Reply to Referee #2

Referee #2 - Comment

The authors have worked on all of my comments and most adequately covered.
Unfortunately, the key equation (now Eq. 9 former Eq. 6) is in my opinion still not correct. As the authors obviously do not take into account how the DOD(AOD) at CALIPSO is calculated.
Imagine a visually thin layer of dust that is missing an AOD of 0.15 – naturally, you need a larger LR to obtain the missing AOD (because there is less integrated backscatter). If, on the other hand, you imagine an optically thick dust layer that is missing 0.15, then it is sufficient to raise the LR only slightly to extract the missing AOD from the already large backscatter. It is not the absolute difference that matters, but the relative difference. I tried to explain/describe the issue in more detail in the attachment.

Because of this issue, I have meanwhile doubt that the content of the paper is correct and thus publishable. Therefore, I hope the authors can comment on this!

For this reason, I also only briefly checked the other issues but would do more intensively when the authors have replied accordingly.

For the publication of the LIVAS data set, I do not agree on the statement provided as the data providers are also co-authors of this paper. Are there any contractual issues to no publish it in a public repository or why should it only be available via email? If you cannot put it "as is" on zenodo or similar you should deliver it as a supplement. However, I appreciate the attempts to make the novel CALIPSO dust data set available to the public.

For this reason, I also only briefly checked the other issues but would do more intensively when the authors have replied accordingly.

We thank Referee #2 for the detailed and technically insightful comments concerning the key equation of our manuscript. The reviewer correctly identified a fundamental inconsistency in the previous version of the manuscript, namely that the adjustment of the lidar ratio (LR) was based on absolute differences in dust optical depth (DOD), without explicitly accounting for the dependence on the vertically integrated backscatter signal.

The reviewer's comment led to an extensive revision of the entire methodology. In response, we developed a **new equation (Eq. (9))** for the estimation of the dust LR, which is now consistently derived from first principles and applied throughout the revised analysis, fully replacing the previous approach. In the revised manuscript, we focus on the methodological framework for estimating the LR and its application over distinct regions of North Africa and the Middle East encompassing major dust sources. Based on this approach, we provide a summary table of regionally representative dust LR values together with their associated uncertainties, which is intended to serve as a practical reference for subsequent observational and modeling studies.

The revised approach is presented in Section 3.3 of the manuscript, while the **complete analytical derivation of the new Eq. (9) is provided in Section S2 of the Supplement**. We note that the symbols used in Eq. (9) are explicitly adapted for dust cases, whereas the Supplement presents the general formulation applicable to different aerosol species. In particular, the **new LR estimation is performed using the following Eq. (9) (Eq. (S.14) of the Supplement)**:

$$Y = \left| DOD_{CALIOP} - LR^{d}_{CALIOP} \int_{z_o}^{z_G} \left\{ \frac{\left(\frac{\alpha_d}{LR^{d}_{eff}} + \beta_m\right) \exp\left[-2\int_{z_o}^{z}\left(\alpha_d + LR^{d}_{CALIOP}\beta_m\right) d\zeta\right]}{1 - 2LR^{d}_{CALIOP}\int_{z_o}^{z}\left(\frac{\alpha_p}{LR^{d}_{eff}} + \beta_m\right)\exp\left[-2\int_{z_o}^{\zeta}\left(\alpha_d + LR^{d}_{CALIOP}\right) d\zeta'\right] d\zeta} - \beta_m \right\} dz \right| \quad (9)$$

Here, the parameter z is the range from the spaceborne lidar, ζ and ζ' are both surrogate variables representing different instances of range in the nested integrals, z_o is the reference (aerosol free) range, z_G is the ground range, β_m is the vertically resolved molecular backscatter coefficient, a_d is the particle extinction coefficient, LR^{d}_{CALIOP} is the constant dust LR (i.e., 44 sr - Kim et al., 2018), LR^{d}_{eff} is the effective columnar dust LR, and DOD_{CALIOP} is the CALIOP DOD. The z reference system is discussed in the Supplement. Through Eq. (9), the LR^{d}_{eff} is retrieved through the minimization of Y. This approach naturally leads to different LR adjustments for optically thin and optically thick dust layers, thereby resolving the physical inconsistency highlighted by the reviewer.

Based on this methodology all CALIOP derived DODs are equal with the MIDAS (or POLDER-3/GRASP) derived ones using the new lidar ratio and incorporating the new LR impact on the backscatter coefficients derived by CALIOP being in line with the examples provided in the reviewer comments.

Implementing this revised formulation required substantial changes throughout the manuscript, extending well beyond the methodology section. As a direct consequence:

- The final dataset is reduced by approximately **43.4% for the CALIOP–MIDAS synerg**y and **37.0% for the CALIOP–POLDER-3/GRASP synergy**, reflecting the stricter physical consistency requirements imposed by Eq. (9).
- A **new uncertainty analysis** has been introduced, accounting for all relevant sources of uncertainty associated with the extinction coefficient profiles, reference DOD datasets, LR retrieval and grid averaging process.
- The resulting LR maps show physically meaningful but **moderate changes**.
- The AERONET comparison figure of the original manuscript has been omitted due to the fact that since now MIDAS (or POLDER-3/GRASP) DOD and new CALIOP DOD (with new LR and re-solving/iteration of the Klett Lidar equation) are equal thus such a comparison is just a MIDAS (POLDER-3/GRASP) vs AERONET driven by the sampling frequency of CALIOP.
- Statistics of different areas based on LR homogeneity and also purely geographical criteria have been included
- As already mentioned, the focus on the methodology for the new LR retrieval was increased to be possibly serve as a method to be adopted from other future works on CALIOP retrievals.

  To further assist the referee in assessing the impact of the revised methodology, we include in our reply the Fig.1 comparing the spatial distribution of dust LR values obtained using the previous (Version 1) and revised (Version 2) approaches for the **CALIOP–MIDAS synergy**. According to Fig. 1, while a few grids exhibit larger differences reaching approximately **6–8 sr**, these are limited in spatial extent. Over the major dust source regions (e.g. Bodélé), which are also characterized by the largest number of collocated observations, the dust LRs differ predominantly by **~2–5 sr**. Figure 1 is therefore intended to illustrate the magnitude and spatial structure of the changes introduced in the revised analysis and to provide the referee with a clear visual summary of their overall impact. *We note that Fig. 1 includes only grid cells for which dust LR values are available in both Version 1 and Version 2, and for which the number of collocated cases exceeds one in both datasets. This choice is consistent with our updated manuscript, whereby LR estimates based on a single case (N=1) are excluded, as they may not be representative.*

  For the **CALIOP–POLDER-3/GRASP synergy** we don't provide a comparison figure. This is due to the substantially smaller number of available collocated dust cases, resulting from the much shorter period of CALIPSO–PARASOL satellite coincidence (2006–2009), yielding 1,116 cases compared to 2,943 for CALIOP–MIDAS. As discussed in the Results section of the manuscript, these maps are therefore not analyzed in detail. Their use is limited to the regional LR assessment presented in Section 5, where the number of coincident retrievals within each predefined region remains sufficient to derive meaningful statistics.

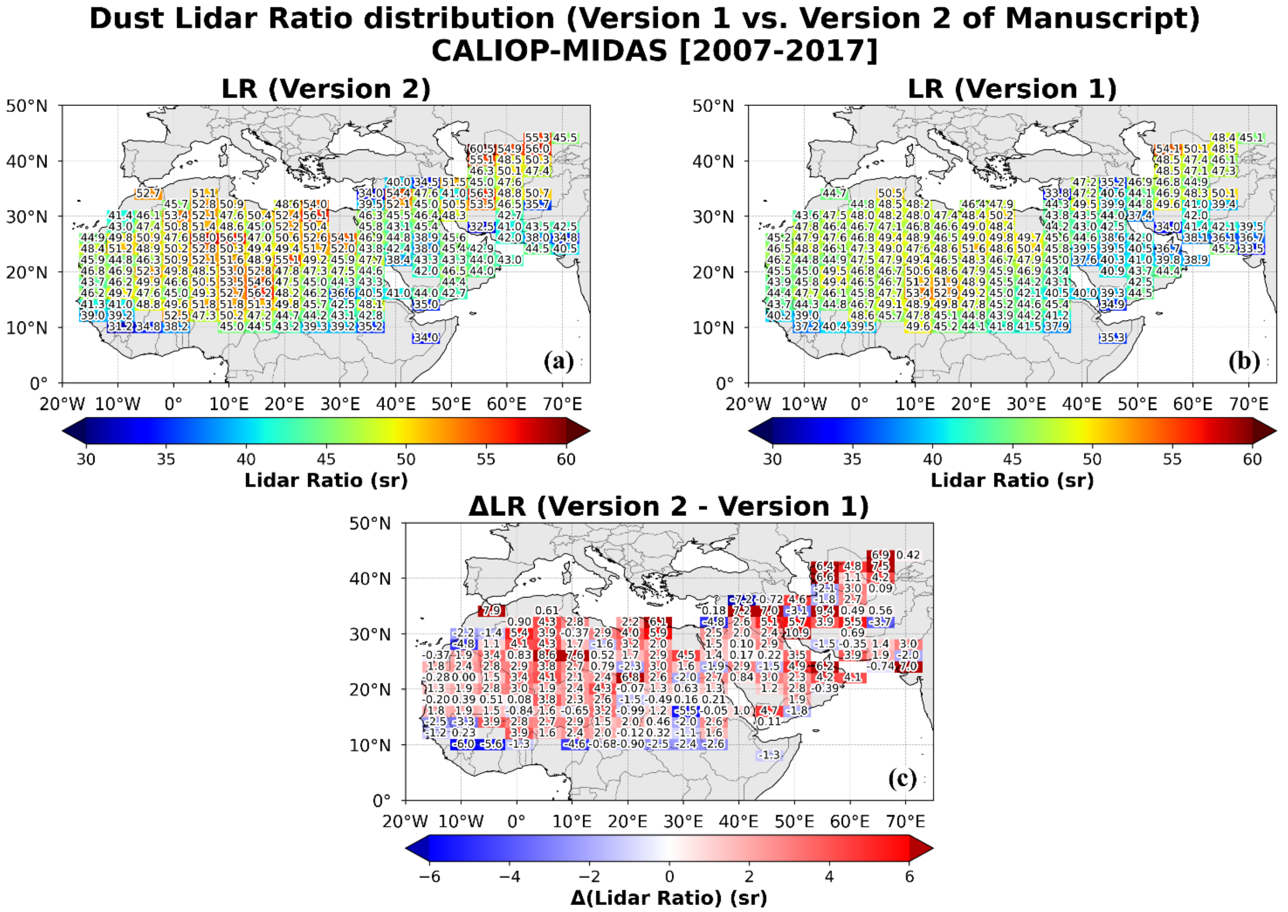

Figure 1: Geographical distribution of the dust lidar ratio (LR) obtained using the different equations of (a) Version 2 and (b) Version 1 of the manuscript, and (c) the corresponding differences (ΔLR = Version 2 − Version 1) for the CALIOP–MIDAS synergy.

Although this study focuses on pure dust cases, the proposed methodology and the associated LR estimation framework are not restricted to dust aerosols. The new Eq. (9) can be applied to other CALIPSO aerosol subtypes, provided that the analysis is restricted to regions and conditions where a single aerosol type dominates and the underlying assumptions of the retrieval are satisfied. Examples include clean marine aerosols over oceanic regions or polluted continental and elevated smoke layers over Central Africa. This flexibility highlights the broader applicability of the proposed approach for refining CALIPSO AOD and extinction retrievals across diverse atmospheric environments.

Overall, these revisions resulted in a manuscript that differs from the original submission and reflects a fundamentally new and physically consistent implementation of the method. We believe that the revised approach fully resolves the conceptual issue raised by Reviewer #2 and substantially strengthens the physical robustness of the study.

We sincerely thank Referee #2 for the detailed explanations and persistence, which were essential in motivating this comprehensive methodological revision.

In respect to LIVAS data availability we thank once again the Referee for raising this important point. LIVAS dataset itself constitutes an independent product with its own release policy, versioning, and dissemination strategy. Decisions regarding its public publication fall outside the scope of the present manuscript. We have been informed by the LIVAS team that an **updated version of the dataset is currently under preparation and will be publicly released in the near future**. In accordance with the data owners' policy, access to the LIVAS dataset is therefore provided **upon request**, as stated in the Data Availability section of the manuscript, where contact details of the responsible data providers are listed.

In contrast, the **novel CALIOP-based dust LR datasets produced within this study** are fully generated by the present analysis and are publicly available. The dust LR datasets from both synergies (CALIOP–MIDAS and CALIOP–POLDER-3/GRASP) are provided in NetCDF format via a public repository (Zenodo), ensuring transparent access to the primary results of this work (https://doi.org/10.5281/zenodo.18016524).

We believe this approach appropriately balances open data practices with respect for existing data ownership and ongoing dataset development efforts.

References

Kim, M.-H., Omar, A. H., Tackett, J. L., Vaughan, M. A., Winker, D. M., Trepte, C. R., Hu, Y., Liu, Z., Poole, L. R., Pitts, M. C., Kar, J., and Magill, B. E.: The CALIPSO version 4 automated aerosol classification and lidar ratio selection algorithm, Atmos. Meas. Tech., 11, 6107–6135, doi:10.5194/amt-11-6107-2018, 2018.