Response to comment of Anonymous Referee #2 on "Cancellation of cloud shadow effects in the absorbing aerosol index retrieval algorithm of TROPOMI" by Victor Trees et al.

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Summary

In this paper the authors discuss the effect of cloud shadows in the magnitude of the qualitative Absorbing Aerosol Index (AAI) parameter derived from TROPOMI near UV observations and verify their findings with 3D radiative transfer (RT) calculations. The reported RT results are a good validation of their developed 3-D RT tool application to UV observations. They conclude that the effect on the AAI is quite small and that, therefore, a correction is not necessary.

General Comments

The detection of cloud shadows signal in the AAI is not a new finding. Cloud shadows in equivalent AAI definitions have been previously identified in satellite observations by sensors with UV observational capability at sub-kilometer spatial resolution [Fukuda et al., 2013; Tanada et al., 2023; Gogoi et al, 2023]. As in the previously published analyses, this manuscript concludes that the cloud shadow effect on the AAI is quite small and does not warrant a correction.

We thank the reviewer for pointing our those references. Although cloud shadows are indeed discussed in Fukuda et al. (2013) and Gogoi et al. (2023), they do not discuss the cloud shadow effect on the absorbing aerosol index (AAI) in its form used by satellite spectrometers such as GOME, OMI and TROPOMI. The Cloud and Aerosol Imager (TANSO-CAI) is an imager measuring in bands, and Fukuda et al. (2013) and Gogoi et al. (2023) retrieved the aerosol optical thickness (AOT) and single scattering albedo (SSA). We are not aware of scientific publications that discussed cloud shadow effects on the AAI. Therefore, we consider our analysis of cloud shadow effects on the TROPOMI AAI as novel.

This conclusion can be further justified by the fact that the AAI is not a physically meaningful parameter. Thus, in its current form, the manuscript's main contribution is the validation of the MONKI UV radiative transfer scheme and could, perhaps, be submitted to an RT specialized journal.

Although the AAI is not a quantity with physical units, features in AAI maps can sometimes be related to other physical phenomena than absorbing aerosols. For example, Kooreman et al. (2020) discuss the AAI increase due to the cloud bow. In our paper, we study the impact of cloud shadows. As we discuss in the introduction of the paper, AAI features that are not directly related to absorbing aerosols require an explanation and/or correction in order to guarantee the quality of this satellite product. Therefore, we think AMT is the appropriate journal for this work.

The authors could advantageously use the documented AAI-cloud shadow detection capability to develop corrections to radiance measurements at relevant channels in the UV-VIS-near-IR range that are used in the retrieval of important geophysical parameters. Although corrections would not be necessary for DOAS (Differential Optical Absorption Spectroscopy) based applications, they would be needed for cloud and aerosol algorithms and other inversion schemes based on the interpretation of discrete channel observations. One such AAI-based reflectance correction was developed and applied to GOSAT/TANSO CAI observations at 672 nm (Fukuda et al., 2013). Similar applications to TROPOMI measured radiances would be an important contribution to improve the accuracy of retrieved physical parameters and contribute towards the error budget analyses of TROPOMI retrieved parameters. I encourage the authors to pursue this goal.

The thank the reviewer for this suggestion. We indeed have the cloud shadow detection DARCLOS which can be used to identify cloud shadow pixels. Because in this paper we conclude that the average cloud shadow effect on the AAI is not apparent, we think that the AAI itself is not a suitable parameter to be part of a potential correction strategy of radiances in the cloud shadow for other TROPOMI products such as the aerosol optical thickness (AOT) (de Graaf, 2022). In addition, we think that first the cloud shadow impact on the AOT should be analyzed (as we did for this paper for the AAI), before efforts are made to design a correction strategy.

Specific Comments

Line 19: Suggest replacing spectrometer with hyperspectral instrument.

We thank the reviewer for the suggestion. The instrument type name of TROPOMI is commonly written as 'spectrometer', see e.g. the TROPOMI paper (Veefkind et al., 2012) or the KNMI and SRON websites: https://www.knmi.nl/kennis-en-datacentrum/project/tropospheric-monitoring-instrument-tropomi and https://earth.sron.nl/project/tropomi/. Therefore, we keep the sentence as is.

Line 22: Suggest adding hyperspectral before predecessors.

We think that adding the word 'hyperspectral' in this sentence would be redundant, and therefore confusing, since the word 'its' in this sentence already refers to predecessors of TROPOMI (which is a spectrometer). Therefore, we keep the sentence as is.

Line 24: It can be said that TROPOMI's 3.6X5.6 km spatial resolution is indeed unprecedented in hyperspectral sensors. However, that is not the case for multi-wavelength sensors. Near UV channels at sub-kilometer resolution have been added to *several sensors over the last decade. In 2009, the Cloud Aerosol Imager (CAI) sensor on the Japanese GOSAT TANSO satellite made 380 nm radiance measurement at 0.25 km resolution (Fukuda et al., 2013). Similar measurements were carried out by the Second-generation Global Imager (SGLI) launched in 2017 (Tanada et al, 2023). Measurements at 339 and 377 nm at 0.46 km resolution have been made by CAI-2 since its launch in 2018 (Gogoi et al., 2023). The recently deployed PACE-OCI instrument measures UV radiances at 1 km spatial resolution (Werdell et al., 2019).*

Our paper focusses on the signals in hyperspectral sensors (at high spectral resolution) rather than multi-wavelength imagers (which use wavelength bands). For the AAI, two wavelengths in the UV (sampled at high spectral resolution) are used. Hence, we have not included a discussion of the measurements taken by imagers in our paper.

Lines 34-35: Another important non-aerosol related effect on measured near UV radiances is pure water absorption over the remote oceans. Suggest adding 'as well as pure water absorption effects over the remote oceans (Fry, 2000)' after (Kooreman et al., 2020).

Possible spectral effects of dissolved matter and chlorophyll in the ocean could indeed affect the AAI. We have added 'constituents in the ocean' as follows:

Lines 34-35: *Hence, AAI features that are not related to absorbing aerosols, for example caused by the ocean glint, absorbing constituents in the ocean water, and clouds at specific scattering geometries (Kooreman et al., 2020), may be undesired for those retrievals.*

Line 39: Suggest adding hyperspectral before predecessors.

We leave the sentence as is. See previous answer to comment regarding line 22, above.

Line 40: A brief discussion on earlier studies on cloud shadows in the near UV applied to observations by other high spatial resolution multi-wavelength instruments (JAXA's CAI, SGLI and CAI-2) should be included here.

We do not believe a discussion on cloud shadows in imager data would improve the introduction of the paper. We think that the reader could be confused by such a discussion, due to the different type of instruments and different type of satellite products.

Line 99. Suggest qualifying or removing the statement 'In the absence of aerosols and clouds, the AAI is, in theory, ideally equal to zero' . Actually, there are multiple non-aerosol related effects such as land surface reflectance spectral effects (deserts in particular) and ocean signal associated with sunglint and clear water absorption (both yielding positive AAI values) as well as chlorophyll absorption that yields negative AAI values. An explanation of how these non-aerosol related effects are detected and flagged should be included.

Those other AAI-modifying phenomena indeed could, in principle, contaminate our data set with shadow-pixels and non-shadow pixels. However, we think that there is no reason to believe that the probability to, for example, encounter chlorophyll is higher in a shadow pixel than in shadow-free neighbour pixel. Since our analysis focuses on the differences between the shadow- and shadow-free neighbour pixels, we do not expect those phenomena to change the conclusions of our paper. We consider those effects to be part of the 'natural variation irrespective of cloud shadows', which is captured by the comparison of the first and second shadow-free neighbour pixels (see Sect. 3.2).

In the introduction we already mentioned that '*[...], AAI features that are not related to absorbing aerosols, for example caused by the ocean glint, absorbing constituents in the ocean water, and clouds at specific scattering geometries (Kooreman et al., 2020), may be undesired [...]*'. To further clarify the sentence on line 99, we have modified it as follows:
Line 99: ~~*In the absence of aerosols and clouds, the AAI is, in theory, ideally equal to zero*~~ *–> In a scene without aerosols and clouds, above a spectrally neutral Lambertian surface, the AAI is, in theory, equal to zero.*

Line 100 Elaborate on the reasons for such a large negative offset. Is the reported AAI adjusted for this offset? If so, how? Provide references on this issue.

The AAI bias was not corrected for in this paper. We have added the following sentences to line 100:
The offset in the collection 1 AAI data used for this paper is due to a radiometric calibration offset and degradation in the TROPOMI irradiance data (Tilstra et al., 2020; Ludewig et al., 2020). The degradation in the irradiance leads to an increase in the derived reflectance, decreasing the average AAI values over time.

Line 101 On the detectability of aerosols above clouds suggest adding the Torres et al (2012) reference.

We thank the reviewer for the suggestion. We have added this reference to line 101.

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