Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2019-348-AC1, 2020

Atmospheric Measurement Techniques Discussions

Interactive comment on "Validating TROPOMI aerosol layer height retrievals with CALIOP data" *by* Swadhin Nanda et al.

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Received and published: 30 January 2020

Reviewer comment (general): The manuscript entitled by "Validating TROPOMI aerosol layer height retrievals with CALIOP data" shows the initial validation results of aerosol vertical structure information from TROPOMI sensor. The aerosol vertical information is important result for the trace gas retrieval and air quality information relating to the PM2.5 etc. For this reason, the validation of aerosol layer height retrieval result is essential to publish. However, several supplements are required before the publication.

Reviewer comment (Specific comment 1): Although the aerosol layer information by the environment satellite mission is limited, several previous studies were investigated

including sensitivity results and methodology. Therefore, please add the reference for the aerosol height retrieval algorithm relating to next generation of environmental satellites (such as GEMS, TEMPO etc.). e.g.)

1. Choi, Wonei, et al. "Effects of spatiotemporal O_4 column densities and temperature-dependent O_4 absorption cross-section on an aerosol effective height retrieval algorithm using the O4 air mass factor from the ozone monitoring instrument." Remote Sensing of Environment 229 (2019): 223-233.
2. Kim, Mijin, et al. "Optimal Estimation-Based Algorithm to Retrieve Aerosol Optical Properties for GEMS Measurements over Asia." Remote Sensing 10.2 (2018): 162.
3. Park, Sang Seo, et al. "Utilization of O 4 slant column density to derive aerosol layer height from a space-borne UV–visible hyperspectral sensor: sensitivity and case study." Atmospheric Chemistry and Physics 16.4 (2016): 1987-2006.
4. Zoogman, P., et al. "Tropospheric emissions: Monitoring of pollution (TEMPO)." Journal of Quantitative Spectroscopy and Radiative Transfer 186 (2017): 17-39.
5. Vasilkov, A., J. Joiner, and R. Spurr. "Note on rotationalRaman scattering in the O 2 A-and B-bands." Atmospheric Measurement Techniques 6.4 (2013): 981-990.
6. Wagner, T., et al. "A sensitivity analysis of Ring effect to aerosol properties and comparison to satellite observations." Atmospheric Measurement Techniques 3.6 (2010): 1723-1751.

Author's response: The recommended citations have been added to the manuscript at specific sections pertaining to their relevance.

Changes to the manuscript: The following paragraphs include the citations requested.

Section 1:

Some notable mentions of missions that retrieve aerosol layer height are Multiangle Imaging Spectroradiometer (MISR) on board the NASA Terra satellite (Nelson et al., 2013), the Deep Space Climate Observatory (DSCOVR) mission with its Earth Polychromatic Imaging Camera (EPIC) (Xu et al., 2017, 2019), the upcoming Multi-Angle Imager for Aerosols (MAIA) mission (Davis et al., 2017), the Ozone Monitoring Instrument (OMI)on board the NASA Aura mission (Chimot et al., 2017, 2018; Choi et al., 2019), and finally the TROPOMI instrument onboard the Sentinel-5 Precursor mission (Veefkind et al., 2012). In the near future, missions like the Geostationary Environment Monitoring Spectrometer (GEMS) and the Tropospheric Emissions: Monitoring Pollution mission (TEMPO) are expected to provide aerosol height retrievals as well (Kim et al., 2018; Park et al., 2016; Zoogman et al., 2017). These instruments are examples of missions demonstrably (some theoretically, others practically) capable of retrieving aerosol layer height accurately.

Section 2.1:

The RTM in this case is a neural network model that has learned parts of a full physics RTM derived from de Haan et al. (1987), described in Nanda et al. (2019) (Section 3), which is three orders of magnitude faster than DISAMAR. In short, the atmosphere is simplified by DISAMAR in20order to reduce computational burden, and the neural network forward model is implemented for a further performance boost in an operational environment; for instance, DISAMAR ignores rotational raman scattering even though literature has shown that the oxygen A-band ring effects are sensitive to aerosol layer height (Vasilkov et al., 2013; Wagner et al., 2010). These decisions have been made in order to speed up line-by-line calculations of DISAMAR, which are the basis of the training data for its neural network counterpart. This decision is motivated by preliminary sensitivity analyses conducted by Sanders and de Haan (2016) which conclude that the effect of ignoring RRS is not significant enough to venture in its implementation into the forward model

Reviewer comment (specific comment 2): In page 4, Lines 34 : For the forward model simulation, the aerosol optical and physical properties based on the Henyey-Greenstein scattering phase function is insufficient. Also, the fixed single scattering albedo affects the estimation errors due to the variability of aerosol optical properties. The atmospheric layer is also too simple as we compared to the previous researches of aerosol height estimation studies. Author has to be explained the reason of simple assumption for aerosol optical and physical properties in the TROPOMI algorithm. Especially, retrieval error of aerosol height relating to the single scattering albedo and size information were reported in several previous studies.

Author's response: Accepted. The manuscript will add explanation for choice of aerosol model and physical parameterisations.

Changes to the manuscript: The following paragraph explains the various choices in aerosol properties and profile parameterisations.

The forward model parameterises aerosols with a Henyey-Greenstein scattering phase function (Henyey and Greenstein,1941) with an asymmetry factor of 0.7, a single scattering albedo of 0.95, and a fixed aerosol optical thickness for an aerosol layer parameterised by a single atmospheric layer with a 50 hPa thickness. These assumptions have to be made since very little a priori information about aerosols in a scene is known. While more complex scattering models exist, the Henyey-Greenstein model has been used for retrieving ALH when the forward model was of line-by-line nature as the number of calculations it requires is far less than a scattering model such as the Mie model. Sensitivity analyses have shown that this assumption has few ramifications (Sanders et al., 2015). Fixing the single scattering albedo is a much bigger concern; while retrievals over the ocean do not suffer for a priori errors in the single scattering albedo, retrievals over land do have large errors and non-convergences which reduce as the the viewing zenith angle increases (Nanda et al., 2018a). The choice of using 0.95 as a fixed value arises from average values derived by Dubovik et al. (2002) from long-term observations using the aerosol robotic network (AERONET). The algorithm assumes a single aerosol layer for the entire atmosphere, within which aerosols are uniformly distributed and the aerosol volume extinction coefficient is constant. This is an important simplification to note when comparing with CALIOP profiles, since these lidar profiles have the capability to detect multiple aerosol layers. The simplicity in the aerosol profile parameterisation arises from the fact that it is impossible to know, without prior information, whether the scene consists of a single or multiple aerosol layers. While fitting of the aerosol layer pressure thickness along with the aerosol layer mid pressure does not result in large errors in the retrieved aerosol layer height, the precision of the retrieved aerosol layer mid pressure significantly deteriorates with increasing errors in the surface albedo (Sanders et al., 2015). More research has to be done before more information on the aerosol profile is retrieved from the oxygen A-band alone.

Reviewer comment (specific comment 3): In page 6, line 11: For the validation of ALH, author used both level 1 and 2 data of CALIPSO. If both data exists, which of the two data do you use first?

Author's response: We use both data at the same time. The manuscript will mention this at this specific line.

Changes to the manuscript: The manuscript now reads:

The data from the CALIOP instrument relevant for validating TROPOMI ALH are the level-1 backscatter profiles and the level-2 aerosol extinction profiles, which are used at the same time.

Reviewer comment (specific comment 4):) In page 7: The CALIOP data has potential error to classify cloud and aerosol. For the validation, additional consideration for cloud contamination in the aerosol products of CALIOP is also important

Author's response: This validation study assumes that the CALIOP extinction profiles are free from cloud contamination. This assumption is incorrect, which is why additional validation study has been done with the calculated extinction heights plotted over CALIOP backscatter profile curtain plots and analysing with the eye. The combination of the two alleviates many cases where the CALIOP aerosol product might be cloud contaminated. Finally, choosing relatively cloud-free scenes also helps in ensuring that cloud contamination is not a large concern. This is clarified in the manuscript.

Changes to the manuscript: The manuscript clarifies the reviewer's concerns with the following changes:

... the colocation technique used in this paper. The CALIOP aerosol product might be cloud contaminated as well, but this is difficult to ascertain. Plotting ALH_{ext} over curtain plots of level-1 total backscatter profiles can be used to visually discern possibly cloud-contaminated CALIOP level-2 aerosol product.

Reviewer comment (specific comment 5): Figure 2: From the Fishman et al. (2012) in BAMS, the reference value of aerosol layer height error is 1 km. However, only 50% of the data satisfies the error within 1 km, and the standard deviation is always larger than 1 km as author wrote in the manuscript. Compared to the expected error (1 km), the error is relatively large. Given these results, do you think the accuracy of these results is sufficient?

Author's response: The errors shown in this manuscript pertain to comparison of aerosol layer heights obtained by two different instruments with two separate principles. Our understanding of numbers such as expected errors pertain to errors with respect to the true aerosol layer height. This is impossible to know, as neither CALIOP nor TROPOMI retrieve the true aerosol layer height or aerosol profile, but simply express what is observed by the instrument and what is retrieved with the available information. The authors of this paper are unaware as to how these reference values by Fishman et al. (2012) were calculated. It is also unclear what this number means, especially considering how retrieval of aerosol layer height from spectral measurements of the top of atmosphere radiance in the oxygen A-band depends on whether the aerosol plume is over a dark or a bright surface. Considering these concerns, the authors make no comment on how the accuracy of these results map to the reference aerosol layer height error values mentioned in Fishman et al. (2012).

Changes to the manuscript: No changes are made in the manuscript pertaining to this reviewer comment.

Reviewer comment (specific comment 6): Figure 7: Compared to the slope value, the Y-intercept is too large. Please discuss the reason of large positive bias of Y-intercept.

Author's response: Accepted.

Changes to the manuscript: The following clarifies the comment:

What is immediately apparent is that, while there seems to be an agreement between the two heights (indicated by the pearson correlation coefficient of 0.64, the slope of fit of 1.0 and an intercept of 0.53 km), CALIOP ALH_{ext} are systematically higher than TROPOMI ALH (indicated by a y-intercept of the fit at 0.53 km). The CALIOP ALH_{ext} is also higher than TROPOMI ALH almost consistently in most cases. This could possibly be due to CALIOP possibly underestimating the aerosol layer thickness due to strong attenuation of the lidar signal at the top of the aerosol layer (Rajapakshe et al., 2017), whereas TROPOMI ALH product does not suffer from such attenuation.

Reviewer comment (specific comment 6): In Page 11: For the further study, the author discusses to update the LER product. However, updating aerosol properties

are most important point in this study. Please add the author's opinion.

Author's response: Accepted.

Changes to the manuscript: The following amendment is made to the manuscript:

Currently, the GOME-2 surface LER product derived from Tilstra et al. (2017) is used operationally, and will eventually need to be updated with a higher resolution version possibly derived from TROPOMI itself. To that extent, owing to the boost in the computational speed of the radiative transfer calculations, the algorithm can now incorporate more complex aerosol property and profile parameterizations. Such a step will benefit the TROPOMI aerosol layer height retrieval accuracy significantly.

Reviewer comment (technical comment 1): In page 9 (Line 17) : correct the typo-error (4thrd -> 4th)

Author's response: Accepted

Changes to the manuscript: The typographical error has been fixed in the manuscript.

Interactive comment on Atmos. Meas. Tech. Discuss., doi:10.5194/amt-2019-348, 2019.