Reply to Anonymous Referee #2

We thank the reviewer for their helpful and constructive comments. Please find our answers (black text) to the comments (blue text) in-line below. Respective changes are indicated in the revised manuscript in blue and are stated here in addition when a reviewer comment lead to a modification of the manuscript along with the updated line number, where necessary.

The upcoming EarthCARE mission will include measurements of M-AOT, or column aerosol optical depth at 670 nm (over land and ocean) and 865 nm (over ocean). The study presents the algorithm for these retrievals and results using simulated EarthCARE data and the MODIS L1 reflectances, comparing this output to existing AOD measurements from AERONET and MAN and to the MODIS aerosol products. It is strange that for both the synthetic test scenes and the MSI algorithm applied to MODIS L1 reflectances, the performance is dramatically better over ocean than over land; this raises questions about its surface reflectance estimation. The comparisons to MODIS and AERONET data need clearer justification.

Thank you for your comment.

Regarding your first point "the performance is dramatically better over ocean than over land": We were actually not surprised about the worse performance over land than over water due to the difficult task of separating the surface and the atmospheric contribution in the TOA signal as stated several times throughout the manuscript. Nonetheless, we additionally clarified in the discussion section by adding:

"In general and as common for near-real time aerosol products over land based on similar passive measurements, the performance of the M-AOT product is worse over land than over ocean. This is due to the very strict surface and aerosol composition assumptions made and due to the lack of higher accuracy surface information available at operational run-time. Nonetheless, a correlation of 0.77 (AERONET) and 0.87 (MODIS MYD04) could be reached using MODIS Level 1 data in the M-AOT algorithm." (L466-470)

Further, we added justifications for comparisons to AERONET and MODIS in the manuscript in L412 (MODIS), L438-440 (AERONET).

My other specific comments are below:

- Line 16. "Aerosols have a special role in the overall context" of what? Consider rephrasing. Rephrased to:

  "Aerosols have a special role in the overall context of radiative interactions in the atmo-sphere [...]" (L16-17)

- Line 21. Another unclear use of "context". Does this mean the lidar data needs to be combined with MSI to obtain geolocation?
  Since the overall EarthCARE concept, is part of a different publication in this special issue, as already referenced in the manuscript, we will not go into more detail in the manuscript itself than we already have. However, to answer your question:
  No. Here it is referred to the fact that, by measurement nature, a space-based lidar is capable to provide vertical information, but only along track (i.e. no across track or horizontal

information) while a space-based imager is able to provide horizontal information, but only for one observed column as a whole (i.e. no vertical information). This in turn means that one could gain additional knowledge from combining these two measurements of one observed location. It also means that you hypothetically could see e.g. the vertical location of a smoke plume in the lidar measurements. However, the imager measurements might offer you the possibility to add information to the lidar knowledge by e.g. hinting at the actual source region of that plume a few kilometers away. Hence, MSI data will be able to add information for that hypothetical case.

- Lines 82-83. What is the spatial resolution of one MSI pixel? Measurements of aerosols at cloud edges (and of aerosols in or near dust or smoke plumes thick enough to be mistaken for clouds) are valuable in themselves, and this seems like it would greatly reduce spatial coverage.
  The actual statement about the spatial resolution of MSI is already available in L58 of the manuscript.
  The various radiative effects close to and at cloud edges cannot be considered in such a simple aerosol retrieval that is supposed to deliver the product in near-real time. This limitation is shared with all other passive imager based aerosol retrievals of that kind. Additionally, we added a clarification:
  "[...] are flagged as well during that step in order to avoid [...] and other three dimensional radiative transfer effects. […] 3 pixel, which is corresponding to 1.5 km." (L95-96)
- Lines 232-334. How often would the land cover type map be updated to account for land use change?
  Currently, it is not foreseen to be updated. However, we could imagine that the need for an update arises during future developments.
- Fig. 3 and Fig. 4. If there's a way to generate RGB images for these synthetic data test scenes, they would be helpful to orient the reader.

  RGB images are not directly available due to the band setting of MSI (i.e. no channel availability in the blue or green).
- Meanwhile, the skill seems very low for the land retrieval, but both scenes are mostly ocean; it's hard to tell how much of this is limited sampling.

  We agree that the algorithm performs worse over land than ocean. However, this is as expected due to the complex task of disentangling surface and atmospheric contribution to the TOA signal.
- Line 357. A reference placeholder (?) has been left unfilled.

  Thank you. Updated. (L394)
- Lines 374-375. The references are for the MODIS Dark Target algorithm, but the MODIS L2 aerosol file includes retrievals from Dark Target, the Deep Blue algorithm, and a combination DTDB. Make sure to specify which is meant.

  Updated. "Dark target" is specifically stated now. (L411)

- Lines 381-383. Unless the MODIS comparison is meant to use the Deep Blue or DTDB retrievals exclusively, the L2 product reports Dark Target AOD at 660 nm (land and ocean) and 860 nm (ocean) directly. Inferring the values from the Ångström exponent and the 550 nm retrieval instead risks losing precision.

  Agreed. However, the M-AOT product reports AOT at 670 nm and 865 nm. In order to compare AOT at the same wavelength, MODIS dark target AOT was extrapolated to these wavelength. The loss in precision is expected to be negligible compared to other potential sources of inconsistencies such as different assumptions about e.g. aerosol types or surface parameterization.

  Nonetheless, this pre-launch exercise has been executed in order to give an indication of the expected performance of the EarthCARE MSI stand-alone aerosol retrieval.

- Lines 383-384. The MODIS Ångström exponents are calculated for ocean only by the Dark Target retrieval and for land only by Deep Blue, so the underlying algorithms being compared here are not equivalent. Also, double check these wavelengths.

  Even though it is stated that the transfer (or "extrapolation" in the updated manuscript) has been executed via the Ångström parameter, it was not stated that this is the "official" MODIS reported value but rather that it is based (calculated) on the official AOTs. Hence, only the dark target AOT values have been used to our best knowledge. The wavelength have been double checked and are based on the reported "long_names" in the MODIS HDF product(s).

- Fig. 6. The corresponding MODIS RGB image would be helpful here, too.

  We omit the RGB image here too in order to keep the general structure of both verification sections as equal as possible and kindly refer you to publically and freely available MODIS RGBs using for instance NASA worldview https://worldview.earthdata.nasa.gov/ (last visited 28 Apr 2023)

- Fig. 8. Any idea why these scatterplots form branches at higher AOD values? It's still odd that the correlation for land is so much lower than for ocean.

  Branching for higher AOD:

  As already stated in the manuscript (L434-435), this is mainly attributed to different assumptions in the MODIS and M-AOT retrieval, in particular aerosol type choice.

  We further added: "The resulting AOT differences exist for both, low and higher AOT. However, they become amplified for higher AOTs." (L435-436)

  Land vs ocean:

  We are not surprised that the correlation is worse over land than over ocean. As stated in subsection 2.3.4, the contribution of the surface to the TOA signal is stronger over land than over ocean. Hence, it is much more difficult to separate the atmosphere and surface contribution to the TOA signal from another. This in turn makes it much more difficult to precisely estimate the AOT over land.

- Line 402. 5 km is a tighter spatial radius than is commonly used for satellite/AERONET matches, and this does not necessarily improve representativeness. How were the match criteria chosen?

  This value has been chosen according to a common amount of pixel used and stated for

example in Concha et al 2021. There, for ocean match-up validation studies for example, a value between 3x3 and 7x7 pixel is used. Translated to the MODIS resolution used in M-AOT of 1 km times 1 km, our chosen value of 5 km lies right in the middle.
Javier A. Concha, Marco Bracaglia, Vittorio E. Brando, Assessing the influence of different validation protocols on Ocean Colour match-up analyses, Remote Sensing of Environment, Volume 259,2021, 112415, ISSN 0034-4257, https://doi.org/10.1016/j.rse.2021.112415.

- Line 414. Are there plans to report a 670 nm/865 nm Ångström exponent as part of the MSI product?
  Yes, it is planned to be part of the MSI product.