Reviewer: Abhay Devasthale (abhay.devasthale@smhi.se)

Alfaro-Contreras et al analyze CALIOP and OMI data sets to investigate frequencies and trends in above-cloud aerosol (ACA) events. In the process, they derive baseline values of above-cloud AOD from CALIOP and Aerosol Index from OMI that can be used (albeit subjectively) to distinguish background noise. The ACA frequencies are then investigated using both these approaches. Overall, I think the manuscript is well written and is easy to follow logically. Scientifically, the manuscript has potential to be published in ACP after improvements. I have some comments/suggestions that authors may like to consider. I will keep it short and to the point.

We thank the reviewer for his/her constructive suggestions and comments.

Specific comments:
1) The first thing that came to my mind: why is the synergy between CALIOP and OMI is not used to further improve the work by Devasthale and Thomas (2011) that was based alone on CALIOP rather than focusing again on CALIOP separately? Considering how deep authors are into these data sets and analysis, it feels like a missed opportunity not to exploit their synergy. For example, OMI is very good in separating absorbing and non-absorbing aerosols. So wouldn't it be scientifically more insightful to do a pairwise comparison of CALIOP and OMI to at least separate smoke and dust ACA using aerosol typing from both CALIOP and OMI? After all, the radiative impact of absorbing and non-absorbing aerosols over clouds could be quite different.

Response: This is a nice suggestion. It was our intention initially. However, due to the row anomalies that affect the OMI aerosol products, OMI AI are not available along the CALIOP overpasses after 2008. This makes a pairwise comparison less feasible for the full data record. Still taking the comment, we have performed a pairwise comparison between OMI-MODIS and CALIOP analyses for the period from June 2006 through November 2008. From this collocated data set, we have further explored the observed differences between CALIOP and OMI-based ACA cloud-sky ACA differences due to cloud detection, QA settings and absorbing vs non-absorbing aerosol, which is now included in Section 4.2.

2) Authors subdivide their CALIOP data into summer and winter half years. I think it would be rather interesting, not least to bring out strong seasonality in aerosol and cloud distributions, to analyze and discuss four seasons separately (DJF, MAM, JJA, and SON). As shown in Devasthale and Thomas (2011), ACA has a strong seasonal character. The aerosol plume heights and their spatiotemporal distribution over clouds (esp. in the regions of dust outbreaks and biomass burning) differ strongly over four seasons. I can understand that authors may have had statistical robustness of samples or brevity (of space) in their mind when dividing the year into two seasons, but this is also an area where they could complement CALIOP using spatial relevance of OMI.

Response: This is a good suggestion. We do agree that certain characteristics pertaining to ACA (i.e., aerosol and cloud distributions as well as aerosol plume height) have a strong dependence

For

on seasonality as the reviewer suggested. However, CALIOP data are rather scarce, and by dividing a year into two halves as opposed to four seasons, we hope to increase the spatial and temporal sampling, as well as the signal to noise ratio of the study.

A second area of concern is that the traditional 3 month seasons split major aerosol features. For example, using Jun-July-August as distinct from Sept-October November perfectly bisects the biomass burning season for the three top regions. Similarly, Dec-Jan Feb versus March-April-May, begins to split Asia. By using bi-seasons, we can capture entire aerosol seasons in their entirety which fits better with a long term trend analysis. We Thus, we thus would like keep this part of the study unchanged.

3) *I am not sure what we could learn from the ACA trend analysis using just 7-8 years of data, except the fact that OMI trends could be spurious. I would rather remove this section altogether and focus on points 1 and 2 mentioned above, or at least compress that section. The authors themselves show that (in Figs. 8, 12 and 13) the interannual variability in aerosols and clouds for such short period is high, casting doubts on the interpretation and statistical significance of trends. I think investigating ACA frequencies using CALIOP and OMI has enough scientific merit to stand on its own rather than having add-on trend analysis.*

Response: This is a good point. As 7-8 years of CALIOP data is not sufficient we have changed the term from “trend” to “inter-annual variability”. However, we believe the temporal knowledge of variation in ACA events are worth reporting as no previous attempts have been made on this issue to our knowledge. Thus, we have not removed this section from the study. For example, several clear sky aerosol trend analyses suggest that increasing trends in AOD are found over India and Middle East. Increase in ACA frequencies are also found for the two regions from this study. Although these results are not statistically significant, it is worth noting.

4) Page 4176, lines 10-20: For climate monitoring, one needs to have sufficiently long time series and enough samples as well. But authors seem to confuse between the two (or at least it not clear to me based on how it is expressed). Agreed that passive sensors like OMI could fill spatial gaps compared to CALIOP, but the time series is nonetheless short for climate monitoring.

Response: This is a nice suggestion. We have changed the term from “trend” to “inter-annual variability”, consistent with the reasoning above.

5) When I first saw Fig. 1 without reading the corresponding text (which I agree is my mistake), I thought it probably shows a nice statistic on cloud heights during ACA events and that it is predominantly low level clouds that are capped by aerosols and that this is contrasted against average cloud height for all clouds (right column). But when I starting reading the corresponding text, the context was completely different, which threw me off a little bit. Fig. 1 is *actually shown to argue that CALIOP cannot see super thin sub visual aerosol layers (AOD<0.01). I would rather see this figure with a positive note. I can't help but ask if these "missed" sub visual aerosol layers radiatively matter?*

Response: Thanks for the suggestion. To avoid confusion, we have removed figure 1 from the paper based on the comment as well suggestions from another reviewer.

Technical comments:
There is virtually no discussion on what kind of quality control was applied to CALIOP, OMI, and MODIS datasets during analysis. There could be devil in the details. CALIOP data comes with a number of quality flags and CAD score (cloud aerosol discrimination). As we have shown in Devasthale and Thomas (2011), the ACA frequency could be quite sensitive to these flags. In your case the varying selection of these quality flags could easily introduce or explain the differences in observed ACA frequencies from CALIOP and OMI. It is probably worth checking sensitivity to these flags as well.

Response: This is a very good point. Section 2 refers to Alfaro-Contreras et al. (2014), which describes in further detail the QA applied to our data sets. From the OMI aerosol products, the OMI algorithm flags were applied to eliminate sun-glint contaminated regions and the path length, described further in Yu et al. (2012), is constrained between values of 3-7. For the MODIS cloud products, only scenes found to have a cloud fraction of 1.0 (100 % cloudy) with medium confidence or higher. For the CALIOP aerosol layer data set, we required that integrated layer AOD for the column be greater than 0 found to be of high or medium confidence, from the CAD score and Fearture Classification Flag. Additionally, this AOD layer was required to be above a cloud of COD > 0 derived from the cloud layer data set. The only restriction set on the CALIOP cloud layer data set is that the cloud optical depth be greater than zero regardless of the QA (we have added a new section, Section 4.2, to explore the effects of the QA flags as well). We have added some discussion in the text.

In addition, as suggested, we have added a whole new section (4.2) which studies the difference between OMI-MODIS- and CALIOP-based methods using collocated MODIS, OMI and CALIOP data and explores the sensitivity of QA flags to the cloud-sky ACA frequencies in details. Thanks for the suggestion.

For

Anonymous Referee #2

*Comment on "Investigating the frequency and trends in global above-*cloud aerosol *characteristics with CALIOP and OMI"*

This paper studies the capabilities and limitations of two satellite-based ACA-detection methods, CALIPSO-lidar vs. OMI UV AI, through a series of inter-comparisons and sensitivity tests. My overall impression of this paper is that many problems expose here, e.g., passive and active sensor difference for aerosol retrieval, CALIPSO daytime vs. night time difference, OMI instrument issue, have already been known or studied in the previous work. While it is interesting to see these issues manifest as problems in ACA-detection, this paper doesn't seem to shed new light on those problems. In addition, there are quite a few confusing arguments and technique issues in the study that need to be clarified.

Response: We thank the reviewer for his/her constructive suggestions and comments. We believe the paper has merits, as for the first time, the concept of above cloud aerosol baselines have been raised. While aerosol particles are always present above clouds, it is only the significant above cloud aerosol events that really matter to a variety of studies. Also, to our knowledge, the combined use of OMI, MODIS and CALIOP data for ACA studies for their full data records has not been attempted before, and thus is worth reporting.

In addition, for the revised version of the paper, we have added a pairwise comparison between CALIOP-OMI-MODIS methods, over two and half years (June 2006 – November 2008), for comparison against the original full data record (June 2006 – November 2013). Results of this analysis are indeed an effort trying to explore the difference between cloudy-sky ACA frequencies from the OMI_MODIS- and CALIOP-based methods. .

General comments: First of all, I didn't find the exact definition of above-cloud aerosol (ACA) in the paper. I understand that the definition is subjective and instrument-dependent. But there ought to be a clear definition in the paper (I'd suggest a separate and dedicated section) about what is ACA to CALIPSO and MODIS-OMI. For example, how is ACA defined and identified using CALIPSO data? The description in Section 2 is too vague. What is the CALIPSO horizontal averaging limit (5km, 20km or 80km) used in aerosol detection? And why? Is the CALIPSO result sensitive to horizontal averaging? For OMI-MODIS combination, is there requirement on sub-pixel cloud fraction, cloud optical thickness or cloud inhomogeneity? I'd like to see these questions addressed, along with tables or flowchart to show the definition and identification of ACA in the revised paper.

Response: We would like to thank the reviewer for his/her comments. As suggested, we have added Table 1 to the revised manuscript which includes definitions of ACA frequencies used in the study.

In this study, the standard CALIPSO Level 2 cloud and aerosol layer products are used. The CALIPSO Level 2 cloud and aerosol layer products include horizontal averages at all levels (e.g.

For

5, 20 or 80 km averages). While the 5km averaging detects the most “reliable” cloud and aerosol signals, the 80-km averaging locates cloud or aerosol layers with “weaker” signals. For example, the 80km averages for the cloud products are included to increase the detectability for thin cirrus clouds. We didn’t attempt to single out a single averaging scheme but rather use the combined averaging scheme as implemented in the standard CALIOP products, as we believe it is the right approach. Details of the averaging steps are included in Vaughan et al.(2009). We have included discussion in the paper.

For the OMI-MODIS collocation scheme, the collocated OMI AIs are assigned to 100% cloudy MODIS scenes (as determined by MODIS, with a COD > 0). This collocation process and methods are further described in Alfaro-Contreras et al. (2014). Thus, ideally, there is no sub-pixel cloud fraction issue. However, cloud inhomogeneity is not considered, and we leave the topic for another study. We have revised the paper to reflect the changes.

There is little discussion on the dramatic difference in footprint size and therefore sampling rate between CALIPSO and OMI. CALIPSO’s L2 product has resolution up to 333m, while OMI has a much larger footprint of 13x24km. As such, many issues could come in the way when comparing the two. For example, is it possible that some portion of OMI footprint is covered by ACA while the rest is covered by clean cloud or even clear-sky? What does the CALIPSO tell about such scene? How to reconcile the difference between CALIPSO and OMI in such case? I suspect that the difference between the two methods over the dust region may be partly caused by this. Clouds in generally are more broken over the dust region than the sub-tropical stratocumulus region. It seems possible that in such case CALIPSO would yield less ACA-detection that OMI. A related question (already mentioned above) is what horizontal averaging limit is used to screen CALIPSO data. In the operational CALIPSO layer product, the CALIPSO lidar signal may be averaged over up to 80km scale to obtain better signal to-noise ratio. Note that difference horizontal scales maybe used for aerosol and cloud layers in the CALIPSO product. What is the impact of this difference on the ACA detection using CALIPSO?

Response: This is a good question. However, we feel that there is a little confusion about the OMI-MODIS collocation process. As mentioned previously, we have collocated OMI and MODIS data and assigned OMI AIs to 100% cloudy MODIS scenes. All calculations are based upon the 100% MODIS cloudy scenes. So, the ACA events as determined by the OMI-MODIS based method are also 100% cloudy cover as determined by MODIS. However, the cloud detectability is different in between MODIS and CALIOP. We have observed, as the reviewer suggested, that more clouds may be detected from the CALIOP-based method, thus causes a difference in ACA frequencies. We have included the discussion in then new Section 4.2.

Again, the Level 2 CALIOP aerosol and cloud products include all three horizontal averaging schemes (5, 20 and 80 km averages). Still, as suggested, we have performed a sensitivity analysis on the horizontal averaging schemes (5, 20 and 80 km averages). Since all three horizontal averaging are used in this study and to avoid confusion, we didn’t include the plot in the paper but we have added it here for the reviewer’s reference.

For

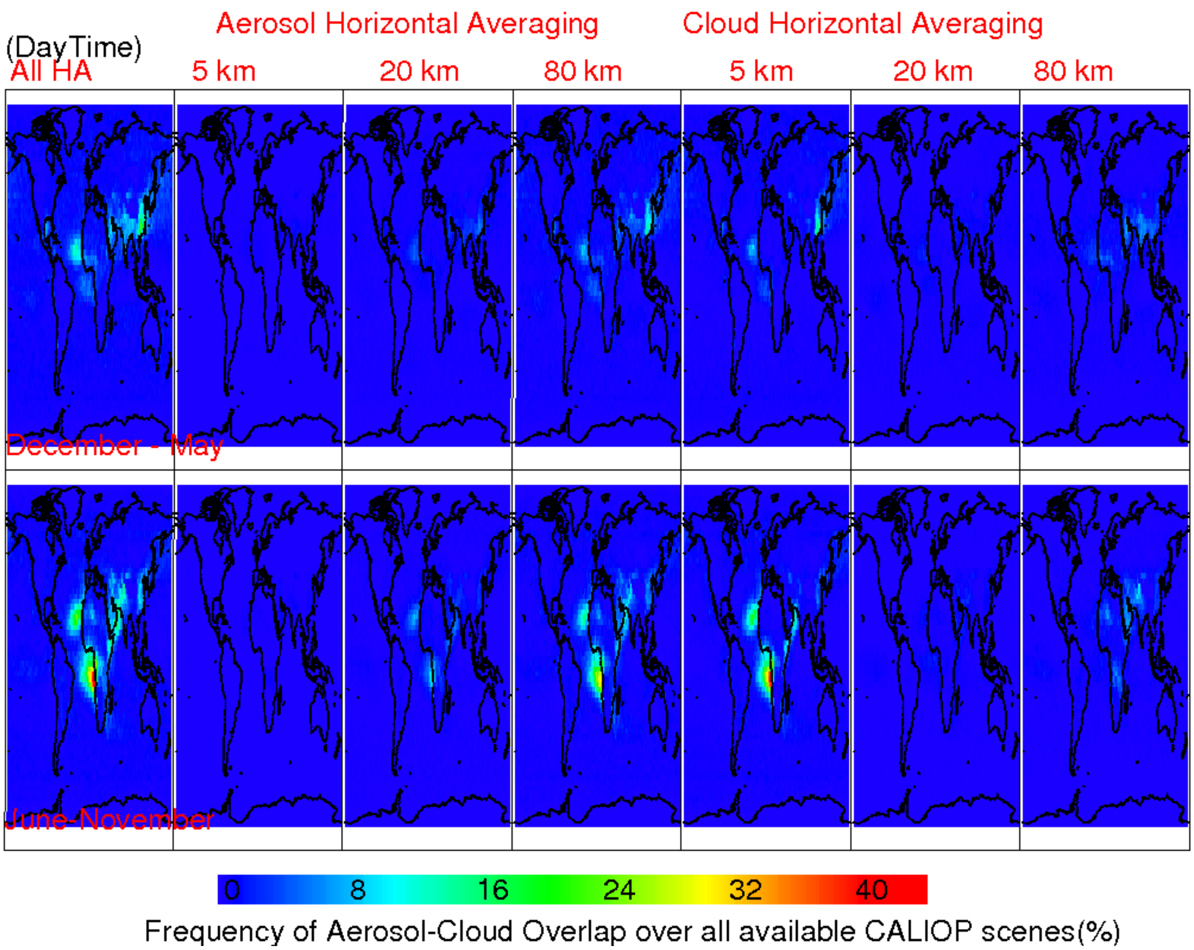

Figure 1. Shown here is the daytime all-sky ACA frequency with the application of different Horizontal Averaging schemes for both detected cloud and aerosol layers. The top row and first column on the left depicts the all-sky ACA frequency using all detected cloud and aerosol layers, regardless of the averaging used to detect the feature during the December to may period (2006-2013). Moving to the right, the plots are created for ACA frequencies using only those aerosol features detected at 5, 20 and 80 km, respectively while using all detected cloud layers. Starting from the fourth column, the plots are created for all-sky ACA frequencies using only those cloud layers detected at 5,20 and 80 km, respectively, while using all aerosol detected layers. The QA for this analysis for cloud and aerosol layers is the same as those applied to the section 4.1 of the study. The second row depicts the same information as first row for the June - November period.

There is also little discussion on the cloud detection in the paper. CALIPSO ACA detection relies on CALIPSO cloud detection. OMI-MODIS ACA detection relies on MODIS cloud detection. It is known that CALIPSO and MODIS have different sensitivity to cloud and their cloud masking products are different. For example, sub-visible thin cirrus clouds are frequent in the tropics. As a result, it is possible that CALIPSO sees three layers, cirrus at the top, a dust layer in the

For

middle and a low cloud layer at the bottom. Is this an ACA case for CALIPSO? Would OMI-MODIS report different in this case? The impact of cloud masking difference on the ACA frequency difference should be investigated and reported in the paper.

Response: This is a very good question. It is true that CALIOP and MODIS have different cloud detection techniques, as well as different sensitivities that may be one of the causes of the difference in ACA frequency derived from each method. In order to investigate the impact the difference cloud detection schemes have on our study, we have performed a pairwise comparison between the OMI, MODIS and CALIOP data sets for June 2006 – November 2008, which allows us to investigate the percentage ACA scenes derived from the OMI-MODIS technique are being missed by CALIOP and vice-versa. Our study suggests that a much higher cloud fraction is reported from the CALIOP-based method, which indeed contributes to the difference between the OMI-MODIS and CALIOP-based methods. We have added a new section (4.2) and have added discussion relating to this issue.

There seems to some confusion of what an ACA scene is, as derived from CALIOP, which may be the result of a lack of a proper definition. Aerosol layers are only recorded if they are found over the highest cloud in the atmospheric column. Thus is it not possible (ideally), from our methods, to find a thin cirrus cloud over an ACA scene. This description has been inserted into the text of the manuscript.

I'd suggest the authors not to use the word "trend" (instead use "multi-year variation" or "inter-annual variation") in this paper. Only 8 years of data are used here. I am not convinced such a short time period can tell us anything about trend. Moreover, CALIPSO has a very limited sampling rate. I found it difficult to believe CALIPSO is able to detect any trend within 8 years. In fact, my impression is that the last few sections are not really about trend, but more about an issue in OMI instrument. So why not directly say so in the manuscript? Detailed comments/questions? In section 3, the discussion on Figure 1 is confusing and hard to follow. Are you suggesting that ideally if a perfect lidar detects aerosols above every cloud, Figure 1a should be same as Figure 1b? I could agree with the statement that "there are always aerosols above clouds", but I don't really see why Figure 1 is necessary. After all, there is no "perfect instrument" that is able to detect ACA over every cloud and there is no need to do so either. So I'd suggest removing Figure 1.

Response: This is a good suggestion. Eight years of CALIOP is not sufficient for a meaningful trend analysis, which we have shown in the study. Thus, we have omitted the phrase "trend" where appropriate and replaced it with terms such as "inter-annual variability" and "year to year variations"

We have removed Figure 1 from the paper along with some of the discussion that is not related to our discussion of AC.

There should be some information about the quality control metrics used to screen the data in Section 3

For

Response: This is a very good suggestion. The OMI and MODIS QA screening are explained in Alfaro-Contreras et al, (2014). We have added discussion on QA flags used as well as their impacts to the cloudy-sky ACA frequencies (e.g. new Section 4.2).

The ACA frequency for OMI-MODIS combination is defined as "the number of collocated MODIS-OMI cloudy scenes with AI retrieval greater than our noise floor (e.g., 1.0) divided by the number of MODIS cloudy scenes with valid AI retrievals." Is there any MODIS cloudy scene with invalid AI retrievals? What is fraction of such case? Why not just use MODIS cloudy scenes as denominator?

Response: This is a very good question. There are MODIS cloudy scenes with invalid AI retrievals that accounts for less than 10% of the data that pass our QA as described in Alfaro-Contreras et al. (2014).

The numerator is calculated from retrievals with valid AI, and thus we also require the denominator to be computed from retrievals with valid AI to avoid statically related bias. As we are not 100% certain that retrievals with invalid AI are not from ACA scenes.

Is there any requirement about MODIS cloud fraction (for example >90%) when identifying the OMI-MODIS ACA scene? Is the result sensitive to this?

Response: The MODIS cloud fraction used to identify a cloudy scene during the OMI-MODIS collocation process is 100%. Since we are only concerned with opaque and contiguous clouds with no holes or gaps, we set a hard threshold of our cloud fraction at 100 %.

I'd like to see some aerosol type analysis (using CALIPSO aerosol type product) when CALIPSO and OMI disagree on the ACA detection. Note that OMI AI is more sensitive to absorbing aerosols than scattering aerosols, while CALIPSO is mainly sensitive to backscatter. This sensitivity difference might explain the difference in ACA frequency in certain region e.g., SE Asia.

Response: We have added an analysis of aerosol speciation separating CALIOP observations into absorbing and non-absorbing aerosol types. The results are discusses in the text (Section 4.2).

For

For

Anonymous Referee #3

This paper provides a comparison of two techniques for identifying cases of aerosol above clouds. The comparison is of an active lidar-based technique using data from the space-borne CALIOP instrument, and the other is a passive imager-based technique combining data from the MODIS and OMI instruments, which are available during daytime only. The two techniques rely on measurements with very different characteristics, and therefore one should expect significant differences between the two, yet both techniques have been used previously in the literature to draw conclusions about the frequency and consequences of aerosol over cloud. Thus a comparison of the two the other two reviewers that this paper does not quite succeed in clearly articulating why the two techniques agree or disagree for different regions or conditions. Nor is it clear what we have gleaned that is new about conditions of aerosol over cloud as a consequence of this comparison. The paper should be suitable for publication in ACP if the authors can revise the manuscript to better distinguish the differences between the techniques and how they contribute to the differences between them. This is elaborated a bit more below.

Response: We would like to thank the reviewer for his or her comments. Point is taken and we have added a new Section 4.2 to explore the difference of the two methods. In particular, collocated OMI-MODIS-CALIOP data are used to explore the difference in ACA frequencies from the two methods, and our study suggests that the difference in cloud detection capabilities and QA flags are among the major causes of the difference.

Section 4 provides an extensive discussion of the global patterns of aerosol over cloud from the two techniques. However, the discussion completely ignores one of the key distinctions (also noted by the other reviewers), that CALIOP detects the presence of scattering aerosol while OMI primarily responds to the presence of UV absorbing aerosol. The obvious question left unanswered here is: how much of the difference between the two techniques is attributable to this fundamental difference in the nature of the aerosol detection? Furthermore, can the CALIOP aerosol detection (or perhaps published aerosol climatologies) provide some guidance on where we should expect the techniques to agree and disagree?

This is a good question. We have performed an analysis separating UV-absorbing from non-UV absorbing aerosols using CALIOP's ability to distinguish different aerosol types. Our study suggests that UV-absorbing versus non-UV-absorbing aerosol is not the major cause of the difference between the two methods as the majority of the ACA events are UV-absorbing aerosol related (dust, smoke, polluted dust as indicated by CALIOP). The results are discussed within the text of the manuscript (Section 4.2).

Echoing another comment also made by another reviewer: the MODIS cloud detection is performed at a much larger spatial scale compared to CALIOP. For example, if the authors are screening the data according to MODIS cloud optical thickness, then they are restricted to cases where the cloud is homogeneous on spatial scales of 1 km. At best, MODIS can only identify clouds at scales of 250 m or larger. Thus the MODIS cloud mask may miss many cases of small *clouds. In contrast, the CALIOP level 2 data are based on individual LIDAR samples with a comparatively much smaller footprint. Can the authors determine that there are many cases where CALIOP identifies aerosol over small clouds that MODIS/OMI is likely to miss?*

Response: This is a good point to bring up. We have performed a pairwise comparison between OMI, MODIS and CALIOP data sets from June 2006 to November 2008 in order to investigate what percentage of ACA scenes is being missed by each method. As the reviewer suggested, the CALIOP-reported cloud frequencies are higher in general due to a better detectability of small and/or thin clouds (Section 4.2). That is one of the reasons why OMI_MODIS-based algorithm reports higher ACA frequencies over North Africa. We have included both figures and discussion in the paper.

For

Reviewer: K. Peters (karsten.peters@mpimet.mpg.de)

Dear Authors,
I have briefly read over the submitted manuscript out of personal interest and found that the citation to
Peters, K., Quaas, J., and Bellouin, N.: Effects of absorbing aerosols in cloudy skies: a satellite study over the Atlantic Ocean, Atmos. Chem. Phys., 11, 1393–1404, doi:10.5194/acp-11-1393-2011, 2011.
shows up in the Reference section, but it does not appear anywhere in the main text of the manuscript and should thus be corrected.

Indeed, the above study focuses on topics thematised in the Introduction and the Method Sections of the submitted manuscript. In particular, Peters et al. (2011) calculated the direct radiative effect of aerosols above clouds by a combination of MODIS, AMSR-E, CERES and OMI measurements. Similar to the methodology applied in the submitted manuscript, the OMI AI was used to sample for absorbing aerosols in cloudy scenes.

Further, I suggest the authors be more cautious with using the term "trend" in their submission. A period spanning not even 8 consecutive years does not allow for a trend analysis in a climate context. As the authors also mention, the tendencies found in the data could simply be explained by measurement artifacts.

Response: We thank the reviewer for his comments. We have modified the text, particularly the conclusion of the paper, and added the above reference within the text. Therefore, we leave the citation on the reference page.

We do agree that eight years of CALIOP data is not sufficient volume of data for a trend analysis, thus, we have switched to the term “inter-annual variability” or “year to year variation” as opposed to trend.

Conclusions:

In the last paragraph, the authors speculate "whether or not ACA represents a fundamental climate phenomenon that requires specific monitoring long-term in a potentially changing climate" (technical: this sentence needs to be rewritten). I strongly endorse specific monitoring of ACA, as I explain in a short example below:

A non-negligible fraction of the fires occurring during the biomass burning season in southern Africa (about July-October) is considered to be of anthropogenic origin. These fires lead to long range transport of biomass burning aerosol over the stratocumulus cloud decks off the West-African coast and lead to substantial positive TOA radiative forcing, which is even non-negligible when averaged to a global scale (cf. Peters et al. (2011)). Under climate change, agricultural behavior, biodiversity and circulation patterns may change. This warrants specific monitoring of the ACA situation.

For

Thanks!
Kind regards, Karsten Peters

Response: This is a good suggestion. Peters et al. show that ACA does in fact represent a fundamental climate phenomenon, thus we have changed the sentence in the final paragraph, for which we include the citation for Peters et al. (2011).

For

H. Jethva (hiren.t.jethva@nasa.gov)

The submitted manuscript examines the multi-year variations, which has been referred to as 'trend analysis' in the paper, of the above-cloud aerosols (ACA) detected by two different sensors and techniques, i.e., one based on the space lidar CALIOP on board CALIPSO satellite, and one that relies on the columnar cloud and aerosol parameters measured from MODIS and OMI passive imagers. Author carries out ACA detection analysis on a global scale with emphasis on several aerosol laden regions and found discrepancies between the two techniques. Of the several interesting issues discussed in the manuscript and also raised by the anonymous reviewers, the trend in ACA frequency detected using OMI-MODIS technique drew my attention most.

Since mid-2007, OMI observations have been affected by a likely external obstruction that perturbs both the measured solar flux and Earth radiance. This obstruction affecting the quality of radiance at all wavelengths for a particular viewing direction is referred to as "row anomaly" since the viewing geometry is associated with the row numbers on the charge-coupled device detectors. The row anomaly issue was detected first time in mid-2007 for few rows which over the period of operation expanded to other rows in 2008 and later. Figure 1 shows the current status of the row anomaly as identified by the OMI group at NASA Goddard. At present, about half of the total 60 rows across the track are identified and flagged as row anomaly affected positions for which no physical retrievals are being performed.

Given the fact that OMI has lost its viewing capability by half post 2008 period, which has directly affected the frequency of measurements globally over both clear and cloudy skies, the 'all-sky' frequency of measurements of aerosol and cloud parameters should go down. However, we learn from the Figure 8 of the submitted paper that author adopts the 'cloudy-sky' as reference measurements in order to calculate the freq. of occurrence of ACA from both CALIOP and OMI sensors. Author attributes the apparent trend in OMI-derived ACA freq. to the observed dependence of UV-AI on the geometry. First, we verified this dependence by plotting the UV-AI as a function of row # for data collected during 2007.

Figure 2 shows the 2007 (prior to the 2008 onset of the row anomaly) annual average AI parameter as a function of scan viewing position (or satellite zenith angle, nadir corresponds approximately to position 30) for cloudy scenes (LER > 0.25). A scan angle dependence likely associated with cloud scattering phase function effects is observed. The resulting AI values are lowest in the vicinity of nadir, and larger at the far off-nadir positions on both ends of the scan, but largest on the extreme positions on the right side. As a consequence of the row anomaly the observing capability associated positions 24 to 54 has been lost. Since the set of lost viewing conditions contain the lowest range of AI values for high LER conditions, after the anomaly onset the relative frequency of occurrence of aerosol events with AI larger than a given threshold value will be larger than during the pre-anomaly conditions, which seems qualitatively consistent with the reported finding. We conducted an analysis similar to one presented in the manuscript to verify the OMI ACA frequency results obtained by the author.

For

First, we follow the same definition for calculating the freq. of ACA as adopted in the manuscript which is based on the ‘cloudy-sky’ measurements. The freq. of ACA is defined as,

Freq.ACA=(Number of days with ACA condition)/(Number of cloud-sky days in a month)

As suggested by the anonymous reviewers, author should properly define the ACA freq. in the manuscript which is currently missing. Secondly, the conditions or satellite measurements for detecting ACA should be determined in an appropriate way. Given the fundamental difference between signal that is measured by CALIOP (back-scatter) and OMI (aerosol absorption), these conditions would be different for both sensors. In our paper by Torres et al. [2012] which introduced a novel approach to retrieve AOD above cloud and aerosol-corrected COD simultaneously using OMI observations, we have shown that the UV-AI and Lambertian Equivalent Reflectivity (LER) measured by OMI can adequately identify the presence of absorbing aerosols above cloud. While UV-AI (>1.0) serves as a strong indicator of absorbing aerosols, the LER (>0.25) can be a measure of the brightness of background, in this case its cloud deck. These thresholds in UV-AI and LER were determined based on the radiative transfer calculations and co-located OMI and MODIS cloud products.

Using above thresholds as a benchmark for detecting ACA, we calculate the freq. of ACA for each 0.25 x 0.25 degree grid box globally for each month starting from Jan 2005 through Dec 2014. Then, a linear trend has been calculated using monthly frequency ACA estimated in the previous step. Figure 3 shows multi-year variations in the monthly ACA frequency for three datasets, i.e., ‘Alldata’ where all the OMI data withUV-AI>1.0 and LER388>0.25 were used, ‘FilteredData’ where measurements for some specific geometries were excluded from ‘AllData’, and ‘FilteredDataRow1to23’ in which only first 23 rows of OMI were used in the calculations. Further analysis of the OMI data over the regions of strong positive trend, particularly for latitudes greater than 70 deg. revealed that these observations are associated with a set of specific geometry which gave rise to the magnitudes of UV-AI (>1.0 & <2.0) in the cloudy situations. These geometries are:

Solar zenith angle > 60 deg. & Viewing zenith angle >60 deg.

OR

Scattering Angle <100 deg.

Note that the OMI UV-AI has been calculated following a Lambertian approach which appears to break down for the cloudy pixels observed under the combination of above geometries. We believe that the reason for the non-validity of Lambertian assumption under these conditions could be the phase function of clouds which is likely being not treated adequately at above geometries. The deviation of the Lambertian assumption from the true cloud phase function, therefore, can result in higher UV-AI (>1.0) which subsequently interpreted as aerosols above cloud in the present analysis. It is, therefore, essential to ‘filter’ the OMI data by excluding above geometries from the analysis in order to better understand trend or inter-annual variation of freq. of ACA. As a result of filtering out the non-aerosol related signal, the monthly freq. of ACA has reduced significantly from the non-filtered dataset. Nevertheless, both datasets reveal a

For

positive trend in ACA freq. which concurs with the results reported in Figure 8 of the submitted manuscript.

Knowing the fact that UV-AI exhibits scan angle dependence and since OMI encountered the row anomaly beginning 2009, use of full 60 row positions during pre-anomaly period and 23 positions during post-anomaly period can likely result in an 'apparent' trend in the frequency of detection of aerosol episodes using OMI data based on a fixed AI threshold. Particularly, this is true for the ACA situation for which use of first 23 clean rows after 2008 associated with larger viewing zenith angle and hence larger UV-AI yields an increase in cloud-sky ACA frequency relative to the pre-anomaly period. In order to derive a meaningful trend from OMI, therefore, one should look at the measurements acquired by first 23 rows over the entire mission. These rows (1 through 23) were almost unaffected by the row anomaly throughout OMI mission, and therefore can provide a consistent and unbiased record of measurements for the trend analysis.

The 'green' color coded data points in Figure 3 represent the monthly variations in ACA frequency derived using Row # 1 through 23 throughout the OMI decadal record. On contrary to the results obtained in previous two cases, ACA frequency derived from OMI Row # 1 through 23 shows almost no trend which is very much consistent with the results obtained using CALIOP data. This is because the measurements acquired by Row # 1 through 23 have nearly same viewing zenith angle for each respective row, and thus use of these clean rows eliminate scan angle related bias in the decadal trend analysis.

Suggestions to author: The analysis presented in our report reveals that the trend in ACA derived from OMI observations depend on how we identify ACA situation and what dataset is being used for the analysis. We strongly recommend author to redo OMI analysis using measurements from Row # 1 through 23 and the data filtering scheme suggested above. The only difference then will be the cloud mask for which we used OMI LER observations, whereas author uses MODIS cloud product. We expect a marginal difference in the results due to the different cloud schemes. Since aerosols above clouds is a regional phenomenon, it is desirable to carry out trend analysis for the regions where ACA situation is frequently observed from satellites, i.e., south-east Atlantic Ocean, tropical Atlantic Ocean-off the coast of western Sahara, south-east and north-east Asia, and northern Arabian Sea.

Response: We would like to thank the reviewer for his comments. As suggested we have added Table 1 to the study which defines the different ACA frequencies used in the study.

Our OMI AI data were filtered using the following conditions

Solar zenith angle > 60 deg. & Viewing zenith angle >60 deg

These methods are similar to methods suggested by the reviewer and are also implanted in Yu et al. (2012) and explained further in Alfaro-Contreras et al., 2014.

We agree with the reviewer that constraining the OMI data to only specific rows, which were not impacted by the row anomaly, is a very good suggestion and eliminates the bias observed in the year to year variations in the OMI derived ACA frequency over time. Initially, we attempted to

For

perform this analysis however could not figure out the dynamic variability of the row anomaly over time. We would be happy to rerun our analysis with this constraint however we feel that it would not be proper reporting the reviewer's findings as a part of our study. Thus, we leave that task to the reviewer for a future study.

For