

Interactive comment on “Ground-based validation of the Copernicus Sentinel-5p TROPOMI NO₂ measurements with the NDACC ZSL-DOAS, MAX-DOAS and Pandonia global networks” by Tijl Verhoelst et al.

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Dear referee,

Many thanks for your careful reading of our manuscript, and for the valuable feedback. We address your concerns below (and in a modified version of the manuscript).

Referee comment: A consistent theme in the validation process is the underes-
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time of column NO₂ compared to ground-based measurements, both MAX-DOAS and direct sun. The main effect causing the differences is area averaging over the TROPOMI pixel compared to the very local observations from ground-based instruments. Agreement when pollution effects are small or zero is quite good because the stratospheric component of NO₂ is much more spatially homogeneous. The disagreement increases as the pollution level increases along with spatial inhomogeneity. In the present document, the authors treat the spatial averaging effect as uncertain. A comparison of TROPOMI with the larger OMI area averaging effect from its larger pixel size should be convincing. The paper should include a stronger statement about the effect of area averaging on ground-based validation of TROPOMI.

Answer: *Indeed, the underestimation of tropospheric columns (and of total columns when these contain a significant tropospheric contribution) in the S5p product is a clear outcome of our comparisons, which is fully in line with the outcomes of other comparable validation exercises, both on S5p and on other satellite NO₂ data sets. While differences in area averaging most certainly contribute to this, and while this may have been the dominant effect in the underestimation by larger-footprint sounders such as GOME, GOME-2, and OMI, we are less certain it is the dominant cause in our S5p comparisons, for the following reasons:*

- *The S5p pixel size is much smaller than that of the other sounders, and it is comparable to larger emission sources (cities, harbours, . . .). The footprint is still (much) larger than that of the MAX-DOAS or Pandora, but unless the latter is really positioned near the peak of the emission source, the difference in area averaging can work both ways (i.e. not necessarily leading to an underestimation, but mostly increasing the scatter).*
- *In a preceding study on OMI vs. MAX-DOAS and Pandora (Compernelle et al. 2020), we already concluded that area-averaging can not be the sole cause, and that short-comings in the assumed vertical profile, in particular in polluted conditions, probably is a key effect. This is corroborated, for S5p, by several studies demonstrating the reduction in negative bias by replacing the a priori profile with one taken from a more detailed regional*

model (e.g. Ialongo et al., AMT., 13, 205–218, 2020; Tack et al., AMTD 2020-148). While this is to some extent also a horizontal resolution effect (of the underlying profile climatology/model), it is not an NO₂ area averaging effect in itself.

- A similar effect is found for assumed aerosol concentrations (Liu et al, AMTD 2019-500)
- An upcoming improved cloud product, a key input to the NO₂ retrieval, has already been demonstrated to reduce the underestimation (Eskes et al, in prep.).

A comparison between OMI and TROPOMI comparisons should indeed show the impact (i.e. a stronger underestimation) of the larger area averaging of OMI, but it can be argued (as done above) that this does not imply a similar scale issue for TROPOMI vs. MAX-DOAS or Pandora (because TROPOMI is starting to resolve the emission sources, which is much less the case for OMI). We have now mentioned the effect of area averaging explicitly in the abstract, and it is put in perspective (along the same lines as described above) starting at line 389.

Line 27: nitrates, which are -> fixed

Line 30: local national regulations limiting boundary -> fixed

Line 47: on a global scale -> fixed

Line 51: Onwards -> fixed

Line 109: processor versions to which this corresponds -> fixed

Line 294: the referenced site does not contain all the data that were used in this paper. -> These 2 websites (EVDC and PGN) should together contain all the data, as that is where we obtained them. Please provide us with more specifics if something is missing on these archives.

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