Response to Reviewers

Response to comments from Reviewer #2

[Comment 1] *Line 123-124, the definition of SCD and VCD need be rephrased since they are not accurate in current description. Please refer to the product documentation or the DOAS book (Platt and Stutz, 2008).*

[Response] Thanks for the comment and suggestion. We have reviewed the DOAS book (Platt and Stutz, 2008) and the TROPOMI NO_2 issue 2.2 product documentation (S5P-MPC-KNMI-PRF-NO_2), OMNO2 version 4.0 product documentation, QA4ECV NO_2 version 1.1 product documentation. In the book and product documentations, the definition of SCD and VCD are all "slant column density" and "vertical column density" (e.g. Page 345, 347 in the book), the same as mentioned in our manuscript.

[Comment 2] *In Fig.2, in addition to the version of retrievals, the periods are also different. How can we attribute the differences to the retrieval itself rather than the differences of NO_2 in temporal? Please clarify and provide the evidence.*

[Response] Thanks for your comments. Figure 2 shows the differences in monthly mean tropospheric NO_2 columns derived from TROPOMI data and QA4ECV OMI data between December 2019-March 2020 and December 2020-March 2021, which is aim to present the differences between TROPOMI NO_2 v1.3 and 1.4 by QA4ECV OMI NO_2 data as reference on a monthly average basis, not for demonstrating the differences of NO_2 in temporal by these datasets themselves.

The differences of NO_2 in temporal retrieved by TROPOMI, OMNO2 and QA4ECV OMI data are discussed in section 3.1, 3.3 and Figure 1, 5, 6 in our manuscript. We find that TROPOMI v1.3 tropospheric NO_2 VCDs have the largest decrease in the summer months (e.g. 52 % for June, 54 % for July and 50 % for August), and the smallest decrease in the winter months (e.g. 15 % for January, 13 % for February and 22 % for March), as compared to the OMNO2 tropospheric VCDs. Similar seasonal differences exist in the comparison of the TROPOMI tropospheric NO_2 VCDs to the

QA4ECV OMI tropospheric NO_2 VCDs (e.g. -46 % for June, -50 % for July, -48 % for August and 15 % for January, 18 % for February, 49 % for March). Furthermore, TROPOMI v1.3-2.2 data shows strongest seasonal variation of tropospheric NO_2 columns compared to OMNO2 and QA4ECV OMI data, the extents of the observed NO_2 changes in winter or summer month retrieved from TROPOMI exceed those retrieved from OMI.

[Comment 3] *Sect 3.2, when the authors discuss the impacts of DLER over vegetation, only a summer month (August) were selected for Fujian province and China. I guess this month was chose to represent the condition with vivial vegetation. However, a comparative withered season/month should also be considered to show the change in surface albedo and further impacts in DLER and NO_2 products.*

[Response] Thanks for the comment and suggestion. We have added a comparison of daily TROPOMI tropospheric NO_2 columns in December of 2020 (v1.4), 2021 (v2.2) and 2022 (v2.4) over Fujian province and China, as well as a discussion on the impacts of DLER in TROPOMI NO_2 v2.4 retrieval over vegetation during withered month. The impacts of TROPOMI NO_2 v2.4 improvements under conditions with lush vegetation (summertime) and withered vegetation (wintertime) over high vegetation coverage and the whole China are all investigated. The analysis and discussion on the impacts of TROPOMI NO_2 v2.4 retrieval under these conditions are given, please see Line 364-380 and Figure 4 in the revised manuscript.

[Comment 4] *Fig. 5 and other similar inferred conclusions, I think that an independent ground-based measurements of NO_2 VCD datasets can strongly enhance the evidences. Otherwise, it's hard to exclude the upward trends in winter and downward in summer from the seasonal pattern difference from year to year. Similarly, there also other conclusions are not solid and convincible.*

[Response] Thanks for the comment and suggestion. In this work we use OMNO2 and QA4ECV OMI NO_2 products as reference for comparison, not ground-based NO_2 observations, due to the following two reasons. Firstly, up to date systematic and consistent ground-based NO_2 observation data has been only provided till November 2017 (e.g. QA4ECV MAX-DOAS datasets). Secondly, our manuscript focuses on evaluating of TROPOMI NO_2 v1.3-2.4 retrieval improvements over China, based on 3-year data with large spatial scale. For instance, Figure 5 covers a period from December 2019 to June 2022. Such a long-term independent ground-based NO_2 VCD dataset is difficult to obtain. Moreover, up to date OMI and TROPOMI have been the main data sources in satellite monitoring of NO_2 (Biswal et al., 2021), the retrieval of tropospheric NO_2 from QA4ECV OMI proceeds along the same lines as from TROPOMI, and is thus similar in many aspects. Thus QA4ECV OMI data is widely used as reference in previous studies on investigations of impacts of TROPOMI NO_2 version upgrades (Riess et al., 2022, van Geffen et al., 2022).

In addition, since the QA4ECV OMI NO_2 data product is available before 30 March 2021, in order to investigate the impacts of TROPOMI v2.2 (from July 2021-June 2022) and v2.4 (from July 2022-) on NO_2 retrieval, in this work OMNO2 data is also used to compare with TROPOMI data. Overall, comparisons of TROPOMI NO_2 v1.3-2.4 data with OMNO2 and QA4ECV OMI data have been able to well accomplish the evaluation of the impacts of these different retrieval version improvements.

[Comment 5] *Line 426-428, how to create the AMF dataset? By RTM? If it is, please describe the simulation and key inputs in details. And how about the authors' simulation compared to the AMFs used in products retrieval? If not, how to get the AMF?*

[Response] Thanks for the comments. The NO_2 AMF dataset is created using the Doubling-Adding KNMI radiative transfer model, and the input parameters to the NO_2 AMF calculation are surface albedo climatology, priori NO_2 profiles, viewing geometry, terrain height and cloud parameters. Please see Line 136-141 in the revised manuscript.

In this work we create the adjusted AMFs by deriving the differences of TROPOMI NO_2 AMF from v1.3 to 2.4, please see Table 2 in the revised manuscript. Furthermore, the comparisons between our simulation (TROPOMI with corrected by AMF) and satellite NO_2 data products are conducted. Please see Figure 8 in the revised manuscript.

[Comment 6] *Line 487-503, considering there were many literatures that reported the changes of NO_2 VCDs during the 2020 lockdown in China (in both spaced-based sensors and ground based MAX-DOAS), the authors could refer to the reported decreases and compared with the expectation in Figure 9.*

[Response] Thanks for your suggestion. We have reviewed and cited the related findings in the paper of Ding et al. (2020) as follows: "The expected TROPOMI NO_2 reduction over the BTH region (44 %) during the lockdown in February 2020 is consist with the previous study by Ding et al. (2020) who found that most Chinese cities showed strong NO_2 emission reductions of 20-50 % in the same period". Please see Line 514-516 in the revised manuscript.

[Comment 7] *Better to cite the full name of some nouns for the first time even in the abstract, e.g. Tropomi, OMI, QA4ECV, DLER, etc.*

[Response] Done as suggested.

[Comment 8] *Line 165, NO_2 subscript.*

[Response] Done as suggested.

[Comment 9] *Line 193, should be "tropospheric and stratospheric NO_2 SCDs"*

[Response] Done as suggested.

[Comment 10] *I would like to suggest to show the monthly series of different products of NO_2 VCDs from OMI and TROPOMI in another panel in Figure 1 too, which is helpful to show the absolute differences.*

[Response] Done as suggested. Please see Figure 1 in the revised manuscript.

[Comment 11] *Line 328-330, the comparison of spatial distribution between annual averages of these three products may be also presented in Fig. 3.*

[Response] Done as suggested. Please see Figure 3 in the revised manuscript.

Reference

Biswal, A., Singh, V., Singh, S., Kesarkar, A. P., Ravindra, K., Sokhi, R. S., Chipperfield, M. P., Dhomse, S. S., Pope, R. J., Singh, T. and Mor, S.: COVID-19 lockdown-induced changes in NO_2 levels across India observed by multi-satellite and surface observations, Atmos. Chem. Phys., 21(6), 5235–5251, doi:10.5194/acp-21-5235-2021, 2021.

Ding, J., van der A, R. J., Eskes, H. J., Mijling, B., Stavrakou, T., van Geffen, J. H. G. M. and Veefkind, J. P.: NOx Emissions Reduction and Rebound in China Due to the COVID-19 Crisis, Geophys. Res. Lett., 47(19), 1–9, doi:10.1029/2020GL089912, 2020.

Platt, U. and Stutz, J.: Differential Optical Absorption spectroscopy, Principles and Applications, ISBN 978-3-540-75776-4, 2008.

Riess, T. C. V. W., Boersma, K. F., Van Vliet, J., Peters, W., Sneep, M., Eskes, H. and Van Geffen, J.: Improved monitoring of shipping NO_2 with TROPOMI: Decreasing NOx emissions in European seas during the COVID-19 pandemic, Atmos. Meas. Tech., 15(5), 1415–1438, doi:10.5194/amt-15-1415-2022, 2022.

Van Geffen, J., Eskes, H., Compernolle, S., Pinardi, G., Verhoelst, T., Lambert, J. C., Sneep, M., Linden, M. Ter, Ludewig, A., Folkert Boersma, K. and Pepijn Veefkind, J.: Sentinel-5P TROPOMI NO_2 retrieval: impact of version v2.2 improvements and comparisons with OMI and ground-based data, Atmos. Meas. Tech., 15(7), 2037–2060, doi:10.5194/amt-15-2037-2022, 2022.