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Atmospheric Chemistry and Physics Discussions



# *Interactive comment on* "Ability of the 4-D-Var analysis of the GOSAT BESD $XCO_2$ retrievals to characterize atmospheric $CO_2$ at large and synoptic scales" *by* S. Massart et al.

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We would like to thank the second anonymous reviewer. We will try to account for all the comments and remarks in a revised version of the paper. As for the reply to the first reviewer, we answered the general comments in the next paragraphs.

***Comment:*** *In Sect. 2.2 the authors write that they have included in their comparisons all TCCON sites except JPL 2011/Caltech, Dryden, and Eureka, and give good reasons for excluding these sites. However, also Bremen, Ny Ålesund and Tsukuba TCCON sites have been excluded although they were (to my knowledge) operational during*

*year 2013. I would like to know if there is a particular reason for excluding these sites, and if not, I suggest that the authors consider adding them to the revised paper.*

We downloaded the GGG2014 version of the TCCON data in March 2015. Unfortunately, in that version, some of the data were being reprocessed (e.g., Bremen data) and not yet made available in the data base. There was no data available for Ny Ålesund and Tsukuba as well. We downloaded again the GGG2014 version beginning of November 2015 after the reviewer comment. In that last version,Bremen and Tsukuba report some data. Data from Ny Ålesund are still missing.

In the last GGG2014 version we downloaded, Four Corners also reports data. We decided to redo part of the study of the paper including data from Bremen and Four Corners. We decided not to use the data from Tsukuba as we believe that Tsukuba is not a background station. Table 2 of the paper changes with the inclusion of data from Bremen and Four Corners and the new version is included in this reply (Table 1).

Comparing the Table 2 of the paper with this new table including Bremen and Four Corners, one can notice that the statistics changed for Białystok, Karlsruhe and Wollongong. This may be due to some correction brought to the TCCON data – the number of data remains the same. Secondly, the new global statistics are similar to the ones of the paper. The mean bias $\delta$ and its deviation $\sigma$ are slightly lower with the two new stations, both for the analysis and the free run. The precision $\pi$ slightly increases.

With the data of the two added stations, Figs. 2 and 3 of the paper also changed. The updated version of Fig. 2 is available in this reply. Overall the new figure is similar to the old one. The main differences could be seen in the comparison between the free run and the TCCON data. The smoothed bias of the free run is lower at the beginning of the period we studied and higher toward the end of the period. The smoothed bias of the analysis is very much the same with or without the Bremen and Four Corners data.

The main question is whether or not we should include Bremen and Four Corners



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**Table 1.** Same as Table 2 of the paper but with the addition of Bremen and Four Corners.

| | | Free run | | | Analysis | | |
|---|---|---|---|---|---|---|---|
| Site | $N$ | Bias | Scatter | $r$ | Bias | Scatter | $r$ |
| Sodankylä | 1324 | -1.71 | 1.41 | 0.91 | -0.63 | 1.39 | 0.91 |
| Białystok | 924 | -2.93 | 2.06 | 0.81 | -1.82 | 1.86 | 0.79 |
| Bremen | 336 | -1.65 | 1.55 | 0.80 | -0.45 | 1.28 | 0.84 |
| Karlsruhe | 551 | -1.27 | 1.70 | 0.81 | -0.34 | 1.50 | 0.83 |
| Orléans | 577 | -0.58 | 1.37 | 0.83 | -0.04 | 1.20 | 0.89 |
| Garmisch | 753 | -0.86 | 1.59 | 0.81 | -0.26 | 1.59 | 0.80 |
| Park Falls | 1603 | -1.60 | 2.04 | 0.82 | -0.57 | 1.39 | 0.91 |
| Four Corners | 866 | 0.68 | 1.79 | 0.59 | 0.58 | 1.52 | 0.73 |
| Lamont | 1973 | -0.17 | 2.06 | 0.63 | -0.00 | 1.27 | 0.83 |
| Saga | 511 | -1.26 | 1.46 | 0.80 | -0.75 | 1.18 | 0.86 |
| Izaña | 276 | 0.28 | 0.76 | 0.90 | 0.41 | 0.58 | 0.95 |
| Ascension Island | 592 | 2.32 | 1.01 | 0.35 | 0.72 | 0.98 | 0.31 |
| Darwin | 2175 | 1.80 | 1.15 | 0.81 | 0.18 | 1.04 | 0.81 |
| Reunion Island | 1105 | 0.56 | 0.70 | 0.83 | -0.75 | 0.55 | 0.84 |
| Wollongong | 1456 | 0.28 | 1.01 | 0.78 | -1.08 | 0.96 | 0.75 |
| Lauder | 1005 | 0.06 | 0.78 | 0.89 | -0.96 | 0.53 | 0.88 |
| Mean | 16 | -0.38 | 1.40 | 0.77 | -0.36 | 1.18 | 0.81 |
| Deviation | 16 | 1.33 | – | – | 0.64 | – | – |

TCCON data in the revised version of the paper. In one hand the results of the paper would be more accurate if we include more data from TCCON. On another hand, the data were not available when we wrote the paper and we do not know how long one should wait before having the full set of TCCON data. The aim of the paper is to document the operational system we are running at ECMWF to analyse and forecast the atmospheric concentration of $CO_2$. This system runs operationally every day with a delay of 5 days behind real time. We cannot afford to study a past period for which we are sure to have all the possible set of TCCON data. We already decided to only



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document the analysis for 2013 and not for the next years in order to have enough TCCON data. We also waited more than one year between the end of the period we studied and the date we downloaded the TCCON data to be sure to maximize the number of available TCCON data.

The results being very similar with and without the Bremen and Four Corners TCCON data, we think we will not include them in the revised version of the paper. We could indicate the date when we downloaded the data that would help people to reproduce our results if needed.

• *GOSAT BESD* $XCO_2$ *retrievals are only one of several independent GOSAT* $XCO_2$ *retrievals by different teams and retrieval algorithms, and each of these retrievals have their characteristic biases. Even though it is outside the scope of the paper to repeat the assimilation and comparisons for another GOSAT retrieval, I suggest the authors add a brief description and/or a literature review about how the GOSAT BESD* $XCO_2$ *retrievals compare to the other retrievals from GOSAT measurements; at least to the official NIES retrieval product. I think this would be valuable information to the reader because the authors propose that the product of this forecasting system can be considered as an alternative to the satellite* $XCO_2$ *retrievals.*

We will include a brief description of the different GOSAT $XCO_2$ products in the revised version of the paper. We will use the information from Yoshida et. al (2013) for the NIES product and from Dils et. al (2014) for the Leicester and SRON products.

It is difficult to compare the MACC GOSAT BESD $XCO_2$ product with the three other products or to have a clean inter-comparison between all the products using only the literature. In Dils et. al (2014), the Leicester and SRON products are compared to the GGG2012 version of the TCCON data and for the period between April 2009 and April 2011. In Yoshida et. al (2013), the NIES product is compared to the same GGG2012 version of the TCCON data but for a period between June 2009 and July 2010 or the whole available period. Here, we are using the GGG2014 version of



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the TCCON data at for the period between January 2013 and December 2013.

Assuming the comparisons are robust enough and do not depend strongly on the version of the TCCON data or the period under study, we could put into a broader context the quality of the MACC GOSAT BESD $XCO_2$ product and the analysis. The MACC GOSAT BESD $XCO_2$ product has the lowest mean offset among all the products with a value of -0.1 ppm. It is followed by the analysis with a mean offset of -0.47 ppm. The mean offset of the three other products is between -0.57 ppm (Leicester) and -0.94 ppm (NIES). The station-to-station bias deviation of the MACC GOSAT BESD product is higher than the other products with a value of 1.32 ppm. The second highest value of the bias deviation is 0.98 ppm for the NIES product. The analysis has the second best bias deviation after the SRON product. The MACC GOSAT BESD product precision is worse than the precision of the other products (3.36 ppm to be compared to 2.50 ppm for the Leicester product for example). As reported in the paper, since then the precision has been improved in the current GOSAT BESD data (version 1.02) with a value of 2.09 ppm comparable to the other products. The analysis has the best precision among all the products with a value of 1.14 ppm, the second best being the SRON product with a value of 2.37 ppm. The analysis has also a similar correlation coefficient than the SRON and the Leicester products (around 0.8).

In conclusion, the MACC GOSAT BESD and the analysis products are comparable to the other products. The precision is worse for the MACC GOSAT BESD product than for the other products but this has been improved in the current version. The main advantage of the analysis is a higher precision than the other products.

•*Are GOSAT BESD* $XCO_2$ *retrievals not made above the ocean (in the GOSAT glint mode) or were these just excluded in the paper (if so, why)? Some other retrieval algorithms retrieve* $XCO_2$ *over oceans from the GOSAT glint mode measurements. How would inclusion of ocean retrievals affect the assimilation results?*

The GOSAT BESD $XCO_2$ retrievals are not available over the ocean because the BESD



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algorithm is not yet able to retrieve data from the glint observation mode of GOSAT. Including $XCO_2$ data over oceans would probably help correcting the background atmospheric $CO_2$ and therefore the model background bias.

GOSAT glint observation mode allows to retrieve $XCO_2$ over oceans within a latitude band. This band has a width of about 40 degrees and moves northward or southward depending of the season, but remains close to the tropics. For these reasons, we believe that assimilating sun glint GOSAT products would not help reducing the residual bias we still have at high latitudes. Over the tropics and at mid-latitudes, the analysis bias is already low and comes mainly from errors in the surface fluxes over land. Having more data to assimilate over ocean would certainly have a positive impact but this impact would be smaller than the impact of the data we assimilate over land.

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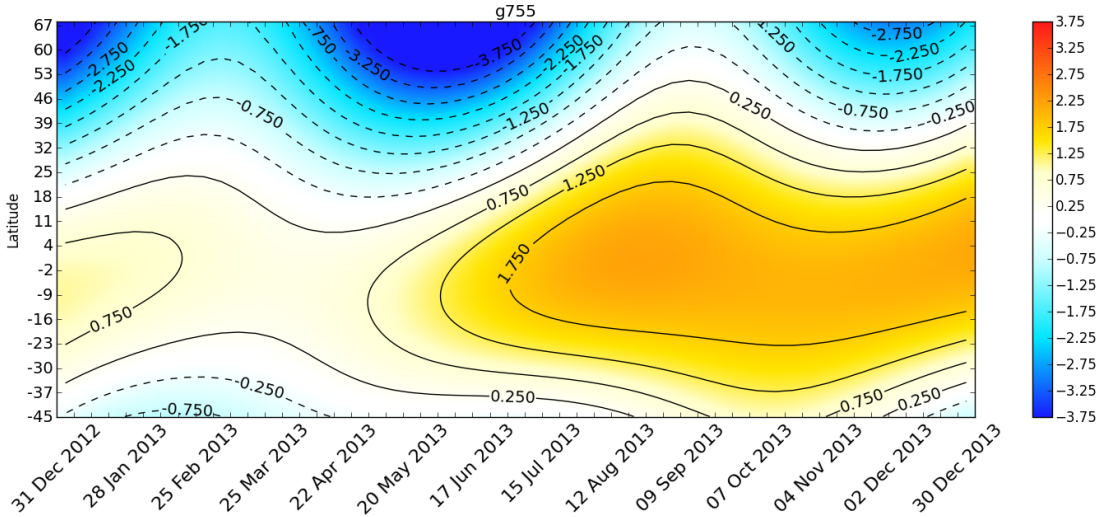


**Fig. 1.** Same as Fig. 2(a) of the paper but including the TCCON data from Bremen and Four Corners.



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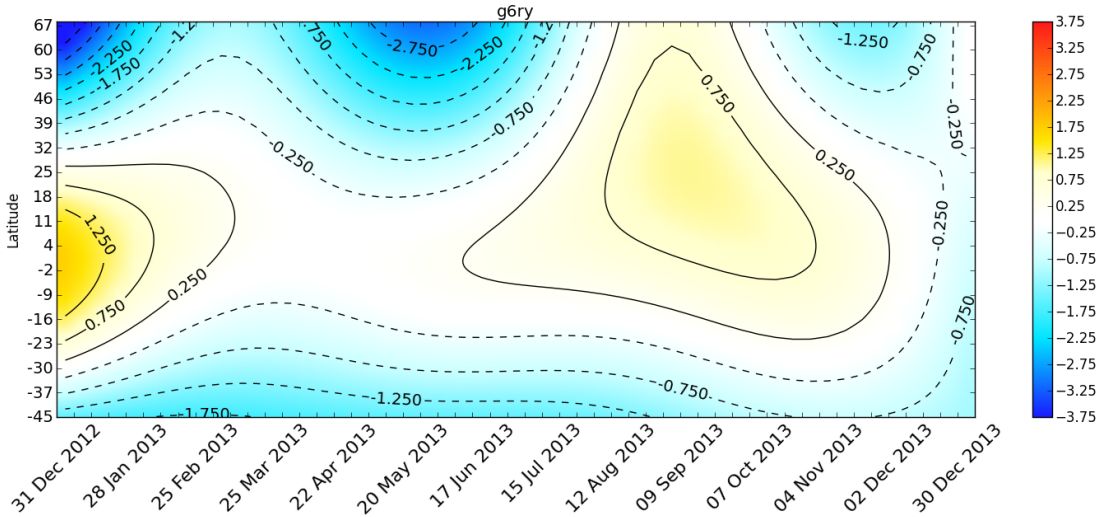


**Fig. 2.** Same as Fig. 2(b) of the paper but including the TCCON data from Bremen and Four Corners.



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