Referee #2

Responses to Anonymous Referee #2 on the manuscript of "Regional uncertainty of GOSAT XCO2 retrievals in China: Quantification and attribution"

Thank you for your suggestions and valuable comments very much. We have fully considered all your comments, and carried out our revision and improved our manuscript accordingly. The item-by-item response to the specific comments is as follows (referee's comments in **red** and our response in **black)**.

Referee #2:

Major points : See the comments from the other reviewer :

- EMMA should be left out as it is the combined product of all other retrieval products shown

We removed EMMA from the analysis according to you suggestion and the related analysis were updated in the revised manuscript. Please refer the details to the revised manuscript because of difficulty in presenting it here since the changes were made across several sections.

The new analysis results for four algorithms (ACOS, NIES, OCFP, SRFP) have not changes only Table 5 (new and old shown as below) have slight changes as EMMA is the median value among multiple algorithms including our discussing four algorithms.

New Table 5

The average of the absolute differences (ppm) and standard deviation (ppm) of the target algorithm (in column) matching all other algorithms for each cell. Values in parentheses are the corresponding standard deviations. The differences, which are larger than 1.5 ppm, are highlighted in bold and underlined.

Left longitude of cells(°E)	80	85	90	95	100	105	110	115
ACOS	1.3(1.1)	1.2(1.0)	1.0(0.7)	1.4(1.2)	1.2(0.9)	1.0(0.7)	0.9(0.6)	0.7(0.5)
NIES	1.1(0.7)	1.3(0.9)	1.2(0.9)	**1.6**(1.2)	1.1(0.8)	1.1(0.8)	1.1(0.8)	0.9(0.6)
OCFP	**1.5**(1.1)	1.4(1.0)	1.4(1.0)	1.3(0.9)	1.2(0.9)	0.9(0.6)	0.8(0.6)	0.8(0.6)
SRFP	1.1(0.9)	1.2(1.0)	1.4(1.1)	1.2(0.9)	1.1(0.8)	0.9(0.6)	1.0(0.7)	0.8(0.5)

Old Table 5

Left longitude of cells(°E)	80	85	90	95	100	105	110	115
ACOS	1.5(0.8)	1.4(0.7)	1.2(0.4)	1.6(1.0)	1.4(0.6)	1.1(0.4)	1.1(0.2)	0.9(0.2)
NIES	1.6(0.2)	1.8(0.4)	1.6(0.4)	**2.2**(0.6)	1.6(0.3)	1.5(0.3)	1.5(0.3)	1.3(0.2)
OCFP	**2.2**(0.6)	**2.1**(0.6)	1.9(0.5)	1.7(0.2)	1.7(0.4)	1.2(0.1)	1.1(0.1)	1.0(0.2)
SRFP	1.3(0.5)	1.4(0.7)	1.6(0.8)	1.4(0.6)	1.3(0.5)	1.1(0.3)	1.2(0.4)	1.0(0.2)
EMMA	1.6(0.9)	1.6(1.0)	1.3(0.6)	1.3(0.6)	1.3(0.6)	1.1(0.5)	1.1(0.4)	1.0(0.4)

- Shorten the part on the new version of ACOS, or use only the new version data

We shortened the part on the new version of ACOS, and moved part of it to the appendix according to your suggestion. Please refer the details to the revised manuscript. We use ACOS V3.5 instead of ACOS V7.3, the more recently released products, in the analysis because we considered that (1) ACOS V3.5 have been being currently used in our studying group; (2) as described in reference[GES DISC, 2017], which says, T*he retrieval algorithm used to create the Build 7 ACOS data product is consistent with that used to create the OCO-2 v7.3 data product. This will allow comparison of the ACOS and OCO-2 data without having to consider algorithm differences*, ACOS V7.3 is not exactly the newer version of ACOS products.

- Provide a more quantitative analysis of the effect of aerosols and albedo on the observed differences between different algorithms

According to your suggestion, we added a quantitative analysis about the effect of aerosols and albedo in the discussion section in the revised manuscript and presented it here:

We discussed the influences of albedo and AOD on XCO_2 retrievals from ACOS, NIES, OCFP and SRFP in further. Fig. 1 plots the scatters of albedo and AOD with the differences between GEOS-XCO2 data (created in section 3.1) to XCO_2 retrievals, hereafter referred to as $dmXCO_2$, for ACOS, NIES, OCFP and SRFP. The albedo data obtained from GLASS02B06 is used for OCFP as there are no albedo data available from its released data product.

Fig. 1 shows that $dmXCO_2$ of both ACOS and NIES demonstrate a slightly decreasing trend with albedo whereas slightly increasing trend with AOD. The $dmXCO_2$ of ACOS tend to be larger in 80 ℃ -90 ℃ of deserts with high albedo than that in other regions. The dmXCO2 of OCFP demonstrate a clear decreasing trend with albedo and AOD comparing to the other algorithms. The $dmXCO_2$ of SRFP basically does not show a clearly dependence on either albedo or AOD. We further investigated the standard deviation of $dmXCO_2$ by a variation of the bin-to-bin $dmXCO_2$ with albedo and AOD. $dmXCO_2$ is averaged by surface albedo within 0.05 albedo bins and AOD within 0.05 AOD bins, respectively. The standard deviation of the mean $dmXCO_2$ in each 0.05 albedo (AOD) bins, i.e. a measure of the bin-to-bin $dmXCO_2$, is calculated. It is found that the dmXCO2 for the four algorithms change with both albedo and AOD in bin-to-bin. In the whole study area, the standard deviation in albedo is the largest for OCFP, up to 0.7 ppm, while that is smaller from ACOS, NIES and SRFP, 0.4 ppm、0.3 ppm and 0.2 ppm, respectively. The standard deviation of $dmXCO_2$ in AOD is larger for SRFP (0.5 ppm) than those for ACOS (0.2 ppm), NIES (0.3 ppm) and OCFP (0.4 ppm). Viewing to the deserts (80 ℃ -90 ℃), the standard deviation in albedo is the largest from NIES (1.5 ppm), and the smallest from OCFP (0.2 ppm) while they are 1.0 ppm and 0.5 ppm for ACOS and SRFP, respectively. The standard deviations in AOD, however, are similar (0.2-0.4 ppm) in this area. As a result, OCFP tend to be more sensitive to albedo and AOD compared to other algorithms. In the deserts, NIES are the most sensitive XCO_2 retrievals to surface albedo and OCFP the least.

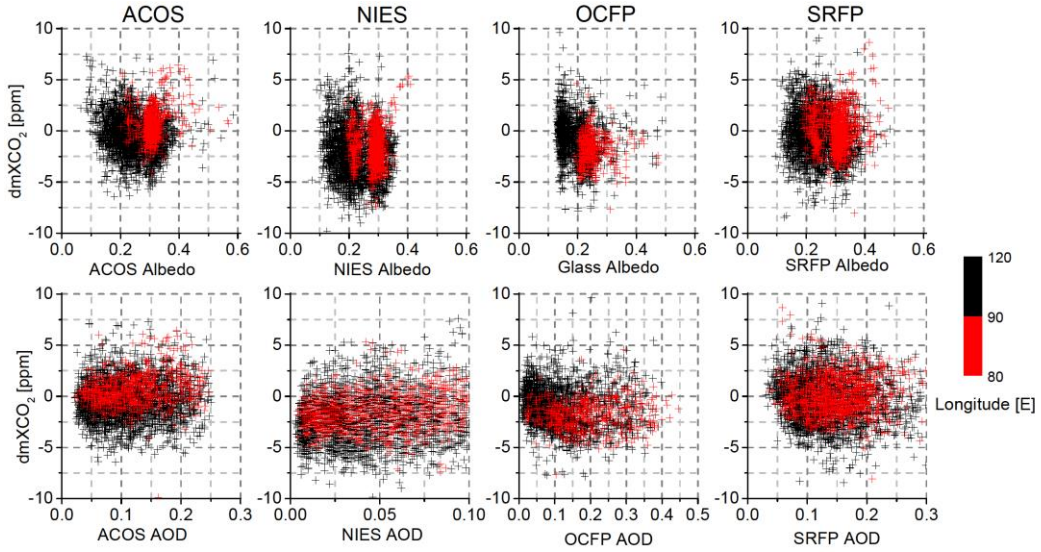

Fig. 1: Scatter plots of the differences ($dmXCO_2$) between GEOS-XCO_2 to ACOS, NIES, OCFP and SRFP respectively, with respect to albedo (the upper panels) and AOD (the lower panels). Colored points represent the data from different cells: red-[80 °E, 105 °E], black-[105 °E, 120 °E] in the study latitude zone [37 °N, 42 °N]. Colored solid lines display the corresponding linear regression trend line for the total points. Albedo and AOD are extracted from data products of the retrieval algorithms except albedo data in OCFP in which GLASS data are used.

Figure Fig. 2, moreover, demonstrates the influence of albedo and AOD on the standard deviation (STD) of XCO_2 from four algorithms at the same footprints (timely in the same day, geometrically located within $\pm 0.01°$ in space). Averaged albedo (the left panels) and AOD (the right panels) of the four algorithms are used whereas the averaged albedo is obtained only using three attached albedo in the algorithms except OCFP.

The increasing trends of STD with both albedo and AOD can be seen from Fig. 2. The mean STD is 1.3 ppm in the western cells (80°E -90°E) where albedo is mostly within 0.25-0.35. This STD is lightly larger than that (1.0ppm) in eastern cells (90°E-120E°) where albedo is comparatively smaller (mostly within 0.15-0.25). It is found from the statistics presented in Fig. 2 that the correlation coefficients of STD with albedo and that with AOD is almost the same (both are 0.3) for all the data. Particular influence from albedo in desert over the western cells can be clearly observed. These results indicate that the inconsistency of XCO_2 retrievals from four algorithms tend to be increase with the enlargements of albedo and AOD so as to imply that uncertainty of satellite-retrieved XCO_2 should be mostly alerted with the elevations of albedo and AOD.

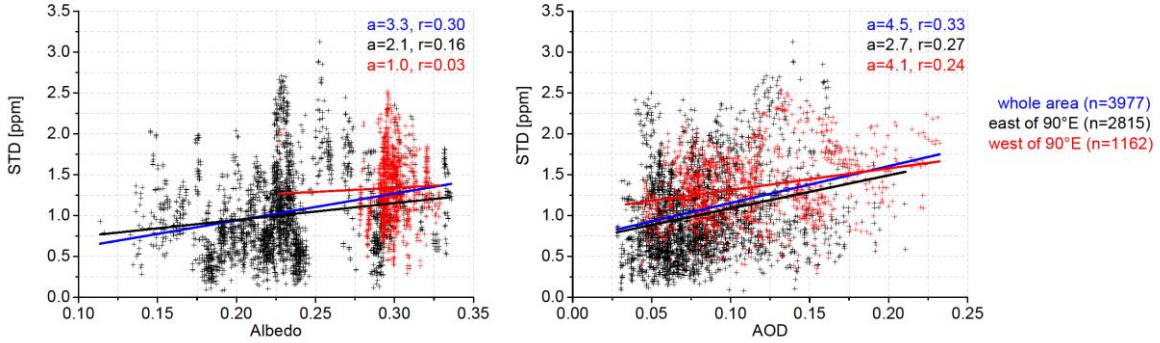

Fig. 2: Scatter plots of the standard deviation (STD) of XCO_2 from the four algorithms to albedo (the left panel) and AOD (the right panel). Colored points represent different cells: red-[80 °E, 105 °E], black-[105 °E, 120 °E] in the latitude zone [37 °N, 42 °N]. Colored solid lines display the corresponding linear regression trend line for the scatter plots with the regression slope (a) and the correlation coefficient (r) also presented. n is the number of samples. Albedo is the mean surface albedo in 0.75-um band from the three algorithms including ACOS, NIES and SRFP. AOD is the mean AOD in 0.75-um band from the four algorithms.

- Provide some clear evidence of performance of GEOS-Chem wrt total column XCO2

We added comparisons of GEOS-Chem with 14 TCCON sites. The added descriptions and validation results are shown in the revised manuscript and as follows:

We compared GEOS-Chem CO_2 simulations from the global model driven by CHRED with daily mean TCCON data from 14 TCCON sites (version GGG2014 data version) (Blumenstock et al., 2014; Deutscher et al., 2014; Griffith et al., 2014a, 2014b; Hase et al., 2014; Kawakami et al., 2014; Kivi et al., 2014; Morino et al., 2014; Sherlock et al., 2014; Sussmann et al., 2014; Warneke et al., 2014; Wennberg et al., 2014a, 2014b, 2014c). All TCCON measurements between 12 pm and 13:30 pm are used in the comparisons, where GEOS-Chem CO_2 profiles are taken according to the location of TCCON stations (latitude and longitude) as well as the observing date and transformed to XCO_2 by convolved with the individual averaging kernel in each station as Wunch (2010) suggested. The statistics results are shown in Table 1.

Table 1. Statistics of comparison between GEOS-Chem CO_2 simulations driven by CHRED and TCCON data from January 2010 to February 2013, which includes biases (Δ), the standard deviations (δ), the correlation coefficients (r) and valid days (days) when TCCON data are available. Δ, δ and r are calculated using coincident daily mean data averaged between 12:00 pm and 13:30 pm.

ID	Station name	Latitude	Longitude	Δ[ppm]	δ[ppm]	r	days
1	Sodankyla	67.37	26.63	2.03	2.00	0.83	269
2	Bialystok	53.23	23.02	0.49	1.84	0.87	196
3	Karlsruhe	49.1	8.44	0.84	1.69	0.84	152
4	Orleans	47.97	2.11	0.44	1.70	0.85	223
5	Garmisch	47.48	11.06	0.65	1.64	0.83	293
6	Park Falls	45.94	-90.27	1.17	2.14	0.75	494
7	Lamont	36.6	-97.49	-0.04	1.22	0.90	642
8	Tsukuba	36.05	140.12	1.43	1.66	0.75	217

9	JPL	34.2	-118.18	-1.30	1.15	0.90	289
10	Saga	33.24	130.29	-0.39	1.65	0.86	159
11	Izana	28.3	-16.48	0.85	1.04	0.90	114
12	Darwin	-12.43	130.89	0.65	0.90	0.88	447
13	Wollongong	-34.41	150.88	0.53	0.83	0.94	347
14	Lauder	-45.04	169.68	0.92	0.42	0.97	370
	Mean			0.59±0.80	1.42±0.50		

The results of Table 1 show that the bias ranges from -1.30 to 2.03 ppm for all TCCON sites with standard deviations of the difference varying from 0.42 to 2.14 ppm. The mean standard deviation at the TCCON sites, a measure of the achieved overall precision, from using GEOS-Chem simulations driven by CHRED is 1.42±0.50 ppm which is slightly different from using GEOS-Chem simulations driven by ODIAC (1.41±0.49 ppm). Those validated results with TCCON comparing GEOS-Chem CO_2 simulations driven by CHRED to that by ODIAC indicate that the GEOS-Chem CO_2 simulations driven by CHRED is more likely not to change the global magnitude of CO_2 concentration but rather to depict fine spatial distribution of CO_2 concentration in China.

Minor : Textual suggestions :

-p.2 line 46 : I think you should leave out TanSat in that particular sentence as that instrument has not yet contributed to a better understanding of…as far as I know.

Yes, TanSat have not produces XCO2 data available as to its some problems as you know. We removed the description of TanSat in the revised manuscript.

-p.3 line 85-86 : rephrase 'that trend …to east' because unclear what is meant

Modified to: " there are anthropogenic emissions increasing from west to east." in line 83.

-p.9 GLASS albedo is used. For which wavelength is this albedo?

It is broadband albedo product rather than albedo in narrow bands. The following was added: " GLASS02B06 is a daily land-surface shortwave (300-3000nm) broadband albedo product in temporal resolution of eight days.".

-table 2. Add to the table caption : All biases > 1 ppm are underlined.

We added it in the caption of table 3, which is the previous table 2. The caption is modified to: "The biases (ppm) and their standard deviations (ppm) of the four algorithms vs GEOS-Chem in each cell, where the upper line indicates bias (the corresponding standard deviations in parenthesis) for each algorithm vs GEOS-Chem and the lower line is the available number of used samples. The biases, larger than 1 ppm, are highlighted in bold and underlined." in the revised manuscript.

-Change 'the values in parentheses are the biases and their …" → "the values are the biases and –in parentheses- their…'

We revised this incorrect description, which also refers to the caption of table 3, in the revised manuscript. If you have read the last item, the following five lines can be skipped.

The caption is modified to:"The biases (ppm) and standard deviation (ppm) of the four algorithms vs GEOS-Chem in each cell, where the upper line indicates bias(the standard deviations) for each algorithm vs GEOS-Chem and the lower line is the number of used samples. The biases, larger than 1 ppm, are highlighted in bold and underlined." in the revised manuscript.

-Table 3 table caption. What are the underlined values ?

They are differences (ppm) larger than 1.5 ppm between two algorithms (column algorithm minus row algorithm) for each cell.

The caption of Table 4, which is the previous table 3, was modified to: "Differences (ppm) between two algorithms (column algorithm minus row algorithm) and the standard deviation (ppm) for each cell, where values in parentheses are the corresponding standard deviations. The differences, larger than 1.5 ppm, are highlighted in bold and underlined." in the revised manuscript.

p.18 line 350 ('To summarize the quantification…SRFP') : I do not understand this sentence given the data.

Thank you for pointing it out. This sentence has been deleted in the revised manuscript because we are also aware that this sentence makes the results confusing.

-Fig. 8 Figure caption 'and the differences of detrended…. and GEOS-Chem' should that be '… with GOES-Chem' ?

Corrected. Modified to :" The spatial (in the study latitude band) and temporal (in seasons) changing patterns of detrended XCO2 from ACOS, NIES, OCFP, SRFP retrievals and GEOS-Chem simulations (left) and the differences of detrended XCO2 to GEOS-Chem for ACOS, NIES, OCFP and SRFP."

-p.21 line 423/424 I do not understand the sentence 'No bias was found …R2=0.77' based on what I see in Table 6. Also it is not consistent with what is written in line429/430.

It is our incorrect expression. The results that no bias was found in ACOS V7.3 from GEOS-Chem with a standard deviation of 1.6 ppm and R2=0.77, is for the whole study area. The original Line 429/430 which states, *"It can also be found from Table 6 that the bias of ACOS V7.3 relative to GEOS-Chem is within 0.3 ppm but above 1.3 ppm, in cells east and west of 90°E, respectively."*, is focused on the regional performance.

The sentence has been modified to:" No bias was found in ACOS V7.3 from GEOS-Chem with a standard deviation of 1.6 ppm and R2 of 0.77 in the whole study area." in the appendix.

-p. 23, line 462 results above → results described above

Corrected.