Point-by-point response letter

Note: The black font are comments from the referees, and the red font are authors' responses as well as the related change clarifications.

(1) Detailed response to the editor's comments:

Thank you very much for your insightful comments and valuable suggestions, which have greatly helped improve this paper. Responses to all your comments are provided below.

Comment 1: Throughout the manuscript: Please check again all instances where you write about NO2, NOx and NO. In several places, in particular in section 4.2, NO or NO2 is written in the paper where NOx is meant.

Response: Thank you for this important comment. We have carefully checked the use of NO_2, NO_x and NO throughout the manuscript, especially in Section 4.2. We have revised the relevant sentences to ensure that NO_2 is used when specifically referring to satellite-retrieved NO_2 columns or NO_2 fluxes, while NO_x is used where broader nitrogen oxides or regional reactive nitrogen emissions are meant.

Comment 2: I agree with the reviewer that the relatively short lifetime of NO2 and how it impacts your results deserves a paragraph in the section on uncertainties.

Response: Thank you for the suggestion. We have added a new subsection, Section 4.1.3 "Uncertainty associated with the chemical lifetime of NO_2", to the uncertainty analysis. This subsection discusses that NO_2 chemical loss during transport may affect the estimated magnitude of cross-boundary transport signals, especially during photochemically active seasons or along longer transport pathways. We also clarify that persistent features such as transport pathways and seasonal variations are expected to be more closely controlled by the background large-scale circulation. Therefore, the chemical lifetime of NO_2 is now discussed as an uncertainty in the interpretation of transport intensity, together with satellite retrieval errors, vertical profile representation and wind-field uncertainties.

Comment 3: P2, l18: affect => affecting

Response: Corrected as suggested.

Comment 4: P3, l3: over => of

Response: Corrected as suggested.

Comment 5: P4, l16: Please include the version of TROPOMI product used.

Response: Thank you for the suggestion. We have added the version information of the TROPOMI NO_2 product used in this study in the data description section.

Comment 6: P11, l10: To my knowledge, much shorter lifetimes than the 8 hours mentioned here have been found in several studies for NO_2 in the boundary layer.

Response: Thank you for pointing this out. We have revised this statement to avoid overestimating the boundary-layer lifetime of NO_2. The revised text now states that the lifetime of NO_2 in the boundary layer is typically on the order of a few hours, while longer lifetimes may occur in the free troposphere or under weaker photochemical conditions. Please see the detailed revision in lines 15–16 on page 11.

Comment 7: P11, l12: I do not think that enhanced horizontal wind speeds can increase the NO_2 residence time.

Response: We agree with this comment. We have removed the statement implying that enhanced horizontal wind speeds increase the residence time of NO_2. The revised text now states that stronger winds may facilitate longer-distance transport before complete chemical removal, rather than increasing the chemical lifetime or residence time itself. Please see the detailed in lines 18 to 19 on page 11.

Comment 8: P11, l32: I do not agree with the statement that small deviations over high-albedo regions are amplified. I think the opposite is true – low-albedo surfaces lead to small AMFs, which in turn lead to stronger amplification of small deviations.

Response: Thank you for the clarification. We have revised this statement accordingly. The manuscript now states that low-albedo surfaces can lead to smaller AMFs, which may amplify the influence of small deviations in the retrieval process. Please see the detailed in lines 37 to 38 on page 11.

Comment 9: P12, l2: I do not agree – I think that OMI (and TROPOMI) NO_2 underestimation is largest in high-loading regions.

Response: Thank you for this correction. We have revised the relevant statement and now indicate that NO_2 underestimation by OMI and TROPOMI is generally larger in high-loading regions, rather than in low-loading regions. Please see the detailed in line 7 on page 12.

Comment 10: P12, l8: I do not agree with this statement – in my opinion, algorithmic improvements can do little about random noise, which is intrinsic to the spectra and can only be reduced by better instruments and more averaging.

Response: We agree with this comment and have revised the statement. We now distinguish between algorithm-related systematic retrieval uncertainties and random spectral noise. The revised text clarifies that random noise is intrinsic to the spectral measurements and can mainly be reduced by improved instruments and temporal or spatial averaging, rather than by algorithmic improvements alone. Please see the detailed in lines 13 to 15 on page 12.

Comment 11: P13, l10: Where do you take the NO_2 vertical profile from? If it is from GEOS-chem, then please add this information.

Response: Thank you for the suggestion. We have clarified the source of the NO_2 vertical profile used for the effective wind-field weighting. The revised manuscript now states that the NO_2 vertical profiles were obtained from GEOS-CF simulations. Please see the detailed in line 13 on page 13.

Comment 12: P13, l29: shape dominate => dominate

Response: Corrected as suggested.

Comment 13: Acknowledgements: Remove CO, add NO_2, add EDGAR.

Response: Corrected as suggested. We have removed CO and added NO_2 and EDGAR in the acknowledgements.

Comment 14: Figure 6: Please use the same map region in both plots.

Response: Thank you for the suggestion. We have revised Figure 6 so that both plots use the same map region.

Comment 15: Figure 7: Platea => Plateau

Response: Corrected as suggested.

(2) Detailed response to comments from referee #2:

Response to Referee #2:

Thank you very much for your insightful comments and valuable suggestions, which have greatly helped improve this paper. Responses to all your comments are provided below.

The manuscript has improved considerably with the previous comments of the reviews taken into account. Large parts of the text are rewritten and give a much clearer description of the research. The method has been adapted and improved on several aspects.

Also the chemical lifetime of the reactive gas NO2 has been discussed. However, the effect of the chemical decay of NO2 on the uncertainty of the transport is not clear to me. Can it be neglected using the presented methodology? It would be useful if a small section discussing this will be added by the authors to the uncertainty analysis in section 4.1.

Response: We thank the reviewer for the constructive comments. Regarding the chemical lifetime of NO_2, we have added a new subsection, Section 4.1.3 "Uncertainty associated with the chemical lifetime of NO_2", in the revised manuscript. This subsection discusses the chemical lifetime of NO_2 as an additional source of uncertainty when interpreting cross-boundary transport signals. Specifically, NO_2 may undergo chemical loss during transport, which may affect the estimated magnitude of the transport signal, particularly during photochemically active seasons or along longer transport pathways. However, relatively persistent features, such as transport pathways and seasonal variations, are generally more closely controlled by the background large-scale circulation. Therefore, the influence of NO_2 chemical lifetime is considered as an uncertainty in the interpretation of transport intensity, together with satellite retrieval errors, vertical profile representation, and uncertainties in wind fields. We also note that future studies incorporating chemical lifetime constraints and chemistry-transport modeling would help further assess the relative contributions of dynamical transport and chemical transformation.

Minor comments

-Abstract: page 1, Line 37 Please add the meaning of the acronym SHAP.

Response: Thanks for your suggestion. The meaning of the acronym SHAP has been added.

-Sect. 4.1.1, page 11, line 42: use capitals in "Differential Optical Absorption Spectroscopy"

Response: Thanks for your suggestion. The capitalization in “Differential Optical Absorption Spectroscopy” has been corrected