Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2020-453-AC1, 2021
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Atmospheric Measurement Techniques Discussions

Interactive comment on "XCO_2 retrieval for GOSAT and GOSAT-2 based on the FOCAL algorithm" *by* Stefan Noël et al.

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Received and published: 9 March 2021

Reply to referee 2

We thank the referee for the detailed review. The comments will be considered in the revised version of the paper. In the following, the original reviewer comments are given in *italics*, our answer in normal font and the proposed updated text for the revised version of the manuscript in **bold** font.

Answers to major comments:

1. *Section 2.3 "True database"*

   (a) *It remains unclear whether the actual TCCON measurements are used or not in the procedure. My current understanding is that the "valid" simulations are those where the total column, computed with an homogeneous weighting and the same with the TCCON averaging kernel, differ by less than 0.75 ppm. If my understanding is correct, then (i) I do not understand why this is a valid criterium to select the most accurate simulation data and (ii) there is no need to compute the "daily mean" TCCON. If my understanding is incorrect, the description needs some re-writing.*

   For the "true" database we first determine a set of daily TCCON data for each station. These TCCON data are an average over all measurements within 13 h $\pm$ 2 h local time of one day at one station. This is no daily mean as it is only a 4 h average (we'll clarify this in the paper). From this, we get one value per day and station. We then select collocated CarbonTracker (CT) data for each day and station, apply the TCCON averaging kernels to them and compute XCO2. This ak-corrected CT XCO2 is then compared with the corresponding TCCON XCO2. For all days where both values agree within $\pm$ 0.75 ppm, we define contiguous regions around each station where the CT XCO2 data deviate less than 0.75 ppm from the CT value at the station. The CT data inside these regions are then inserted into the database.

   The "true" database therefore contains only CT data, which are confirmed by TCCON measurements but may differ by up to 1.5 ppm from the TCCON value. This is explicitly stated in the manuscript at the end of this section:

   "Please note that the "true" database does not contain any TCCON data - it only contains CT data which were confirmed by TCCON, but individual

values may differ by up to 1.5 ppm."

The choice of the 0.75 ppm ranges is based on a trade-off between accuracy (agreement with TCCON) and spatial coverage of the database.

We will update the section about the "true" database for clarification.

(b) *Line 138-139 "which were confirmed by TCCON" is really unclear, especially since it is said above that there is "more data in the Southern hemisphere" that is notably poor in TCCON coverage. How can such data be confirmed by TCCON.*

As explained above, "confirmed by TCCON" means that all CarbonTracker data used in the "true" reference database agree within 1.5 ppm with TCCON. This essentially defines an area around each used TCCON station where CarbonTracker data are compliant with this criterion. The spatial coverage of the "true" database varies from day to day depending on how many data agree with TCCON. This of course also limits the spatial coverage of the "true" database (e.g. there are less data in the southern hemisphere), but nevertheless all data in the "true" database fulfil the criterion and are therefore confirmed by TCCON.

The sentence "There are typically more data in the southern hemisphere during the second half of the year" just means that there are more data during the second half of the year compared to the first half of the year, not more data in the south than in the north. We will clarify this in the text and also show example maps from the "true" data base to illustrate this.

(c) *As a consequence, it is really unclear why the database build as described, can be considered as a truth.*

For the XCO2 bias correction we have to assume some kind of "truth", and we think our choice to use a subset of CarbonTracker data which is confirmed by measurements is a valid one. We hope that with the explanations given above this is now clearer.

We also decided to rename the "true database" to "reference database" to indicate that the content is not necessarily the (essentially unknown) "true" XCO2 at a certain time and place but only an estimate which should on average reproduce large scale features correctly.

2. *Section 3.1.2 Cloud Filter*

*It is said that the Cloud Filter is based on the fact that clouds are bright (OK) and higher in the atmosphere so that there is little water vapour above them. Then, one my expect that, when the water vapor estimate is low, a cloud presence is suspected. Yet the description of the test indicates that a cloud is detected when the water vapor estimates is **larger** than a threshold. This is inconsistent.*

The referee is completely right. The term "water vapour path" which we use to name one of the filter criteria for cloudiness is misleading. As written in the manuscript, this filter is defined as the ratio between the median radiance and the median of the estimated noise, i.e. it is indeed high in case of low water vapour content and vice versa.

We will rename "water vapour path" to "water vapour filter" to clarify this.

3. *Section 3.3.2 Random Forest Filter*

(a) *The difference between the estimate and the "true" reference database is used. It is said that the difference is subtracted by the global monthly mean bias. This assumes that the global mean bias of the reference is zero which is a strong assumption.*

As written in the manuscript, for the filtering we are not interested in a potential global bias of the data. The main purpose of the random forest filter is to reduce the scatter in the XCO2 data. This is why we subtract the global median of the bias before filtering. It is indeed the global median for land and water, not the monthly global median, which is subtracted – this will be

corrected in the paper. This essentially makes the filtering independent from a global bias.

For the bias correction, however, we assume that our reference (the "true" database) is on average the "truth", i.e. large scale features are well reproduced. This is indeed a strong assumption, but this is how a bias correction works, and we think we made a reasonable choice for the reference.

(b) *This section lacks a quantitative discussion: What are the mean values of the differences to the "true" reference dataset. What is the order of magnitude of the bias correction? Does it has some spatial patterns. In the case of ACOS, the bias correction is similar to the signal which is an important information. Is it the same here?*

Note that this section is not about the bias correction, it is about filtering of data. The bias correction is addressed in the following section, which also gives some quantitative information. Finally, we only use data where the estimated bias is within $\pm$ 2 ppm around the global mean bias, which is different for land and water (see Table 9). The scatter (global standard deviation) of the estimated bias is below 1 ppm.

We will add this information in the paper and also maps of the bias correction for GOSAT and GOSAT-2 such that spatial patterns can be identified.

(c) *It is then said (line 321) that the random forest classification is accurate in about two thirds of the cases. How is this evaluated? How can one decide whether it is accurate or not?*

The accuracy is estimated from the performance of the filter for the training and the test data sets (for which we know the truth). It is defined as the fraction of correctly classified samples.

We will explain this in the updated paper.

4. *Figures*

(a) *There is certainly no need for Figure 3 to 6. A couple of examples would be sufficient rather than the 28 pannels that indicate similar behaviors (and differences that are not commented).*

We agree and will replace Figs. 3 to 6 by a single one showing only an example of the noise plots for GOSAT and GOSAT-2 (two fit windows each).

(b) *Figure 9 to 12 provide no usefull information. Figure 13 to 16 could be limited to a few examples rather than the 30 pannels. I strongly recommend to combine figure 9 and 13 so that one can identify whether the fine scale structures of the residuals correspond to absorption lines*

We agree and will replace these figures by two figures (one for GOSAT and one for GOSAT-2) which will show both spectra and residuals in one plot for only one polarisation direction as indeed results for S and P are very similar.

5. *Section 4; Results*

This section contains several hypothetical statements "likely", "most likely", "which may explain"... that deserve investigations

We agree that some of our formulations are too cautious. We will check the text and update it accordingly.

Answers to other comments:

1. *Abstract : Line 21 "regional bias".*

There is no demonstration that TCCON is representative of a region, neither that the bias at the TCCON location is the same over a region.

With "regional bias" we refer to the "station-to-station bias" which is a measure for the variability of the bias between different stations and thus regions. For clarification, we will use the term "station-to-station bias" in the abstract.

2. *Section 2.2; line 111-112*

   Why a factor of 5 for H2O "to reduce dependencies on the a-priori" but not the same factor for the CO2

   The natural variability of H2O is much higher than for CO2, therefore we use a stronger a-priori constraint for CO2 than for H2O.

3. *Line 117 "very accurate". Please quantify.*

   The estimated accuracy of TCCON XCO2 measurements is 0.4 ppm (1 sigma). We will specify this in the text and add a reference.

4. *Line 124 : "daily mean".*

   I understand the mean is over 4 hours. How can this be considered a daily men ?

   Yes, the mean is indeed over 4 hours (13$\pm$2 h LT), we will correct this:

   Then we determine from the TCCON data for each day mean values (XCO_2^{TCCON}) for 13 h $\pm$ 2 h local time.

5. *Line 188 : "It is given by the ratio between the median radiance and the median of the estimated noise in this spectral range". Unclear.*

   This is the definition of the "water vapour path" filter, see also above. We will reformulate this:

   This filter is defined as the ratio between the median radiance and the median of the estimated noise in this spectral range.

6. *Line 278 : The case is rejected when the Angstrom coefficient is outside of the range [1 – 5]. This is strange. Clouds and aerosols can have Anstrom coefficients that are close to zero. Conversely, values larger than 2 have never been reported to my knowledge.*

   The FOCAL forward model considers only a single Lambertian scattering layer to describe all scattering effects. All retrieved scattering parameters such as Ångström exponent can be considered "effective" parameters as they have to account for not only cloud/aerosol scattering but also Rayleigh scattering (which has an Ångström coefficient of 4). Because Rayleigh scattering is always present and we filter out cloudy scenes, we usually get higher effective Ångström coefficients than those expected from clouds or aerosols only. We will clarify this in the text.

7. *Line 335: "But with this filter applied". Which filter ?*

   The random forest filter, will be clarified:

   For the bias correction we use as input the same data set as for the random forest filter, but with this random forest filter applied.

8. *Line 343 : What is the order of magnitude of the bias correction?*

   This is explained in the following text; values are given in Table 9. We will also add maps of the bias correction, see our answer to the major comments.

9. *Line 349: "On the derived XCO2 bias".*

   What bias is that? Is it before or after the correction? The paragraph indicates it is after correction, but then how can it be evaluated?

   This is the bias estimated via the random forest classifier. We will clarify this:

   These are filtered out by an additional filter on the XCO2 bias derived via the random forest classifier.

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