Red : referee's comments  Black : authors' answers

Referee #1:

General comments:

Manuscript "Validation of TANSO-FTS/GOSAT XCO2 and XCH4 glint mode retrievals using TCCON data from near-ocean sites" from Zhou et al., submitted for publication in Atmos. Meas. Tech., presents results from a new study aiming at validating GOSAT XCO2 and XCH4 retrievals using TCCON ground-based XCO2 and XCH4 retrievals focusing on glint-mode retrievals over the ocean. Previous validation publications primarily focused on retrievals over land. The manuscript therefore presents new results, is very well written and covers a topic appropriate for Atmos. Meas. Tech. I therefore recommend publication of this paper after the mostly minor comments listed below have been carefully considered by the authors.

We want to thank the referee for the detailed analysis of our paper.

Specific comments:

Page 10900, line 11 and following: Statement "The column-averaged dry-air mole fraction measurements (XCO2 and XCH4) are sensitive not only to the surface but also to the free troposphere, which allows a better distinction between transport and local emissions." Please add a reference which supports this statement.

We add the following reference to support this statement.

Yang, Z., Washenfelder, R. A., Keppel-Aleks, G., Krakauer, N. Y., Randerson, J. T., Tans, P. P., Sweeney, C. & Wennberg, P. O. 2007 New constraints on Northern Hemisphere growing season net flux. Geophys. Res. Lett. 34, L12807. (doi:10.1029/2007GL029742)

Yang et al. (2007) stated that the column vertically integrates the concentration of $CO_2$ above the surface, so that it is much less affected by vertical transport than surface in situ measurements. Therefore, the horizontal gradients in measured $XCO_2$ are more directly related to the underlying regional-scale fluxes than is the case for the surface in situ measurements of $CO_2$. Combined with the local in situ measurements, the column-averaged dry-air mole fraction measurements could allow a better distinction between transport and local emissions.

Page 10900, line 15 and following: It is written that "A large set of studies used the total column or column-averaged dry molar fraction observations to improve the precision of atmospheric inverse models". What is "the precision of atmospheric inverse models"? Please explain. I guess you mean the quality of the surface fluxes obtained by inverse modelling where quality refers to reduced (better) uncertainty considering random and systematic errors.

Thanks for your suggestion, and I'll make this sentence more clear to the readers:

A large set of studies used the total column or column-averaged dry molar fraction observations to improve the quality of the surface fluxes obtained by atmospheric inverse models where quality refers to reduced uncertainty considering random and systematic errors.

Page 10900, line 21 and following: Sentence referring to GOSAT "It is the first space-based sensor designed specifically to measure greenhouse gases from high-resolution spectra at SWIR wavelengths." NASA's OCO has also been designed to achieve this pretty much at the same time than GOSAT (or even earlier). I recommend to modify the first part of the sentence as follows: "It

is the first space-based sensor in orbit ”

It is the first space-based sensor in orbit specifically to measure greenhouse gases from high-resolution spectra at SWIR wavelengths.

Page 10901, line 3: For completeness I recommend to also add the BESD algorithm and to cite Heymann et al., 2015: Heymann, J., M. Reuter, M. Hilker, M. Buchwitz, O. Schneising, H. Bovensmann, J. P. Burrows, A. Kuze, H. Suto, N. M. Deutscher, M. K. Dubey, D. W. T. Griffith, F. Hase, S. Kawakami, R. Kivi, I. Morino, C. Petri, C. Roehl, M. Schneider, V. Sherlock, R. Sussmann, V. A. Velazco, T. Warneke, and D. Wunch, Consistent satellite XCO2 retrievals from SCIAMACHY and GOSAT using the BESD algorithm, Atmos. Meas. Tech., 8, 2961-2980, 2015.

We add this reference in the text to make it more comprehensive.

Page 10901, line 7 and following: It is written that “the satellite products should reach a demanding precision of 2% or better (< 8ppm for XCO2 and < 34ppb for XCH4), in order to improve the precision of inversion models (Buchwitz et al., 2012)”. As highlighted in Buchwitz et al., 2012, achieving low biases (high relative accuracy) is even more important (and more demanding) than precision to obtain reliable surface fluxes via inverse modelling. This needs to be mentioned here and needs to be considered when discussing the validation results presented in this manuscript. See also page 10912, line 23.

Thanks for your suggestion. We change the sentence to highlight the high relative accuracy is even more important.

the satellite products should reach a demanding precision of 2% or better (< 8ppm for XCO2 and < 34ppb for XCH4), in order to improve the precision of inversion models. Besides, achieving high relative accuracy (<0.5 ppm for $XCO_2$ and <10 ppb for $XCH_4$) is even more important and demanding than precision to obtain reliable surface fluxes via inverse modeling (Buchwitz et al., 2012).

We also add this information when discussing the validated results.

page 10912, line 23. “this means that they meet the single precision threshold quality criteria for inverse modeling (34 ppb $XCH_4$) together with low bias (10 ppb $XCH_4$).”

Page 10902, line 4: It is written that SRON/KIT product v2.3.5 has been used. On http://www.esa-ghg-cci.org/sites/default/files/documents/public/documents/GHGCCI_DATA.html, where this product is available for download, it is written for v2.3.5 products: “Minor bugs detected -> please use v2.3.6”. Please confirm that v2.3.5 products have been used and not v2.3.6. Do these bugs influence the results shown in the manuscript or has a work around solution been developed and used to avoid the impacts of the reported problems?

In this paper, v2.3.5 products have been used and not v2.3.6. In v2.3.6, there were a few data points passing through the filter with xch4 = 0 (only for SRPR) as well as some additional secondary variables were added. These should not have any significant effect on our findings as we checked 2.3.5 for the TCCON co-located data and did not find any discrepancies w.r.t 2.3.6.

Page 10904, line 15 following: Sentence “Thanks to all these efforts, TCCON has already become a reliable source to validate the satellite retrievals.” The first part of this statement sounds a bit strange taking into account that TCCON colleagues are coauthors. Furthermore, I recommend to

add that improvements are still ongoing, see: Kiel et al., Improvement of the retrieval used for Karlsruhe TCCON data, Atmos. Meas. Tech. Discuss., 8, 12203-12242, 2015.

Thanks for your suggestion. We change the sentence as:

Thanks to all these and on going efforts ( Hase et al., 2013; Kiel et al., 2015), TCCON has been extensively used to validate satellite $XCO_2$ and $XCH_4$ retrievals (e.g. Wunch et al., 2011b; Guerlet et al., 2013; Yoshida et al., 2013; Dils et al., 2014; Kulawik et al., 2015).

Page 10905, line 28 following: "this meets the precision requirement of the ground-based measurements". What are these requirements? Please list them and give a reference.

Wunch et al.(2011; 2015) stated that TCCON achieves an accuracy and precision in total column measurements that is unprecedented for remote sensing observations (better than 0.25% for $CO_2$ and 0.2-0.3% for $CH_4$).

Within a 4 h time window, the error(1σ) is on average 0.4 ppm (about 0.1%) for XCO2 and 2.5 ppb for $XCH_4$ (about 0.12%).

Therefore, we complete the sentence like this:

this meets the precision requirement of the ground-based measurements (better than 0.25% for $XCO_2$ and 0.2-0.3% for $XCH_4$) (Wunch et al., 2011a; 2015).

Page 10906, line 14 following: "hi corresponds to the normalized airmass-weight function of layer i". What is a "normalized airmass-weight function of a layer". Please add explanation.

Thanks for your suggestion. We add the following explanation in the text:

$$h_i = \frac{m_i}{\sum m_i}$$

Where, $m_i$ corresponds to the mass of dry air in layer i

Page 10908, line 11 following: "we always apply the correction factor to the satellite product, not to the TCCON product". It sounds a bit strange that the satellite data need to be modified (significantly) for comparison with reference data and not the reference data. Is there a good reason for this?

It is a very interesting question. The reason why we modify the GOSAT product not the FTIR data is that the dry-mole CO2/CH4 profile is provided by GOSAT products, which is better to present the CO2/CH4 vertical profile above the GOSAT footprints, not the FITR site, because of the distance between GOSAT footprints and FTIR site. However, If we want to modify the FTIR data, we could change the formula like this:

$$c_{FTIR}^{alt} = \frac{1}{\alpha} c_{FTIR}.$$

It indeed sounds a bit strange that the satellite data need to be modified (significantly) for comparison with reference data and not the reference data. However, We prefer to modify the GOSAT products, not FTIR measurements.

Page 10909, line 20 following: "This is due to the strong fluctuation in near-surface CO2 concentrations of the a priori CO2 profile of the ACOS algorithm." The effect is quite large. It would therefore be interesting for the reader to get more information on the ACOS priori CO2 profile. Does it depend on latitude, longitude and time and if yes, what is the spatial-temporal resolution and sampling?

As we only select the $\pm 5°$ latitude $\pm 15°$ longitude co-located GOSAT-TCCON data pairs, the a priori $CO_2$ profile slightly depend on latitude and longitude in such area. Left panel of Figure 1 show the near-surface $CO_2$ concentrations of the a priori $CO_2$ profile of the ACOS algorithm is quite different at each season in 2011. The $CO_2$ concentration is decreasing with the altitude in Spring and Summer while in autumn and winter the maximum $CO_2$ concentration is around 600 hPa or even higher. The $CO_2$ a priori profile of SRFP above Izaña in 2011 (right panel) show that there is no significant difference between each season. The $CO_2$ profiles almost keep constant below 130 hPa. Therefore, the fluctuation in near-surface $CO_2$ concentrations of the a priori $CO_2$ profile of the ACOS algorithm mainly depend on time.

So, we change the sentence as: This is due to the strong seasonal fluctuation in near-surface $CO_2$ concentrations of the a priori $CO_2$ profile of the ACOS algorithm.

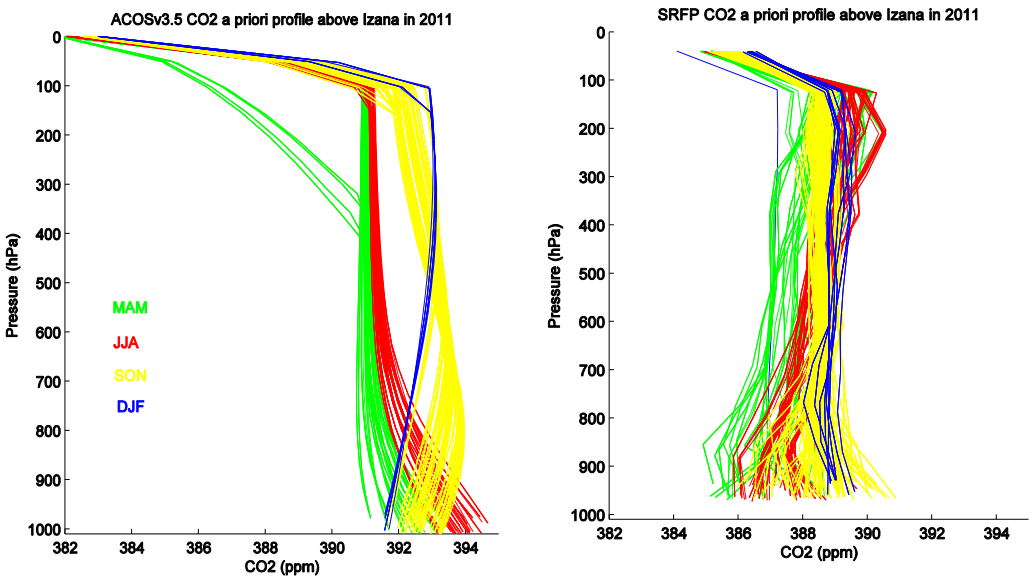


Figure 1. the CO2 a priori profiles of ACOS(left) and SRFP(right) above Izaña in 2011.

Page 10911, line 12: "0.33±0.018 and 0.13±0.013% for NIES": In Tab. 3 nearly all numbers are negative but these numbers are positive. What do positive numbers mean? A high bias or a low bias of the satellite data relative to TCCON? According to Eq. (11) "TCCON-satellite" has been used to compute biases. If this equation has been used consistently in the paper a positive value means a low bias of the satellite data (i.e., satellite values below TCCON values). Please check. I recommend to use "satellite-TCCON" in Eq. (11) but this is only a suggestion (not mandatory). But it needs to be made clear what positive / negative difference mean.

Thanks for your suggestion. The Eq (11) has been used consistently in the paper. Now, we change it as Satellite-TCCON (better to validate the GOSAT product). Therefore the positive values indicate that the FTIR measurements are less than the GOSAT/NIES products. We add some detail information in the title of Table 3 and 4 to make it more clear.

Table 3. $XCO_2$ results of NIES, SRFP and ACOS algorithms at 5 TCCON stations based on all individual satellite-TCCON data pairs. The 95% confidence interval of relative bias, relative scatter, R and N are defined in section 3.4. Between brackets are the results without altitude correction. Positive/negative bias means the FTIR measurement is less/ larger than the GOSAT product.

Page 10915, line 10 following: Number given in brackets, e.g., "NIES ( 0.020.032 vs.0.350.019%)". Please add which numbers refer to ocean and which to land.

Thanks for your suggestion, We add the numbers refer to ocean and which to land in the last sentence.

Averaged over all 5 TCCON sites, the relative bias with 95% confidence intervals of ocean data is less than that of the land data for NIES (0.02%±0.032% vs. -0.35%±0.019%), SRFP (0.04%±0.051% vs. 0.20%±0.018%) and SRPR (-0.02%±0.028% vs. 0.06%±0.012%) along with the numbers refer to ocean and to land for NIES (1939 vs. 5075), SRFP (618 vs. 6539) and SRPR (3123 vs. 13672).

Figure 1: Please enlarge and better center the region shown as it appears that parts of the data for Wollongong are not visible.

Thanks for your suggestions. We enlarge the map region.

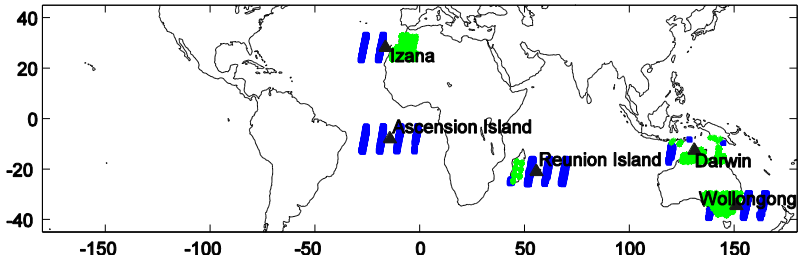


Figure 8: Very difficult to see the details and the colors in a printout. What is the meaning of the colors? Please add this information.

Thanks for your suggestion. We add the color information for this figure.

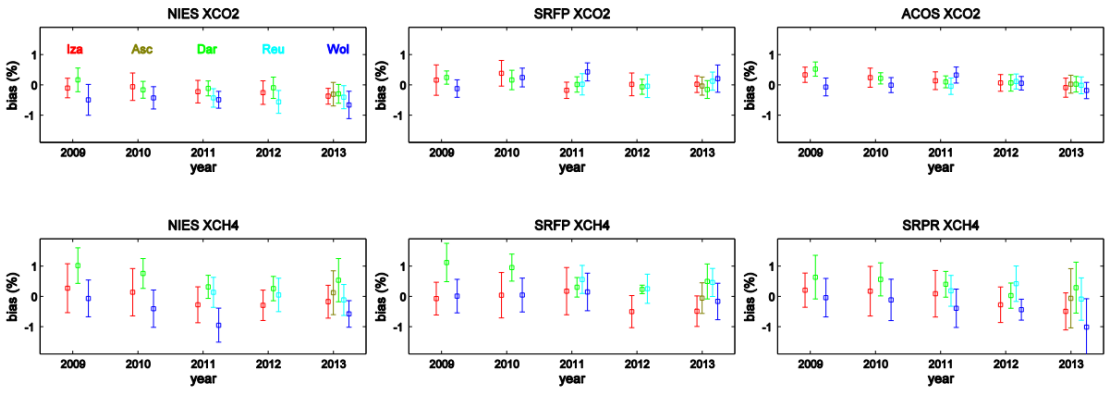


Figure 8. Annual mean bias of ocean data for each TCCON stations from different algorithms from 2009 to 2013. The error bar represents the standard deviation. Each color represents one TCCON site (red : Izaña; olive-green : Ascension Island; green : Darwin; light blue : Reunion Island; navy blue : Wollongong).

Technical corrections:

Page 10903, line 21: I recommend to change this sentence as follows: “ACOS v3.5 products have been bias corrected using TCCON GGG2014 products.”
Thanks for your suggestion. We accept your correction.

Caption Fig. 4: Use plural “data pairs”. Same for Fig. 6.
Thanks for your suggestion. We accept your correction.

Reference:

Hase, F., Drouin, B. J., Roehl, C. M., Toon, G. C., Wennberg, P. O., Wunch, D., Blumenstock, T., Desmet, F., Feist, D. G., Heikkinen, P., De Mazière, M., Rettinger, M., Robinson, J., Schneider, M., Sherlock, V., Sussmann, R., Té, Y., Warneke, T., and Weinzierl, C.: Calibration of sealed HCl cells used for TCCON instrumental line shape monitoring, Atmospheric Measurement Techniques, 6, 3527-3537, 10.5194/amt-6-3527-2013, 2013.

Kiel, M., Wunch, D., Wennberg, P., Toon, G., Hase, F., and Blumenstock, T.: Improvement of the retrieval used for Karlsruhe TCCON data, Atmospheric Measurement Techniques Discussions, 8, 2015.

Kulawik, S. S., Wunch, D., O'Dell, C., Frankenberg, C., Reuter, M., Oda, T., Chevallier, F., Sherlock, V., Buchwitz, M., Osterman, G., Miller, C., Wennberg, P., Griffith, D. W. T., Morino, I., Dubey, M., Deutscher, N. M., Notholt, J., Hase, F., Warneke, T., Sussmann, R., Robinson, J., Strong, K., Schneider, M., and Wolf, J.: Consistent evaluation of GOSAT, SCIAMACHY, CarbonTracker, and MACC through comparisons to TCCON, Atmos. Meas. Tech. Discuss., 8, 6217-6277, doi:10.5194/amtd-8-6217-2015, 2015.