

Response to Reviewer 3's Comments

We deeply appreciate the reviewer for comments that develop our manuscript substantially. The reviewer's comments are written in blue, and our responses are in black. Following the reviewers' comments, we revised our manuscript – major changes are summarized below.

- (1) We replaced the emission inventory used for WRF-Chem simulation from EDGAR-HTAP version 3 to AQNEA version 2, with additional 20% reduction of NO_x emissions over South Korea to reflect decreasing trends of NO₂ between 2019 and 2021.
- (2) We also updated the GEMS IUP-UB products from version 0.9 to version 1.0, which includes considerations for the effects of clouds.
- (3) To clarify the content, we reorganized the experiment into five cases: TM5, CTRL, CONST, FINE, and MIXED. Further details can be found in Section 2.2.

One-on-one responses and information on the revision are given below.

General comments:

(1) For an overview of the IUP algorithm, only an unpublished study (Richter et al) is cited. Published references are given for some of the details including features fit to the spectra (Ring, NO₂ with temperature correction and other trace gases), a radiative transfer model, LER reflection values, etc. Most of these are fairly standard in DOAS retrievals. The stratosphere-estimation algorithm of Beirle et al. is also cited, but applying this to a GEO satellite is nontrivial. The authors should provide more details of the GEMS NO₂ retrieval used here, including an explanation of the cloud correction/screening.

➔ To consider the cloud correction, we updated the GEMS IUP-UB products from version 0.9 to version 1.0 (Lange et al., 2024). In the updated version, adjusted cloud fractions and pressure from the GEMS L2 cloud product were adopted to apply the AMF cloud correction. Also, cloudy scenes were excluded by using pixels with qa_value higher than 0.75.

(2) What is the temporal data domain for the study? Dates are given in figures 5, 6, 7, but elsewhere are GEMS retrievals from all days of each month combined into monthly/hourly means? Was the same done for the model output? What cloud screening was used, if any? For completeness, please also give the year.

➔ In the previous version of the manuscript, we investigated all days of January, April, July, and October 2021 for the comparison of WRF-Chem v3 and TM5, while only four days (October 25 – 28, 2021) were analyzed for comparing WRF-Chem v2, f2, and v3. Also, there were no cloud considerations in the previous version.

In the revised manuscript, the data from all days of January, April, July, and October 2021 were analyzed to compare the CTRL and TM5 cases, and the data from all days of July 2021 were investigated to compare CTRL, CONST, FINE, and MIXED cases. By updating the GEMS IUP-UB products from version 0.9 to version 1.0, cloud corrections are included by using cloud pressure from the GEMS L2 cloud product and recomputed cloud fractions by SCIATRAN (Lange et al., 2024). We also excluded cloudy scenes with cloud radiance fraction higher than 0.5.

(3) I'm confused by the f2 line (yellow) in figure 6. If a fixed NO₂ profile is used, shouldn't the TropVCD in the model be constant by definition? Why are there differences in the afternoon? I'd suggest eliminating the f2 line, unless I'm misunderstanding what it means, in which case

some explanation should be added.

→ The values of TropVCD in the model surely did not change by time. Since we excluded the model pixels where observations do not exist, the domain-averaged model values can be fluctuated. Especially, **Figure 6** in the previous version of the manuscript shows the mean values during only four days (October 25 – 28, 2021); masking of each pixel can affect the mean values. In the revised paper, the fluctuation of model TropVCD from CONST case is also captured by the same reason. We added related explanation into the caption of Figure 6 in the revised manuscript.

Minor comments and suggested corrections:

We appreciate your suggested corrections. Since this paper has been majorly revised, many sentences you suggested for corrections have been deleted or rewritten. However, we have incorporated your suggested edits as much as possible during this process.

(1) Page 2, Lines 10, 17: Please state what the ranges represent.

→ The ranges represent the maximum values in July from TM5 case to WRF-Chem v3 case.

(2) Page 4, Line 3: Might be clearer stated as “...NO₂ TropVCD between the WRF-Chem- and TM5-based GEMS datasets...”

→ Changed.

(3) Page 5, Line 18: “...chemistry scheme follows the Regional Atmospheric Chemistry Mechanism ...”

→ Changed (Page 5, Line 26).

(4) Page 5, Line 24: "...were combined with..."

➔ Changed (Page 6, Line 4).

(5) Page 7, Line 7: "...may affect NO₂ TropVCD values for each month."

➔ The sentence is deleted in the revised manuscript.

(6) Page 7, Line 15: "VCDs from the two GEMS products were similar throughout..."

➔ The sentence is deleted in the revised manuscript.

(7) Page 7, Line 20: "For all times..."

➔ The sentence is deleted in the revised manuscript.

(8) Page 8, Line 2: "The differences in GEMS..."

➔ The sentence is deleted in the revised manuscript.

(9) Page 8, Line 18: "Figure 5 compares the diurnal changes in GEMS NO₂ TropVCD..."

➔ The sentence is deleted in the revised manuscript.

(10) Page 8, Line 21: "...the two GEMS data products..."

➔ The sentence is deleted in the revised manuscript.

(11) Page 9, Lines 4-5: Giving a range here is confusing. I suggest “Therefore, NO₂ TropVCDs calculated using WRF-Chem f2 show values up to 16.5% lower before 13:45 KST and up to 4.9% higher...”

→ The sentence is deleted in the revised manuscript, but I refer to your comment to prevent any further confusion during the revision.

(12) Page 9, Lines 6-8: “Notably, despite the diverse diurnal variations in a priori data from TM5 and WRF-Chem v3, the retrieved columns based on these data exhibited similar diurnal patterns...”

→ The sentence is deleted in the revised manuscript.

(13) Figure 2: This figure is hard to read because the maps are small. Is it possible to expand them? Also, the label on the color scale is too small to see clearly. It would help to add “WRFChem v3 minus TM5” in the figure caption(s).

→ The expanded and zoomed-in maps are displayed in Figure 9 to Figure 11 in the revised manuscript. Also, we added “(CTRL – TM5)” in the captions of Figure 3 and Figure 11 in the revised manuscript.

(14) Figure 6: Consider omitting the yellow line (f2). See “General comments”.

→ As mentioned in the General comments #3, the diurnal changes of ‘WRF-Chem f2’ case in the previous version or ‘CONST’ case in the revised version occur during calculating domain-averaged values – the location and number of pixels excluded during the collocation with satellite data vary over time during the day.

References

Lange, K., Richter, A., Bösch, T., Zilker, B., Latsch, M., Behrens, L. K., Okafor, C. M., Bösch, H., Burrows, J. P., Merlaud, A., Pinardi, G., Fayt, C., Friedrich, M. M., Dimitropoulou, E., Van Roozendael, M., Ziegler, S., Ripperger-Lukosiunaite, S., Kuhn, L., Lauster, B., Wagner, T., Hong, H., Kim, D., Chang, L.-S., Bae, K., Song, C.-K., and Lee, H.: Validation of GEMS tropospheric NO₂ columns and their diurnal variation with ground-based DOAS measurements, *egusphere [preprint]*, <https://doi.org/10.5194/egusphere-2024-617>, 2024.