This paper presents extensive comparison between satellite measurements and COCCON measurements at two high-latitude Russian cities, St. Petersburg and Yekaterinburg. A method of scaling CAMS model data to COCOON observations is developed, for a better comparison with the satellite measurements. I have several main concerns, which should be addressed before this paper can be published in AMT.

We would like to thank anonymous Referee #3 for evaluating our manuscript and for constructive comments that will definitely improve it. Below, we list the original comments/questions in blue colour and our answers/comments in black, respectively.

1. When comparing the satellite products with COCCON measurements, have you considered different averaging kernels for the satellite data and the ground-based remote sensing measurements?

We would like to thanks our referee for pointing this out; in the initial manuscript, we did not use averaging kernels in both comparisons COCCON and CAMS-COCCON vs Available Satellite products, because we assumed that the adjustments resulting from the smoothing would be minor. Nevertheless, we agree that performing a comparison without removing the smoothing error arising from use of different a-priori profiles is a technical error and we therefore have updated the manuscript and applied the averaging kernels for removing the smoothing error bias from our comparisons. We added the section 4.2 as follows:

4.2 Removal of the smoothing error bias

Because we aim at comparing different data products from space-borne with COCCON products and each of them have different sensitivities and use a different a-priori profiles; it is important to account for these differences when comparing a defined Xgas specie as described by Rodgers and Connor, (2003) and Connor et al., (2008). Such procedures have been applied in other similar studies (Hedelius et al., 2016, Yang Yang et al., 2020, M. K. Sha et al., 2021). In this study, we used the method described in Connor et al., (2008). We took as starting point the eq. (13), then the state vector can be written as:

$$\overrightarrow{VMR}_{gas,obs} = \overrightarrow{VMR}_{gas,apr} + A\left(\overrightarrow{VMR}_{true} - \overrightarrow{VMR}_{gas,apr}\right) \qquad \text{Eq. 1}$$

Where $\overrightarrow{VMR}$: represents the Volume Mixing Ratio. The left-term of the equation represent the retrieved value, while the right term represents the VMR calculated based on the a-priori plus the effect of the averaging kernel matrix A applied to difference of the VMR between the true atmospheric gas concentration and the a-priori. By dividing the atmosphere in "k" layers, this equation can be written as follows:

$$X_{gas,obs} = X_{gas,apr} + \sum_{0}^{k} h_k a_k (VMR_{true,k} - VMR_{apr,k}) \qquad \text{Eq. 2}$$

Where:
$X_{gas,y} = \sum_k h_k . VMR_{y,k}$ With "y" being a defined a-priori used and h_k: the pressure-weighting function in a defined layer "k" (Connor et al., 2008), i.e:

$$h_k = \frac{(p_{k-1} - p_k)}{p_0} \qquad \text{Eq. 3}$$

By using Eq. 2 with a "new" and "old" satellite-a-priori we obtain (*) and (**) as follows:

$$X_{gas,obs-new} = X_{gas,apr-new} + \sum_0^k h_k a_k (VMR_{true,k} - VMR_{apr-new,k}) \qquad (*)$$

$$X_{gas,obs-sat} = X_{gas,apr-sat} + \sum_0^k h_k a_k (VMR_{true,k} - VMR_{apr-sat,k}) \quad (**)$$

Then we subtract (*) from (**):

$$X_{gas,obs-new} = X_{gas,obs-sat} + (X_{gas,apr-new} - X_{gas,apr-sat}) + \sum_0^k h_k a_k VMR_{true,k} - \sum_0^k h_k a_k VMR_{apr-new,k} - \sum_0^k h_k a_k VMR_{true,k} + \sum_0^k h_k a_k VMR_{apr-sat,k}$$

Which turns into:

$$X_{gas,obs-new} = X_{gas,obs-sat} + (X_{gas,apr-new} - X_{gas,apr-sat}) + \sum_0^k h_k a_k (VMR_{apr-sat,k} - VMR_{apr-new,k})$$

Where $X_{gas,obs-new}$ in Eq. 4 becomes the smoothed satellite product, which takes into account the a-priori used for the COCCON retrievals.

For using Eq. 4, both a-priori profiles need to be resampled on the same pressure grid. The vertical profiles used for the COCCON analysis are interpolated to the pressure levels of different satellite products (TROPOMI CO, GOSAT CO_2 and CH_4, OCO-2 CO_2 and OCO-2 FOCAL CO_2) by using the mass conservation method described in Langerock et al., (2015).

The smoothing correction is not applied to the XH_2O, because the natural variability of XH_2O is very high anyway.

2. For the regression plots shown in this paper, how are the R2 values determined? I understand that the fits are forced to go through origin. However, the reported R2 values are all very high, and I can not see how a R2 = 0.9999 is possible for the middle plot of Fig. 19, where there is no correlation between the scatter points and the regression line, and how in Figure 10 the top left and bottom left plots can have the same R2. Please check your regression algorithm.

We would like to thanks to the referee for pointing this out. We agree that this can confuse the reader, when the fitting lines are forced to cross the origin point. We then decided to change to a linear regression without forcing to cross the origin point and therefore we have updated all the figures accordingly.

3. You use a co-location criteria for satellite and ground-based measurements of up to 200 km. Have you checked whether there are emission sources in between? I doubt that the comparison can be objective if the distance is so large.

We use a collocation radius of 200 km for the OCO-2 comparison because there are so few OCO-2 observations within 50 km or 100 km, see Table 1. We have added Figure 2 and Figure 3 below (on reply to question 9.) which indicates that there is no significant increase of bias when increasing the collocation radius.

Table 1. Number of observations for OCO-2 and OCO-2 FOCAL within different collection radius at Peterhof and Yekaterinburg.

	OCO-2		OCO-2 FOCAL	
	Peterhof	Yekaterinburg	Peterhof	Yekaterinburg
50 km	5	1	0	0
100 km	13	1	1	0
200 km	23	5	13	0

Further suggestions:
1. One map (maybe in appendix) regarding the locations of their measurements (up- and downwind sites) and the potential emission area which you assume to contribute the enhancement (details in Line 170, page 8). It is quite hard to imagine if someone is not familiar with the geographical information for your study.

The requested map is already included in Figure A-2 (a) in the appendix of the paper, together with a HYSPLIT map with backward trajectories arriving to Peterhof on that day. However, to make this clear we have improved the map as suggested by adding a reference to the figure in the main text, and marking the name of the potential source into the appendix figure (see Figure 1).

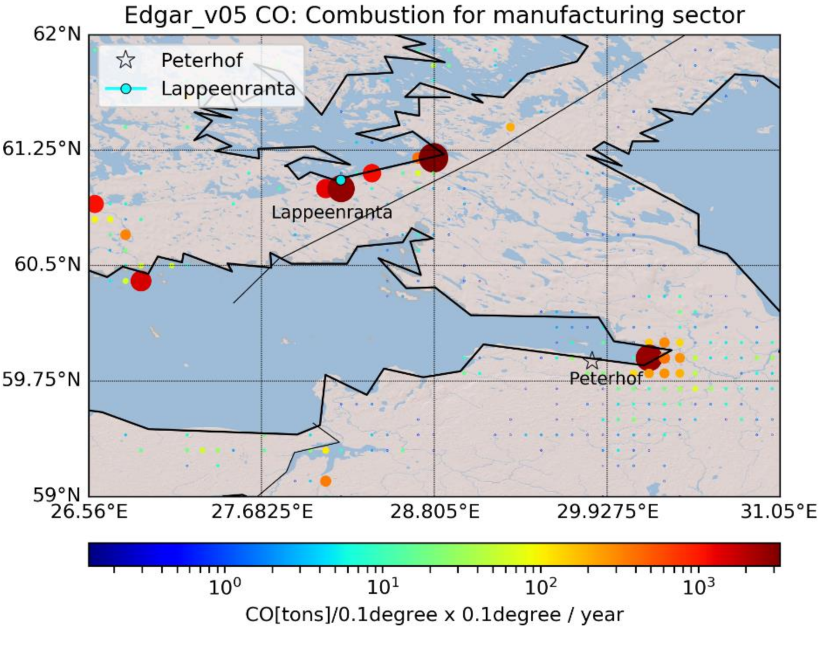

Figure 1 Spatial distribution of CO emissions (tons/0.1 degree × 0.1 degree /year) from Sector-Specific Gridmaps: Combustion for manufacturing. Data source: EDGAR v5.0, 2015 (https://edgar.jrc.ec.europa.eu/dataset_ap50, last access: 04 August 2021); the map was generated with python basemap toolkit by using ArcGIS from a World Shaded Relief Model.

2. Eq. 1: please explain “DT” and n

“n” is defined in L426 of the original manuscript. While for “DT” we have included the next sentence (in red)

These sub-windows have the characteristics of being non-overlapping and they form equally sized bins on the time axis, as defined in the Eq. 1(Eq. 5 in revised version), where ‘DT’ stands for Date-Time, which goes from the first to the last point of measurements.

3. Eq. 2: please explain “t”, which is usually referring the continuous time.

Thank for pointing this out. We have changed “t” for “k” in Eq. 2(Eq. 6 in revised version) to avoid confusions with “continuous time” as you mentioned it, and additionally we have added the next sentence (in red).

The Root-Mean-Square-Deviation (RMSD), which is calculated with the Eq. 2(Eq. 6 in revised version), where “k” stands for the number of points considered during the scaling in each sub-window, between COCCON and the CAMS-COCCON data must be the lowest possible.

4. Line 538: “This discrepancy might be due to the COCCON observation during winter”. So do you think COCCON measurements are not representative for the monthly mean?

We assume that the COCCON measurements in Yekaterinburg are less representative during winter in Yekaterinburg, because the number of observations is so limited. We rephrased the sentence in the revised manuscript as follows:

This discrepancy might be due to the limited number of COCCON observations during winter in Yekaterinburg (Only 12 days of measurements from November to Mach were available).

5. All the legends: ‘xCO2’ should be big ‘X’

The suggested changes were made on Figures: 1, 2, 3, 5 and 7

6. In Figure.5, there are lots of solid vertical lines. Is there some special meaning regarding them?

Sorry for this mistake! The Figure had been adjusted by deleting the solid vertical lines, which is a problem of the resolution of the plot.

7. In Figure.7, the information is quite hard to get. The dates are not readable from x-axis and also not equally distributed. If only showing the information that 22 days are available, maybe you can use a table to show the dates and some features of the measurements, e.g., daily mean +/- std. If the tendency is the key, clarify the x-axis and show the information clearly.

Sorry for this mistake again! The Figure was adjusted accordingly.

8. In Figure.8(b), the unit of XCH4 should be ppb instead of ppm;

Thanks for this observation! The Figure has been modified accordingly.

9. In Line 285-289: how are these three collection radius chosen?

The bias between each TROPOMI XCH_4 observation and the mean value of COCCON observations 1h before and after satellite overpass time shows an increasing tendency with their distance (see Figure 1 below). The biases become more obvious when the distance is larger than 50 km. This situation is not obvious for XCO and XH_2O. To reduce the biases, we thus, use a collection radius of 50 km for TROPOMI at Peterhof.

However, less coincident data are found in Yekaterinburg due to shorter measurement period (See Figure 3). Due to this reason, we use 100 km for TROPOMI and GOSAT in Yekaterinburg.

As explained above (see **Table *1***), a 200 km collection radius is more appropriate for OCO-2 and OCO-2 FOCAL products, as only a few point for 100 km and up to 5 points for 50 km.

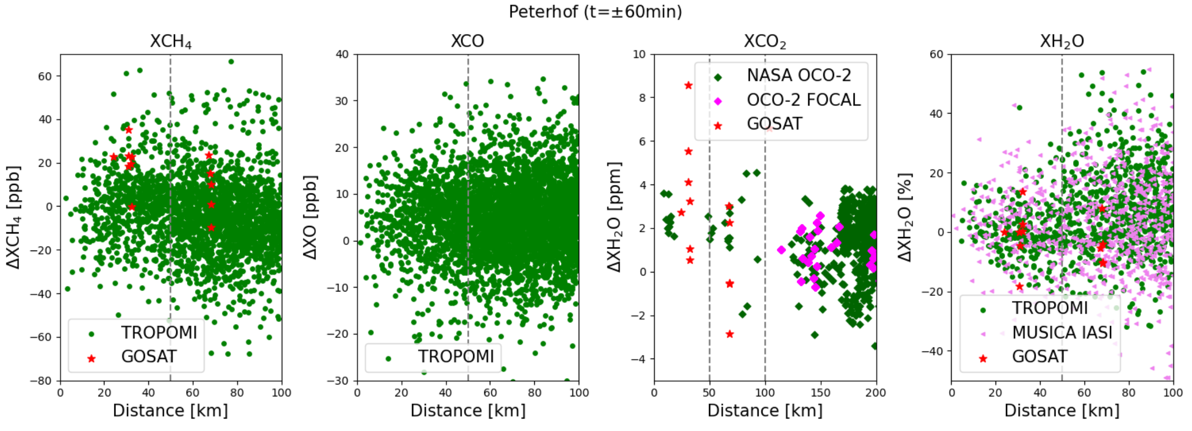

Figure 2 Difference between a single TROPOMI measurement with the averaged COCCON measurement (±1 h of satellite overpass) with respect to their distance.

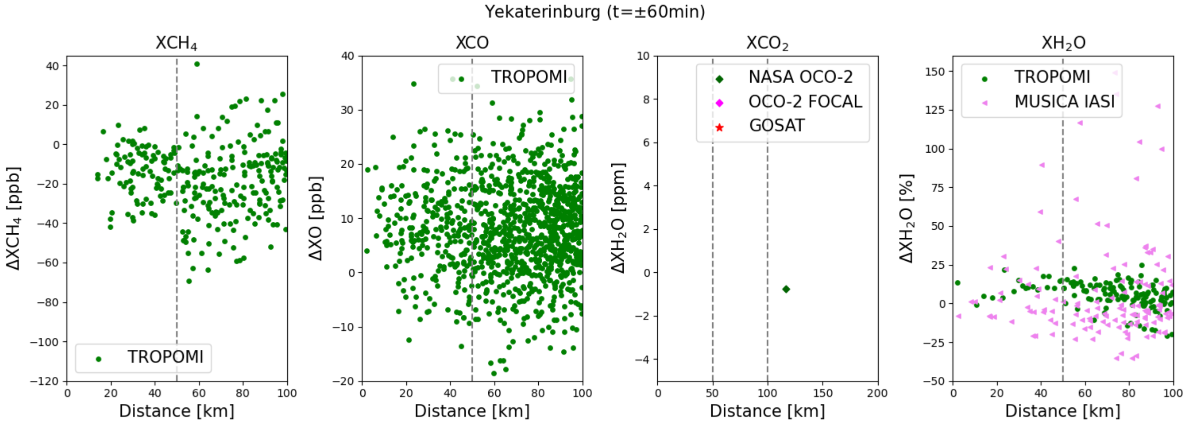

Figure 3 Same as Figure 2 but for Yekaterinburg.

10. In line 300, does ‘with short-term enhancement’ mean those small fluctuations within one month before 2019-08? Please clarify it further.

We refer to the temporary events of enhanced XCH_4, with a typical duration of a week. These might be connected to synoptic processes (variable tropopause altitude), which reside on the same time scale. We have added in the revised version “short-term enhancements of about a week duration, probably related to synoptic variations”

11. For Figure 8 (b) XCH4, is there any explanation regarding the rising signals observed from all products in 2019 from summer to winter?

These seasonal variabilities are of geophysical origin (variation of sources and sinks, atmospheric lifetime, etc.) and are well produced both by the CAMS model and the observations.

12. Please change the order of the figures in the appendix to follow the main paper content

Thanks for this observation! The figures have been sorted accordingly.

13. Figure 16 and 17, XCO2 from CAMS-COCCON are bias-low compared to the values from GOSAT and OCO-2. It looks like a constant bias. Have you looked into the reason behind?

The calibration of the COCCON XCO_2 product will be re-examined in the framework of the just started ESA project FRM4GHG-2. However, we have found excellent agreement of the COCCON XCO_2 calibration with boreal TCCON sites with the current calibration (Sha et al., 2021). The observed boreal sites are low-albedo targets from the satellite perspective; one might speculate that this causes a bias in the satellite observations. Further COCCON observations should be collected in future at these boreal sites.

14. Line 210: you could consider to include the two following references mentioning the permanent network MUCCnet, which is a typical example of continuous deployment and a measurement campaign in US using COCCON spectrometers:

https://amt.copernicus.org/articles/14/1111/2021/
https://acp.copernicus.org/articles/21/13131/2021/acp-21-13131-2021.html

We considered appropriate and therefore we have included these two references to the paper.

15. Figure22(e), 'Delta XO' in x-axis should be 'Delta XCO'

The Figure was modified accordingly and updated in the manuscript.

16. Line 37: here is the first time when the abbreviation 'GHG' appears. The full name of GHG should be explained here, instead of the next line. Additionally, the information demonstrated in Line 37-38 (two sentences) is somehow repeated. Could you rewrite it?

Thanks for these observations! The full sentence between Line 37-39 has been written again, keeping GHGs once and deleting the repetition. The added new-sentence is the following:

Global warming is one of the most discussed negative effects caused by the anthropogenic emissions of greenhouse gases (GHGs); mainly carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O).

17. Line 45: "on that regard" => "in this/that regard". Additionally, a comma should be added.

Changed accordingly.

18. Line 48: "in 2005" instead of "on 2005"

Changed accordingly

19. Line 70: "column" instead of "columnar"?

Changed accordingly

20. Line 226: Schneider et al., (2020) instead of Schneider et al., 2020

Changed accordingly

21. Line 459: "showing RMSD as a function"

Changed accordingly: "the" deleted

22. Please check your reference list. Some of the references are missing there.

We have carefully checked the reference list and added the missing references and the additions after the review process suggested for the three anonymous referees.

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