S5P/TROPOMI NO2 slant column retrieval: method, stability, uncertainties, and comparisons against OMI

by Jos van Geffen, et al.; amt-2019-471

Response to anonymous referee #3

RC This paper describes the slant column density retrieval for the TROPOMI satellite instrument and gives a detailed assessment of uncertainties and comparisons with OMI. The paper is well written and despite the topic being very technical, I found the paper very clear and easy to follow. The details will be of interest to a limited set of scientists (retrieval algorithm developers mostly) but it is a thorough record of the uncertainties and preliminary temporal behaviour of the TROPOMI slant column retrievals. I recommend it be published following a few minor revisions.

We thank the referee for the kind words and for reading the manuscript in great details.

Changes to the manuscript are based on the comments and suggestions of three referees. In addition we have extended the data record of the paper by 3 months, which has lead to updating some figures and numbers, but has *not* affected the conclusions of the paper.

In the following we answer the general and specific comments of referee #3.

RC The paper focussed almost entirely on an analysis of slant columns from tropical observations over the clean remote Pacific. I would have liked to have seen some slant column retrieval comparisons over an entire orbit, as some of the differences between retrieval approaches or instruments might be exaggerated at the highest solar zenith angles. Perhaps adding just a sentence or two describing how well the conclusions drawn about uncertainties, retrieval algorithm comparisons etc extend to cases other than the remote Pacific could be useful.

Pacific Ocean orbits are used for the stability and accuracy analysis of the SCD retrieval because we may assume that those orbits do not show significant (anthropogenic) tropospheric NO_2 concentrations.

- The stripe amplitude stability in Sect. 4.3 uses a 30-degree tropical latitude range over the Pacific Ocean, as that is range is used to define the stripe amplitude.
- The quantitative comparison in Sect. 4.4 uses data from multipile orbits (a) over the Pacific in the latitude range [-60:+60] and mentions results for both July 2018 and Jan. 2019, and thus covers a wide range of SZAs, and (b) over the India-to-China ares in a latitude range of [0:+60] for July 2018 only, thus also covering a fair range of SZAs as well as pollution sources.
- The SCD uncertainty analysis in Sect. 4.6 uses Pacific Ocean orbit data in the latitude range [-60:+60] for all days of the year and thus includes a wide range of SZAs.

In short, we feel that the points raised by the referee are already well covered in the paper.

RC Page 3, Line 11: Give units of conversion factor.

That would be something like "molecules per mol", but since "molecules" is not a proper unit, the conversion factor has the same unit at Avogadros number: 1/mol – added this unit.

RC Page 5, Line 31: I'm a bit confused by the wording describing a satellite latitude range. How is this changing between these two end points of 1 Jan and 1 July?

With "satellite latitude range" we mean the latitude of the sub-satellite point, i.e. the data in the `satellite_latitude` variable, which approximately corresponds to the nadir viewing detector rows. The wording has been adapted to describe this more clearly [P6,L4ff]:

> To investigate the stability and uncertainties of the NO_2 SCD retrieval the "Tropical Latitude" (TL hereafter) range is defined as all scanlines that have their sub-satellite latitude point – corresponding approximately to the nadir viewing detector rows – within a 30° range that moves along with the seasons, in an attempt to filter out ...

RC Page 9, Line 25: Comparing to OMI but no OMI results shown, so could you give a number indicating the magnitude of OMI variations?

Actually the amplitude of the seasonal cycle in OMI's visible channel is comparable to TROPOMI's, as shown by Schenkeveld, et al. (2017) in their Fig. 34, as referee #1 pointed out correctly. The manuscript text has been adapted accordingly [P10,L3-5]:

> A similar seasonal variation of similar amplitude is seen in the wavelength calibration data of OMI's visible channel (Schenkeveld et al., 2017, Fig. 34). Both for TROPOMI and OMI this amplitude does not exceed scatter levels and is thus well within instrument requirements.

RC Page 19, Line 12: define "India and China" latitude/longitude region

Both regions are defined in the legends in the figure panels; a reference to that is included in the text [P19, L20].

RC Page 21, Line 2: degradation of 1-2% relative to what? Is this degradation in throughput per year?

Degradation of the absolute irradiance, w.r.t. the beginning of the mission; the potentially confusing word "notably" has been removed.

RC Figure 7: I find the colors of b and c very hard to follow in my mind. I think it's more common to be looking at a solid line that represents the average and a dotted line of the same color that represents a standard deviation or similar. Here they are different colors but the same pattern for a single orbit (backwards to what I'm used to). Not a significant issue but I just find it a bit confusing.

Your comment and the comment of referee #1 has shown that the choice made for the linetype is too confusing, hence the more intuitive approach is used now, with an updated figure caption, noting that the solid lines for the quantities themselfs almost overlap in Fig. 7b and fully overlap in Fig. 7c.
Note that in the revised version the figure now has number 8.

RC Page 25, Line 3: Define VRS earlier if not done already

Done.

RC Section 5.2, 5.3: These sections seems a bit tacked on to a very detailed earlier analysis. Is there any recommendation about how to deal with the high-NO2 data? Is there a limit at which the data is questionable? Are these cases flagged?

Neither section is based on more detailed analysis by the authors: Sect. 5.2 uses the S5PVT validation results to make a statement about the Pacific Ocean NO_2 SCDs. Sect. 5.3 discusses earlier findings regaring high NO_2 concentrations published by Richter et al. (2014).
As mentioned in the paper, it is unlikely that TROPOMI will detect concentrations of NO_2 so high that the reported concentrations are really wrong. One may in individual

ground pixels find such high values, but there are likely too few points on which to base any sensible statement.
Ground pixels with high NO_2 concentrations are not flagged as such; usually these concentrations will come with a somewhat elevated SCD error but not exceptionally large SCD errors (as in the example mentioned: 883 ± 16 μmol/m^2). Given that there is not a clear-cut limit between good and bad high NO_2 concentrations, there is no sensible criterion to yes of no flag such data.

In the following we answer the technical comments of referee #1.

RC Abstract, Line 16: Change "$\sim$2" to "a factor of $\sim$2"

Done.

RC Page 2, Line 14: change to "in both the troposphere and stratosphere"

Done.

RC Figure 3 caption: I think "d,f" should be "c,f".

You are right, thanks for noting this.