**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.

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.

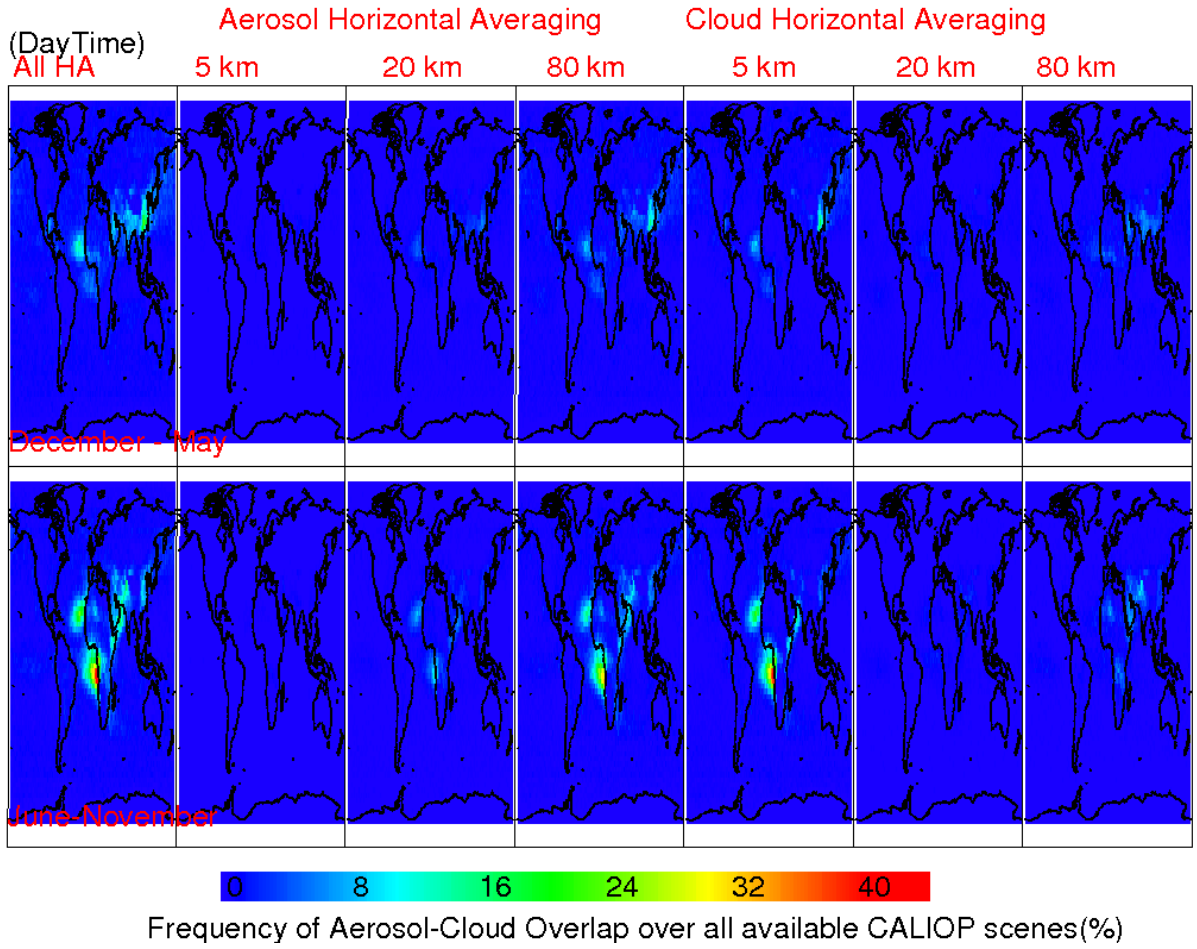


Figure 1. Shown here is the daytime all-sky ACA frequency with the application of different Horizontal Averaging schemes for both detected cloud and aerosol layers. The top row and first column on the left depicts the all-sky ACA frequency using all detected cloud and aerosol layers, regardless of the 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*

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*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*

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).