Response to Referee #1:

We thank referee #1 for their helpful comments. Our responses are given below in black with the referee's comments in blue. The new/revised text in the modified manuscript is given in red (italicized).

Specific comments

I have an issue with the title. I think it should include that the assessment of TROPOMI NO2 data in the GTA. Now it gives the impression that the assessment is exhaustive. Maybe you could add "in the Greater Toronto Area" at the end or something similar

Done. The title has been modified as requested.

Assessment of the quality of TROPOMI high-spatial-resolution NO_2 data products in the Greater Toronto Area

Section 2.1.2. Does ECCC NO2 Modis-based albedo include geometry-dependent information?

No. The product used is a simple Lambertian albedo (MODIS product MCD43C3), and therefore, is not dependent on geometry (analogous to the albedo product used in the KNMI TROPOMI AMF calculation). The TROPOMI ATBD albedo (https://sentinel.esa.int/documents/247904/2476257/Sentinel-5P-TROPOMI-ATBD-NO2-data-products) estimates using this approach, as opposed to a BRDF, which leads to an error of roughly 5% or less (page 35), citing Zhou et al., 2009. The sentence is modified in the text.

Improved albedo inputs were created using averaged monthly albedo for areas without snow cover and a climatology for snow-covered areas using the MODIS MCD43C3 data product (Schaaf et al., 2002) by only considering grid-boxes that were 100% snow-free or 100% snow-covered. The choice of which to use, snow-free or snow-covered, is determined using the IMS snow product.

Section 3.1 Did you analyse how the agreement change in the standard approach if you change the radius (spatial averaging) or the time range? And did you find any dependence on the pixel size (it should be less important than for OMI, since the increase from the center to the side of the swath is much smaller).

Yes, we tested the standard approach with various radius and time range criteria. The current criteria ($d < 20$ km, $t < \pm 10$ min) selected are found to give a good balance between the number and quality of coincident measurements.

For TROPOMI data, we did not filter the pixels by their footprint. For the GTA area (before Aug. 6^{th}, 2019), we found the smallest central pixel has a footprint of 26 km^2 (approximately 7 km × 3.7 km), whereas the largest edge pixel has a footprint of only 100 km^2 (approximately 7 km × 14 km). Thus, even TROPOMI's large pixel has a spatial resolution better than OMI's "small pixel". To reveal the potential dependence on TROPOMI's pixel size as suggested by the referee, we need more ground-based and satellite coincident data (i.e., three or more years of data might be sufficient). With the current one-year data, it is difficult to make a solid conclusion.

Abstract: You might want to add some number e.g. absolute or relative difference or correlation between Pandora and Tropomi NO2 in the abstract. Also for the improvement in the agreement using high resolution model AMFs it could be useful to quantify this improvement here in the abstract.

Done.

It is found that these current TROPOMI tropospheric NO_2 data products (standard and ECCC) met the TROPOMI design bias requirement (<10 %).

The Pandora instruments are found to have sufficient precision (<0.02 DU) to perform TROPOMI validation work.

The TROPOMI ECCC NO_2 research data product shows improved agreement with Pandora measurements compared to the TROPOMI standard tropospheric NO_2 data product (e.g., lower multiplicative bias at the suburban and urban sites by about 10 %), demonstrating benefits from the high-resolution regional air quality forecast model.

P2 L21 You write that Pandora NO2 VCDs have been validated through […] satellite validations That sounds inaccurate. Maybe you mean "have been used in…"?

Done.

The Pandora direct-sun NO_2 VCD_{total} products have been validated through many field campaigns (Flynn et al., 2014; Lamsal et al., 2017; Martins et al., 2016; Piters et al., 2012; Reed et al., 2015), ground-based comparisons (Herman et al., 2009; Wang et al., 2010), and used in satellite validations (Griffin et al., 2019; Herman et al., 2019; Ialongo et al., 2016, 2019; Lamsal et al., 2014).

P2 L23 You can add these TROPOMI validation paper using Pandora data also here: Herman et al 2019 Ialongo, I. et al, 2019.

New citations are included.

P3 L32 Maybe you can mention that the resolution decreased to 3.5 5.5 km since 6 August 2019.

This information has been included.

The instrument has a high spatial resolution of 7 km × 3.5 km (along-track × across-track) at nadir for bands 2-6 (UVN module) (Eskes et al., 2019) (note that since 6 August 2019, the resolution improved to 5.5 km × 3.5 km).

P4 L20 TROPOMI file includes a QA quality flag that is recommended to be used for flagging with QA>0.75 for clear sky. You say here that you use cf<0.3 but later on you say that you use the quality flag which already include the cloud screening: can you clarify?

This extra cf<0.3 filter is used to ensure the comparison between OMI and TROPOMI is straightforward, i.e., we used a cf<0.3 filter for OMI data. The explanation has been included in P8.

Note that the TROPOMI quality assurance value filter (qa_value > 0.75) removes cloud-covered scenes with cloud radiance fraction > 0.5. In this study, to make a straightforward comparison with OMI, an additional cloud fraction filter is used (cloud fraction <= 0.3) for TROPOMI data.

P8 L18 In previous -> Previously

Done.

P10 L20 You find positive bias at Egbert: can you speculate on the reasons? Stratospheric overestimation perhaps (see e.g. Wang et al 2019 AMTD)?

We agree with the referee that stratospheric overestimation in the TROPOMI stratospheric columns could be a reason for this positive bias at Egbert. Currently, Pandora only has a total column NO_2 data product. In the future, Pandora tropospheric and stratospheric column products (e.g., products from zenith-sky and multi-axis measurements) can be used to further this investigation.

The positive bias at Egbert might be due to TROPOMI overestimating stratospheric NO_2 (e.g., Wang et al., 2019).

P14 L9 TROMPOMI -> TROPOMI

Done.

Figure 1. It could be useful to add (perhaps in the appendix or supplement as well) a map like Fig. 1 including OMI data in order to visualise the differences in the mapping capability of the two instruments.

The pixel-averaging plot for OMI is made with its 2015-2018 data (see Fig. R1 in below). The averaging radius is selected to be the same as Fig. 1 (i.e., 7 km). In general, the spatial distribution of high-density NO_2 over the GTA area is consistent with the results in Fig. 1, which use TROPOMI data. Although some small-scale features are not identical, these differences might be due to their different averaging periods (i.e., three years for OMI, but one year for TROPOMI). To fully reveal the mapping capability of the two instruments, we shall wait for another two or more years of coincident measurements. Also, as suggested by the referee that this paper is already figure-heavy, we decided not to include this extra map in the paper.

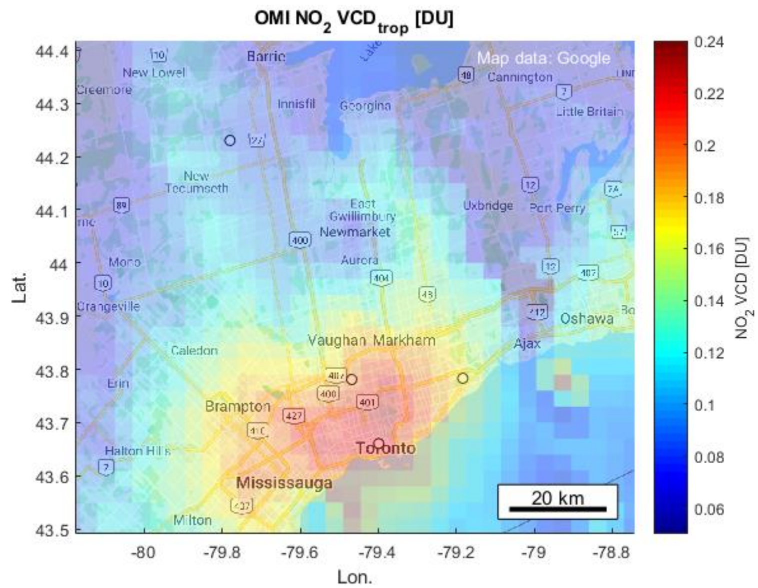

Figure R1. OMI SPv3 NO_2 tropospheric columns smoothed by pixel averaging (2015 to 2018) (© Google Maps).

Figure 8. Could be this go to appendix or supplement? (the paper is quite figure heavy anyway)

Done. Figure 8 has been moved to Appendix A.

The number of coincident pairs and the number of unique days for each wind-bin are shown in Fig. A1.

Reference

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