"Mapping 532 nm Lidar Ratios for CALIPSO-Classified Marine Aerosols using MODIS AOD Constrained Retrievals and GOCART Model Simulations" by Toth et al. documents the updates to the lidar ratio selection methodology for marine aerosols in v5. The updated method uses MODIS AODs and GOCART modeled aerosols to create seasonally and spatially varying maps from which to select their marine aerosol lidar ratios. They find that these updates provide AODs that better align with those calculated through the ODCOD than the previous version (v4.51) and also better agree with those measured by AERONET sites in coastal and island locations. The paper provides valuable documentation of the updated CALIOP data product, which, despite CALIPSO's retirement in 2023, still provides a valuable long-term dataset for cloud/aerosol research. This update to marine aerosol lidar ratios represents a significant advancement through addressing regional and seasonal variability that was previously unaccounted for in the previous fixed value lidar ratio assignment. The paper is generally well organized and written; however, this reviewer found it to be a bit on the long side. I would recommend publication after some minor revisions.

Response: We thank the reviewer for the helpful feedback and comments, which have contributed to strengthening this manuscript.

Major Points:

1. The study provides a valuable update to the assignment of marine aerosol lidar ratios; however, the approach raises fundamental questions about CALIOP's aerosol typing framework. The manuscript would benefit from directly addressing how these new spatially/seasonally varying marine lidar ratios relate to the existing aerosol typing framework, particularly the distinction between marine and dusty marine. Is differentiating between dusty marine and marine needed or useful anymore with these new methods?

   Response: Good question! Our answer is clearly "yes", as identifying (and also quantifying) the dust content in any aerosol plume remains a topic of scientific interest. For an offhand bit of evidence, we point to the increased usage of the LIVAS product developed by the National Observatory of Athens (e.g., see https://acp.copernicus.org/articles/22/535/2022/).

   Many of the regions where the largest differences in lidar ratios occur, such as the Bay of Bengal, are regions where dusty marine and other aerosol mixtures are common. Here the study assigned V5 marine lidar ratios exceeding the V4.51 dusty marine value of 37 sr in some regions. This convergence between the new variable marine lidar ratios and the dusty marine values raises two questions for me: 1) may some of these aerosol layers currently classified as marine in these regions be misclassified dusty marine?

   Response: Yes, of course. The CALIPSO aerosol classification scheme is not perfect. But so long as the optical depths above the layers being classified are fairly low (or, as in the case of this study, zero), the separation between marine and dusty marine is robust, as it relies primarily on the estimated particulate depolarization ratio of the layer (Kim et al., 2018).

   There may, however, be some misclassification of marine as dusty marine in cases of very low humidities where marine aerosols can transition from droplets to desiccated sea salt crystals (Ferrare et al., 2023).

2) Does this new method render the discernment between marine and dusty marine somewhat obsolete?

Response: No, not at all; e.g., see Groß et al., 2013, who show the changes in lidar ratio and particulate depolarization ratio as a function of dust fraction within a layer. Changes in dust fraction are reflected in changes in depolarization, which can then be mapped into changes in lidar ratio for dusty marine mixes.

Connecting lidar ratios to modeled sea salt volume fractions suggests that this approach could be beneficially extended to other marine-influenced aerosol classes, which perhaps is covered by the tables/maps noted at L142, but not shown in this paper.

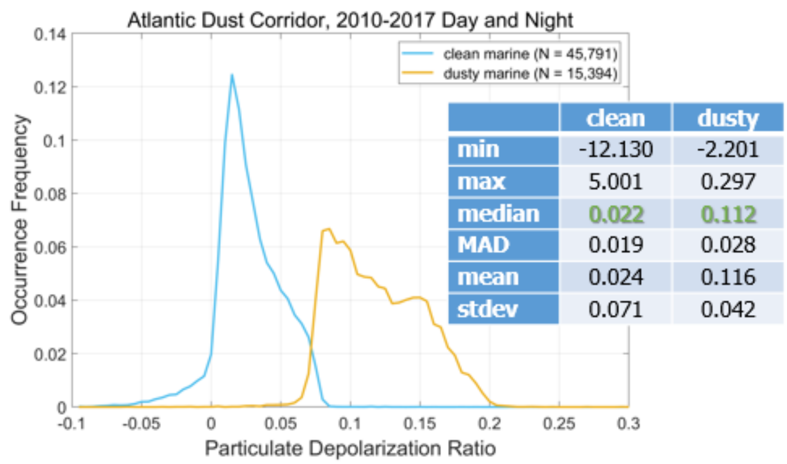
Response: The seasonal maps of marine lidar ratios presented in this paper (and included in V5) do not impact the overall aerosol typing framework, including the distinction between marine and dusty marine. There have been no changes from V4 to the V5 aerosol typing classification algorithms as it pertains to distinguishing between these two CALIOP aerosol types (details of the classification algorithm are included in Fig. 1 in the manuscript and discussed in detail in Kim et al. 2018).

Regarding the question on whether or not differentiating between these two types is needed or useful given the new V5 methods, we believe that this is indeed necessary. In the early stages of our analysis, we did not find a clear difference in the MODIS AOD constrained lidar ratio retrievals between marine-only and dusty marine-only CALIOP profiles. When focusing on "the Atlantic dust corridor" for the period between 2006 through 2017, dusty marine lidar ratios were higher than marine lidar ratios by ~1.8 sr. However, in a later study conducted over the same region but with more rigorous data selection criteria, we found dusty marine lidar ratios exceeded marine lidar ratios by just over 3 sr. Adapting the method given in Groß et al., 2013 shows that this 3 sr difference is equivalent to a dust fraction of ~25%. Because CALIOP depolarization measurements are robust and layer integrated depolarization is a strong indicator of dust fraction, we decided to create separate lidar ratio maps for marine and dusty marine, rather than combine them. Due to our desire to optimize the content and flow of this manuscript, we purposely only focused on the marine maps here, and expect to focus on dusty marine in a separate paper.

Responding to the reviewer's suggestion that this approach could be beneficially extended to other marine-influenced aerosol classes:

Unfortunately, it's difficult to see how we could easily extend this approach to other "marine-influenced aerosol classes". Empirically deriving lidar ratios according to aerosol type requires a highly accurate aerosol type discrimination scheme. Ideally, one would construct such a scheme by measuring several intrinsic properties of the aerosol such as depolarization ratios, color ratios, and lidar ratios, then use these quantities to infer aerosol type. (Note that we've put the cart before the horse here; the intrinsic properties approach assumes that lidar ratios can be either directly measured or trivially retrieved from the direct measurements.) While multi-wavelength HSRLs excel at this (e.g., Burton et al., 2014), elastic backscatter lidars like CALIOP simply cannot perform the same magic. Instead of determining aerosol type base on measured intrinsic properties, CALIOP must use extrinsic properties to determine aerosol type (Vaughan et al., 2021). Then, having determined type, look up tables are used to *assign* the lidar ratios that are subsequently used to *calculate* estimates of the same intrinsic properties that an HSRL can measure. For more discussion on this point, see Burton et al., 2014.

Depolarization ratios provide the single case in which extrinsic properties can (usually) be used to accurately discriminate aerosol types. CALIOP's *estimated* particulate depolarization ratio combines measurements of layer integrated volume depolarization with estimates of the particulate optical depth overlying any layer to approximate the *true* particulate depolarization ratio. As noted earlier, when the overlying optical depths are low, this approximation is gratifyingly accurate and hence a highly reliable metric for identifying aerosol layers with non-zero dust fractions. The discriminatory power of the *estimated* particulate depolarization ratios is illustrated below in Figure 1, which was produced during one of the many sensitivity studies conducted for this paper.




| | clean | dusty |
|---|---|---|
| min | -12.130 | -2.201 |
| max | 5.001 | 0.297 |
| median | 0.022 | 0.112 |
| MAD | 0.019 | 0.028 |
| mean | 0.024 | 0.116 |
| stdev | 0.071 | 0.042 |

Figure 1: distribution of retrieved layer-integrated particulate depolarization ratios for all measurements in the Atlantic dust corridor during 2010 through 2017. The data in this study was restricted to those profiles averaged to 5-km along track resolution in which only a single layer was detected. Both nighttime and daytime measurements are included. Note that the CALIOP aerosol subtyping algorithm defines a depolarization threshold of 0.075 to separate marine aerosol from dusty marine, and this explains the sharp partitioning of the distributions that occurs at that value.

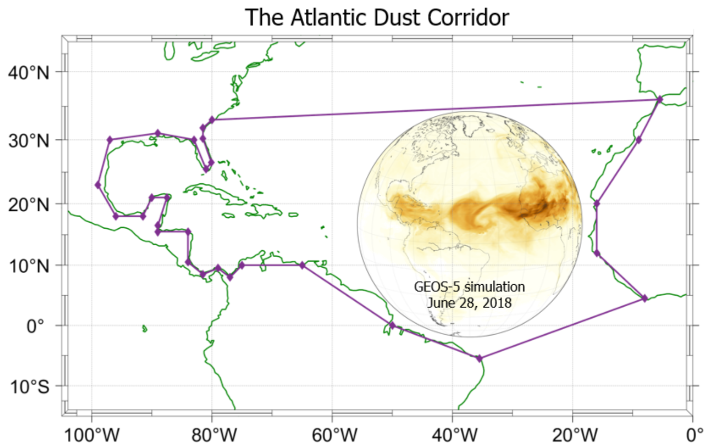



Figure 2: coordinates of the Atlantic dust corridor used to harvest the data in Figure 1.

The only other measured quantity that CALIOP might conceivably use as a proxy for an intrinsic property is the layer-integrated total attenuated backscatter color ratio, $\chi'$. As a substitute for an Ångström exponent, this quantity might be expected to yield information about aerosol size composition and hence give insights into aerosol type. However, as illustrated in Figure 3 and noted in Kim et al., 2018, $\chi'$ shows no skill in differentiating between the seven CALIOP tropospheric aerosol type, as the $\chi'$ frequency distributions for all types lie more-or-less on top of one another.

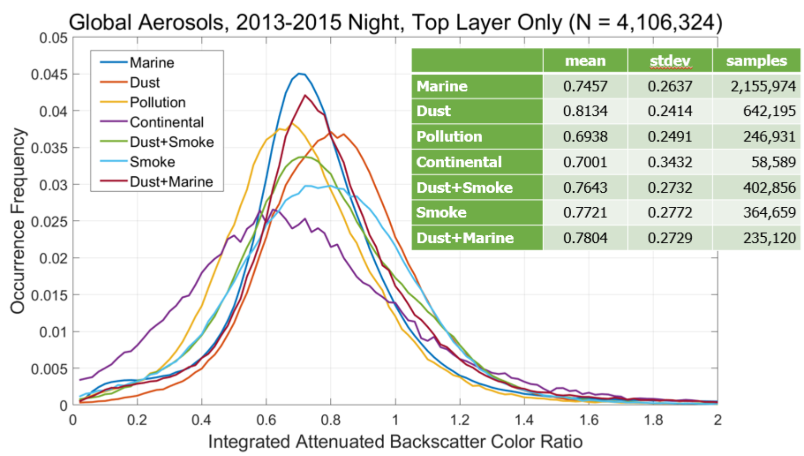



Figure 3: Distributions of layer-integrated total attenuated backscatter color ratio partitioned by aerosol subtype for nighttime measurements of the uppermost layer in a 5 km column acquired during 2013–2015 (shamelessly pillaged from Vaughan et al., 2021).

2. The exclusion of modeled dust aerosols from the SSVF calculations (L407-409) warrants reconsideration or further justification. This study already focuses specifically on CALIOP-identified marine layers, which have already passed the CALIOP typing algorithm's criteria (depolarization or otherwise) for classification as marine vs. dust (or other types). These marine-classified layers would still contain some dust at concentrations below levels that would trigger classification as dusty marine or something else. By

omitting dust from the SSVF denominator, SSVFs would be inflated, especially in transitional, dustier, regions.

Response: As we state in the paper, the primary reason we chose to exclude dust from our SSVF calculations was due to the ability of CALIOP to classify dust through the depolarization ratio. However, we recognize that some residual dust may still be included in the CALIOP-classified marine aerosol layers and agree that the inclusion of dust in our SSVF computations warrants consideration. As part of the extensive analyses required in these modeling-related efforts, we briefly assessed how the SSVFs and corresponding model-assisted lidar ratios would change by including dust for the entire study period (rather than partitioning by year and/or season). While it is true that in dust-prone areas there are reduced SSVFs when including dust, the second order polynomial equation (Equation 1) characterizing the relationship between SSVF and retrieved lidar ratio also changes. This results in a near-zero change in model-assisted lidar ratios for most of the global oceans. The exception is the dust belt in the Atlantic Ocean, for which there could be lidar ratios ~13 sr larger by including dust (however, these cases would be classified as dusty marine or dust; see Fig. 1). We note, though, that any change in SSVF will only impact the model-assisted lidar ratios, not the retrievals (as shown in Fig. 12). When considering this, the area with the most impact by including dust would be the modeled values in the Atlantic dust belt in the JJA season. While it is ideal to further investigate this to fully understand the potential changes, this would require more extensive evaluation, and the implementation of updated lidar ratio maps would require reprocessing of the CALIPSO V5 data products. Due to the closeout of the CALIPSO satellite mission in September 2025, and the simultaneous loss of funding for all members of the CALIPSO project team, this will unfortunately not be possible.

3. The manuscript is a bit lengthy and could be strengthened through some editing, especially in the introduction. The extensive literature review from L148 to 222 largely duplicates the information already presented and effectively summarized in Table 2. Streamlining the literature review and highlighting only the most significant studies would benefit readers.

   Response: We agree with the reviewer that the manuscript is lengthy, particularly in the Introduction during the literature review. As found in the revised manuscript, we have shortened this section by removing several lines of discussion and highlighted just a few studies. The results from other papers are summarized in Table 2.

Minor Points:

L164: is the MPL at 532 or 523nm?

Response: We double-checked the corresponding papers and can confirm that the MPLs for these studies operated at a wavelength of 523 nm, not 532 nm.

L330: This sentence read a bit weird. Consider: “Note that this approach produces a negligible proportion of negative Sa values (less than 0.05%), and our methodology minimizes the influence of these outliers by using median values when creating the Sa maps (Sections 3 and 4).” or something similar. The phrase “our use of medians” sounded off to me…

Response: We have edited this sentence as suggested.

L347: What are typical stratospheric AOD values in the SAPP? It strikes me that removing stratospheric AOD from the column would result in a fairly small correction outside of volcanic/pyrocumulonimbus events.

Response: The stratospheric AODs reported in the SAPP are typically < 0.01, and these were shown to agree generally well with Stratospheric Aerosol and Gas Experiment III (SAGE III) measurements between about 30° S and 30° N (Kar et al., 2019; Li et al., 2022). For our constrained lidar ratio analysis, the global mean stratospheric AOD used was ~0.009, with a global median value of ~0.007. Our sensitivity studies as part of this work resulted in a ~2 sr reduction in lidar ratio globally when accounting for these stratospheric AOD values.

Figure 13: The regional boxes encompass a lot of land. I would recommend being more explicit that the analysis only includes at the oceanic parts of the domain.

Response: Thank you for this suggestion. We have added the following sentence after the first mention of Fig. 13: “While some regions encompass a large amount of land, only the oceanic parts of each domain are used in the analysis.”

L763: State why ODCOD is expected to be greater than v4.51

Response: In the previous paragraph to the sentence in question, we discuss the reasons for the differences between the standard CALIOP retrieval and ODCOD (i.e., $S_a$ selection and layer detection). We have added the following sentence to that paragraph, referring specifically to layer detection: “This can be due to optically thin layers that are below CALIOP's direct detection thresholds and are not detected as features in the standard retrieval but are responsible for attenuation that is accounted for in the ODCOD retrieval.” We have also added “i.e., due at least partly to layer detection” to explain why ODCOD is expected to be greater than V4.51.

L816: Consider adding that models parameterize sea salt emissions by wind speed.

Response: We have added this statement to the paper.

References:


Burton, S. P., R. A. Ferrare, M. A. Vaughan, A. H. Omar, R. R. Rogers, C. A. Hostetler, and J. W. Hair, 2013: Aerosol Classification from Airborne HSRL and Comparisons with the CALIPSO Vertical Feature Mask, *Atmos. Meas. Tech.*, **6**, 1397–1412, https://doi.org/10.5194/amt-6-1397-2013.

Burton, S. P., M. A. Vaughan, R. A. Ferrare, and C. A. Hostetler, 2014: Separating mixtures of aerosol types in airborne High Spectral Resolution Lidar data, *Atmos. Meas. Tech.*, **7**, 419–436, https://doi.org/10.5194/amt-7-419-2014.

Ferrare, R. and 27 coauthors, 2023: Airborne HSRL-2 measurements of elevated aerosol depolarization associated with non-spherical sea salt, *Front. Remote Sens.*, **4**, 1143944, https://doi.org/10.3389/frsen.2023.1143944.

Groß, M. S., Esselborn, B. Weinzierl, M. Wirth, A. Fix and A. Petzold, 2013: Aerosol classification by airborne high spectral resolution lidar observations, *Atmos. Chem. Phys.*, **13**, 2487–2505, https://doi.org/10.5194/acp-13-2487-2013.

Kar, J., Lee, K. P., Vaughan, M. A., Tackett, J. L., Trepte, C. R., Winker, D. M., ... & Getzewich, B. J. (2019). CALIPSO level 3 stratospheric aerosol profile product: version 1.00 algorithm description and initial assessment. *Atmospheric Measurement Techniques*, *12*(11), 6173-6191, https://doi.org/10.5194/amt-12-6173-2019.

Kim, M.-H., A. H. Omar, J. L. Tackett, M. A. Vaughan, D. M. Winker, C. R. Trepte, Y. Hu, Z. Liu, L. R. Poole, M. C. Pitts, J. Kar, and B. E. Magill, 2018: The CALIPSO Version 4 Automated Aerosol Classification and Lidar Ratio Selection Algorithm, *Atmos. Meas. Tech.*, **11**, 6107-6135, https://doi.org/10.5194/amt-11-6107-2018.

Li, Z., Painemal, D., Schuster, G., Clayton, M., Ferrare, R., Vaughan, M., ... & Trepte, C. (2022). Assessment of tropospheric CALIPSO Version 4.2 aerosol types over the ocean using independent CALIPSO–SODA lidar ratios. *Atmospheric Measurement Techniques*, *15*(9), 2745-2766, https://doi.org/10.5194/amt-15-2745-2022.

Vaughan, M., M. Kacenelenbogen, J. Tackett, J. Kar, R. Ryan, A. Omar, S. Young, X. Lu, J. Reagan and G. Schuster, 2021: Exploiting 1064 nm Measurements to Improve CALIOP Aerosol Type Identification, presentation given at the CALIPSO Version 5 Aerosol Lidar Ratio Workshop held virtually March 9-11, 2021; slides available at https://science.larc.nasa.gov/wp-content/uploads/sites/147/2021/04/2021-CALIPSO-V5-ALR-Workshop-Vaughan_Mark.pptx