really like to see a more detailed description of the criteria used to distinguish between the "attached", "detached" and "undetermined" categories. Around line 25 on page 6 the authors state that they use the aerosol base and top altitudes reported in the CALIOP data products. However, the CALIOP layer detection scheme is known to have difficulties determining the full vertical extent of absorbing layers with high lidar ratios (e.g., smoke). Some recognition of this fact should be included, along with some discussion of its possible impacts on the authors' conclusions.

Author's response: Please refer to the answer provided for question 21.

32. Page 15, Line 23: not

Author's response: Thank you for the correction.

Modifications: […] there is not much correlation […]

33. Page 16, Line 4: 'obviously have' instead of 'have obviously'

Author's response: Thank you for the correction.

Modifications: […] hypotheses […] obviously have their limitations.

34. Page 17, Line 18: Hu et al., 2007 (doi:10.1109/LGRS.2007.901085) suggests that DRMHu would likely fail in these cases; e.g., see figure 3 in the region below 39°

Author's response: We took your contribution into account.

Modifications: […] to the surface contribution. Hu et al., (2007a) noticed the surface impact on DRM_{Hu} when the underlying cloud is not entirely opaque, therefore the assumptions used in the DRM_{Hu} AOT retrievals are not met.

35. Page 17, Line 29: this “calibration” implicitly assumes that the multiple scattering characteristics of all water clouds are essentially identical. I'd be happier if more evidence was offered to support this assumption.

Author’s response: We hope that the explanations we offered for comment question 16, Page 9, Line 23 clarify this calibration procedure.

Modifications: No modifications have been made to the text.

36. Page 19, Line 21: See my earlier comment on page 10, line 24. Assuming I properly understand how you distinguish between attached and detected cases, I suspect that the primary difference between attached and detached layers lies in (a) the above-cloud aerosol loading combined with (b) the above-cloud lidar ratio. For high aerosol loading, the CALIOP layer detection scheme is much more successful at identifying the full vertical extent of an aerosol layer when the aerosol lidar ratio is low. The high loading plus high lidar ratio cases (e.g., dense smoke or pollution) are the most difficult cases, because the attenuation within the layer drives the magnitude of the (uncorrected!) attenuated scattering ratios below 1.00, and hence below the layer detection threshold. This in turn leads to the premature identification of layer base. (To do: insert comparison of 532 nm and 1064 nm attenuated backscatter or attenuated scattering ratio profiles to illustrate the point…)

Author’s response: The primary difference between the attached and detached cases lies in the detected CALIOP aerosol base altitude. Therefore, in case of high aerosol loading above-cloud and a high aerosol lidar ratio, the base of the aerosol layer can be misidentified. This can lead to cases of contact within our “detached” class.

Figure 3.SC presents the attenuated backscatter profiles for 1064 nm and 532 nm for the three case studies presented in the article. We can observe larger geometrical thickness of the aerosol layers situated above the clouds for Namibian biomass burning, when retrieved at 1064 nm. Also, the aerosol layer appears mostly detached from the underlying cloud at 532 nm, while at 1064 nm we notice more contact area. Nonetheless, for this particular Namibian biomass-burning case of 13 August 2006, we have a very good agreement between DRM and POLDER (see Table 1 in the manuscript). The Saharan desert dust and the Siberian biomass-burning cases present small differences of backscatter profile between the 532 nm and 1064 nm.

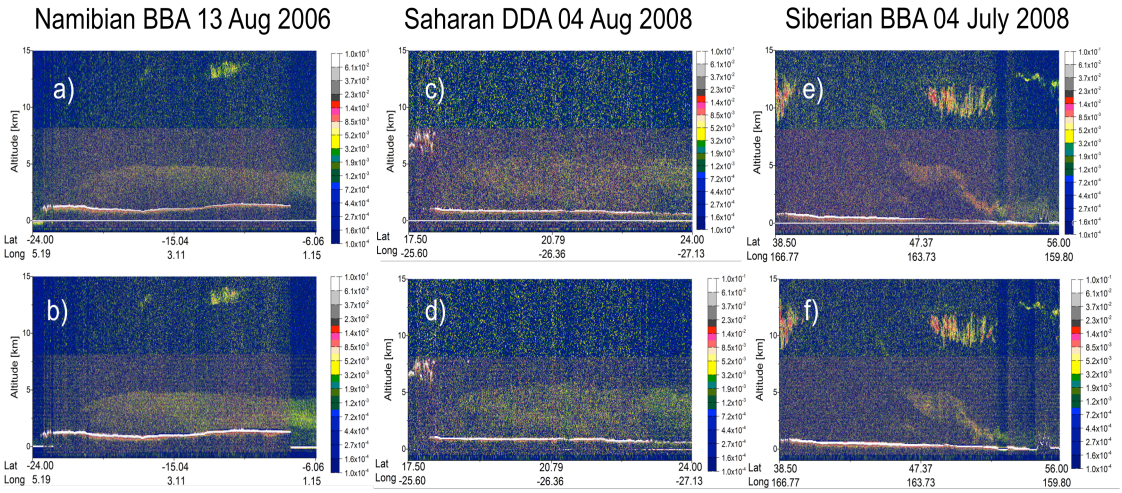


Figure 3.SC: The first row of the panel shows the CALIOP attenuated backscatter coefficients at 532 nm, while the second row presents the CALIOP attenuated backscatter coefficients at 1064 nm for three case studies: a), b)

African Biomass-burning (BBA) aerosols above clouds on 13 August 2006; c), d) Saharan dust (DDA) on 4 August 2008 and e), f) Siberian biomass-burning aerosols over the Okhotsk Sea on 3 July 2008.

Modifications: Figure 1 from the manuscript was modified in order to include the CALIOP attenuated backscatter coefficients at 1064 nm.

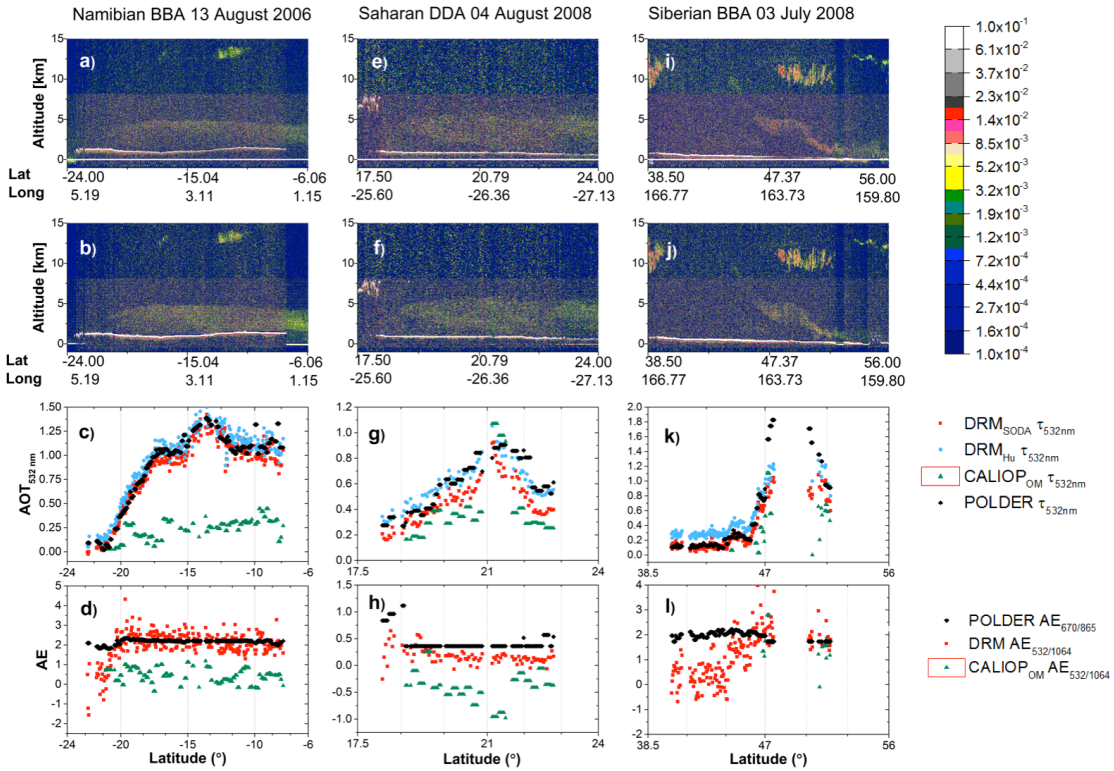


Figure 1: The first row of the panel shows the lidar CALIOP attenuated backscatter coefficients at 532 nm (km-1 sr-1) and the second row presents the CALIOP attenuated backscatter coefficients at 1064 nm for three case studies: African biomass-burning (BBA) aerosols above clouds on 13 August 2006 ((a), (b), (c), (d)), Saharan dust (DDA) on 4 August 2008 ((e), (f), (g), (h)) and Siberian biomass-burning aerosols over the Okhotsk Sea on 3 July 2008 ((i), (j), (k), (l)). For these cases, the above-cloud AOT at 532 nm and the Ångström exponent (AE) as a function of latitude, measured with several techniques are displayed.

Page 12, Line 16-18: According to the CALIOP vertical profile at 532 nm of the biomass-burning case (Fig. 1a), the cloud top is at around 1.5 km and the aerosol layer is located between 3 and 5 km. The 1064 nm backscatter profile (Fig. 1b) exhibits an aerosol layer with a larger vertical extent, showing up more potential contact area with the underlying cloud.

37. Page 34, Line 1, Fig. 1: attenuated backscatter coefficients

Author's response: Thank you for the correction.

Modifications: lidar CALIOP attenuated backscatter coefficients at 532 nm

38. Page 42, Fig. 9: it would be helpful to add another line showing molecular attenuated backscatter coefficients

Author's response: Figure 4.SC. presents the molecular attenuated backscatter, along with mean values of total attenuated backscatter for the attached and detached cases.

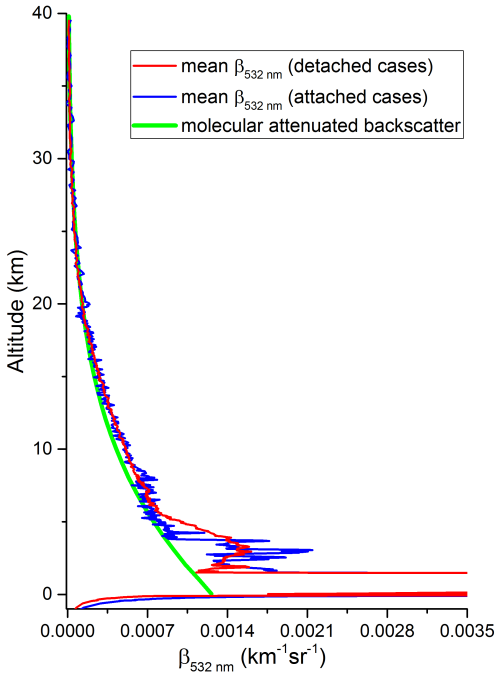


Figure 4.SC. Molecular attenuated backscatter and mean total attenuated backscatter for attached and detached cases, for global measurements from 2006 to 2010.

Modifications: We modified Figure 9 in the manuscript. See question below.

39. Page 42, Fig. 9: for both attached and detached cases, the surface is clearly visible in both the median and mean plots, suggesting strongly that the clouds selected were not 100% opaque

Author's response: Thank you for this observation. The explanation for the surface signal is related to the CALTRACK product. Starting from CALTRACK 5 km with POLDER and DRM valid AOT retrievals, we searched for the corresponding CALIOP 333 m backscatter profiles. The different resolutions of the methods could justify the detected surface signal at 333 m resolution, as fractioned/ heterogeneous cloud covers could not be detected under the aggregated MODIS resolution aggregated at 6x6 km^2 as used in the CALTRACK files. We also pointed out in the manuscript (Page 17, Line 18) that POLDER method and DRM are potentially less accurate for COT < 5 as the algorithm requirements are not met.

As an attempt to rectify the drawback of this procedure we filtered the MODIS COT lower than 5 and then recomputed the median and mean of the backscatter coefficients on a global scale, between 2006 and 2010. As we can observe in Figure 5.SC, the surface signal has been eliminated in the majority of the situations. Nonetheless, there are still cases that can't be filtered just by eliminating all the data with a COT smaller than 5.

Modifications: We modified Figure 9 in the manuscript:

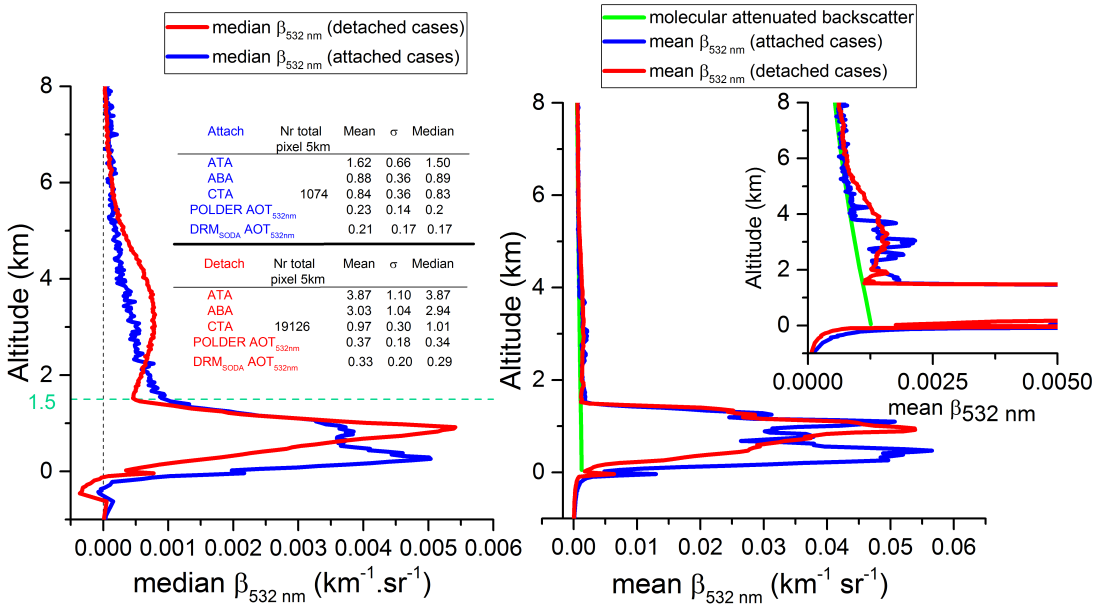


Figure 9. Median (a) and averaged (b) backscatter profiles (km^{-1} sr^{-1}) for aerosol layer detached from the cloud layer (red) and aerosols attached to the top of the cloud (blue), for a period of 4.5 years on the global scale. For comparison, the molecular attenuated backscatter profile is shown in green line. The data was filtered for a cloud top altitude lower than 1.5 km, a cloud optical thickness COT larger than 5 and for a DRM_{SODA} AOT at 532 nm is larger than 0.1. The number of 5 km horizontal resolution pixels is also shown. The mean, standard deviation (σ) and median of aerosol top altitude (ATA), aerosol base altitude (ABA) and cloud top altitude (CTA) are given for each situation. Same values are shown for POLDER AOT at and DRM_{SODA} AOT at 532 nm.

Page 19, Line 2: We only select the attached and detached cases where the cloud top altitude is below 1.5 km, the COT is larger than 5 and the DRM_{SODA} AOT_{532nm} is larger than 0.1.