Response to reviewers: paper acp-2011-581 (Redemann et al.)

We would like to thank reviewer #1 for their suggestions for improvements to our manuscript. Both reviewers recommended publication of our paper, one after “significantly expanding the discussion part”, the other after minor revisions. We found a limited number of parallels between the two reviewers’ suggestions. Incorporating the majority of recommendations from each reviewer resulted in significant improvements to our manuscript. Detailed responses to all reviewers’ comments are given below. We are providing responses to both reviewers below, because our responses to one of the reviewers often cross-reference responses to the other.

We hope that our manuscript is now acceptable for publication in ACP.

Best regards,

Jens Redemann (for the co-authors)

Referee #1:

General comments: The paper address [sic] the important problem of understanding the discrepancies between different aerosol optical depth retrievals from space. I believe the paper has a lot of potential but is too technical in its present state and the results are presented in such a way that it raises more questions than it solves. I suggest the paper to be accepted after the authors have significantly expanded the discussion part.
Also, I would suggest to derive the best filter based only on CALIOP quality flags that provides the best agreement with MODIS data, this way your research could be directly used by CALIOP data users.

Specific comments:
1) About " cloud fractions less than 1% " which is referred several times for example: p. 22988 L17-19 "A restriction to scenes with cloud fractions less than 1% (as defined in the MODIS aerosol retrievals) generally results in improved correlation (R2 >0.5), except for the month of July when correlations remain relatively lower." p. 22998 L5-6 "MODIS cloud fractions (as determined by the aerosol algorithm) to be below 1% (comparison # 4 in Table 1);" p. 22999 L12-14 "As an additional restriction to even more cloud-free conditions, Fig. 2c and f show the comparisons between MODIS and CALIOP for cloud fractions of less than 1% as defined by the MODIS aerosol product (Cloud Fraction Ocean)." Why is a low cloud fraction helping ? Is it because MODIS retrievals are more reliable and a better reference in that case or that cloud creates problem in the CALIOP retrieval?
<u>Response:</u> *We added the following sentences in the discussion section of our manuscript:”A restriction to scenes with cloud fractions less than 1% (as defined in the MODIS aerosol retrievals) generally results in improved correlation (R^2>0.5). This improvement is probably due to the improved performance of the passive MODIS retrievals in the absence of clouds, and also due to the improved performance of the CALIOP retrievals where no aerosol-cloud discrimination needs to be performed”.*

2) p. 22989 L15-16 "with particular strengths over oceans where surface conditions are fairly well known." Please change this sentence. The "surface conditions" are not well known but the dark surface approximation applies relatively well. The recent study of "Kleidman et al. 2011 IEEE TGRS" clearly shows an error in MODIS retrieval introduced by the assumption on wind speed (which influence [sic] the "surface conditions") but the error stays relatively low.
<u>Response:</u> *We changed the sentence to read:"…, with particular strengths over oceans where surface reflectances are less uncertain than over land."*

3) p. 22991 L20-21 "However, their comparisons were screened very differently from our data set, making a quantitative comparison of results difficult." It is a problem and before being published, you should devote some time (and a few more sentences in your paper) to understand and explain how another study using the same data is reaching different conclusions. The source of discrepancy may have important repercussions on your work so the differences should not be discarded with just one sentence.
<u>Response:</u> *We disagree with the reviewer's assessment: "the source of discrepancy may have important repercussions on your work". As we show throughout our paper, the way in which the data sets are screened can have a major impact on the exact AOD differences found. The study by Oo and Holz shows fundamentally the same result, i.e., a bias difference with MODIS AOD greater than CALIOP AOD. Chasing the reasons for differences in the exact biases found seems to be inconsequential to our study. Nonetheless, we changed the sentence to point out that the MODIS-CALIOP difference of 0.064 found by Oo and Holz is not fundamentally different from our finding.*

4) p. 22994 L5-6 "refinements to the layer detection algorithm including the elimination of a bug in the cloud clearing code" Please clarify how the new layer detection algorithm is different. "A bug has been fixed" is not enough.
<u>Response:</u> *There was no "scientific" significance to the bug, it was simply a coding bug that resulted in erroneous layer detection. Our manuscript even refers the reader to the relevant publication by one of our co-authors. No action taken.*

5) p. 22988 L20-21 "Regional assessments show hot spots in disagreement between the two sensors in Asian outflow during April and off the coast of South Africa in July." Where is that disagreement coming from ? Assumptions in MODIS retrieval, lidar ratio selection, something else?
<u>Response:</u> *We feel that a detailed analysis of the reasons for the regional disagreement between MODIS and CALIOP AOD is beyond the scope of our paper. Nonetheless, we added the following paragraph and reference, speculating on the potential reasons: "More in-depth studies are required to determine the most likely cause(s) for these disagreements. For the East Asia case in April, initial investigations might focus on possible failure by CALIPSO to detect diffuse dust layers in the middle troposphere and/or cloud contamination of the MODIS signals (Huang et al., 2011). Closer examination of the cloud-aerosol discrimination algorithms for both sensors would likely be a profitable strategy for assessing the West Africa case in July. "*

6) p. 22992 L25 "30m and 333m at" This is true below around 8km. Although it should be ok for most aerosol studies, I suggest you add something like "A resolution going up to".
<u>Response:</u> *Suggested change made.*

7) p. 22993 L12-15 "It should be noted that the CALIOP instrument was not primarily designed to provide AOD, but instead vertical profiles of aerosol backscatter, depolarization and extinction. As such, the derivation of AOD from integration of extinction profiles is subject to several limitations and uncertainties." This sentence suggests the problem is coming from the integration of the extinction profile and that the extinction is working perfectly well but not the AOD. Although you explain it with more details later, this sentence is misleading and should be rewritten.
Response: We changed this sentence to read: "It should be noted that the CALIOP instrument was not primarily designed to provide aerosol extinction and hence AOD, but instead vertical profiles of aerosol attenuated backscatter (and depolarization), from which aerosol backscatter and extinction can be derived using an inversion algorithm."

8) p. 22997 L28 "CALIOP extinction retrievals to have quality flags of 0, 1 or 2" What does that mean ? Please write a few words to describe what a quality flag of 0, 1 or 2 is and why it is better than a value of 3 and higher.
Response: We added the following explanatory text: "The CALIOP extinction quality flags describe the final state of the Hybrid Extinction Retrieval Algorithm (HERA; see Young and Vaughan, 2009). The most reliable retrievals are those for which a direct measure of layer attenuation can be obtained by comparing the signal magnitudes in clear air regions immediately above and below a layer. In these cases, for which HERA reports an extinction quality flag of 1, the measured attenuation provides a constraint for the solution of the lidar equation and thus a direct estimate of the layer lidar ratio can be retrieved. When this kind of constrained retrieval is not possible (as is always the case with surface-attached aerosol layers), HERA derives optical depths using an assumed value of the lidar ratio. Retrievals of this type are assigned an extinction quality flag of 0. When the assumed value of the lidar ratio is too large, the extinction solution will begin to diverge toward positive infinity, and therefore to obtain a successful solution the lidar ratio must be reduced. As extinction quality flag of 2 identifies these situations, which occur very rarely in the analysis of aerosol layers. Other extinction quality flag values indicate algorithm termination conditions that are considered unreliable for the purposes of the current study."

9) "CALIOP extinction retrievals to have uncertainties less than 200% when extinction is below negative 0.2km^{-1}, or less than 500% when extinction is greater than 2.5km^{-1} and to eliminate profiles for which any extinction retrievals do not have 10 said extinction coefficients and uncertainty limits (as described in comparison # 5 in Table 1);" How is the uncertainty calculated ? How does that translate in term of aerosol properties? Are high optical depth less likely to be present so dust and biomass burning plumes less likely to be included in the statistic ? It is important you try to explain the meaning of those uncertainties in term of aerosol properties.
Response: To address the reviewer's question "how is the uncertainty calculated?" we have added a reference to the CALIOP algorithm theoretical basis document, which is publicly available at the CALIPSO web site. That reference also answers the reviewer's second question about how the uncertainties "translate in term of aerosol properties".
In addition, the paper now includes the following brief explanation on the uncertainty calculations: "Uncertainties in the CALIOP particulate volume extinction coefficient are computed from combined systematic and random errors in the particulate extinction-to-

backscatter ratio and the particulate volume backscatter coefficient (see equation 16 of http://eosweb.larc.nasa.gov/PRODOCS/calipso/pdf/CALIOP_Version3_Extinction_Error_Analysis.pdf). Ignoring multiple scattering concerns in Version 3, the three main sources of uncertainties are the signal-to-noise ratio (depends on the backscatter intensity, the lighting conditions (i.e., day vs. night), and the amount of horizontal averaging applied to the initial attenuated backscatter profiles), the calibration coefficient, and the accuracy of the lidar ratio specified for use in the solution within each detected aerosol layer. Except for constrained solutions, where a lidar ratio estimate can be obtained directly from the attenuated backscatter data, lidar ratio uncertainties are almost always the dominant contributor to optical depth uncertainties, and the relative error in the layer optical depth will always be at least as large as the relative error in the lidar ratio for a given layer.".

Regarding the reviewer's question whether "high optical depths [are] less likely to be present so dust and biomass burning plumes less likely to be included in the statistic?": While it is true that unusually large optical depths (e.g., above ~4 or so) are more likely to be removed than smaller values (e.g., less than 3), this behavior is completely consistent with the fact that the maximum single-scattering optical depth that can be reliably penetrated by an elastic backscatter lidar is the neighborhood of 3 (e.g., Sassen & Cho, 1992; McGill et al., 2002). Looking at the pre-filtered and post-filtered distributions of aerosol subtypes shows that the uncertainty filter parameters chosen for this study do not preferentially include or exclude any of the CALIPSO aerosol subtypes from the final data set. We have added a statement to this effect to section 3.1.

References for our response to comment 9):

McGill, M., D. Hlavka, W. Hart, V. S. Scott, J. Spinhirne, and Beat Schmid (2002), Cloud Physics Lidar: instrument description and initial measurement results, *Appl. Opt.*, **41**, 3725–3734.

Sassen, K. and B. S. Cho (1992), Subvisual-Thin Cirrus Lidar Dataset for Satellite Verification and Climatological Research, *J. Appl. Meteor.*, **31**, 1275–1285.

10) "CALIOP relative AOD uncertainty calculated from the extinction uncertainties to be below 100% (comparison # 6 in Table 1)." Same comment than 9)
<u>Response:</u> *See our response to comment 9).*

11) "larger uncertainties in MODIS over-land AOD retrievals" There may be more uncertainties in CALIOP as the surface reflectance is usually higher over land than over the ocean and the background noise will be higher. Please consider if it is important enough to be noted and add a few sentences of discussion if it is.
<u>Response:</u> *We added the following statement: "Uncertainties in CALIOP retrievals due to increased noise from surface scattering are secondary to the effects mentioned above."*

12) "CALIOP extinction retrievals to fall within the "valid range" (identified in the CALIPSO data products catalog as 0 to 1.25 km□1) (comparisons # 2–4 in Table1);" What is a "valid range". How is that defined and calculated ? Are there specific kind of aerosols not within this range ?

Response: *We added the following statement: "The valid range for 532nm extinction retrievals of 0 to 1.25 km^{-1} was an arbitrary choice and is partially being validated here. To our knowledge this criterion does not exclude specific aerosol types, but instead only unrealistically large aerosol loadings of any type."*