Referee #1

Responses to Anonymous Referee #1 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 #1: general:

-The paper is interesting to the CO2 remote sensing community although in the end it stays rather inconclusive. The reason is that there is no absolute reference for the true XCO2 in this study. The conclusions that are being drawn are based on (in-) consistency between different retrieval algorithms and comparison to the GEOS-CHEM model and are hence to large extend speculative.

For inconclusive problem as you point out, we revised our analysis results concluded in Table 7. In this study, we aim to reveal regional uncertainty of GOSAT XCO2 retrievals via comparison and evaluation of consistence of multi-algorithms for GOSAT observations, and probe the reason why performances of XCO_2 from multi- algorithms are different in same regions. Our results are expected to give a reliable and valuable reference for application of XCO2 data in detection of carbon source and sink at a regional scale, e.g. the result gotten by our analysis, the better consistence of XCO2 from four algorithms (ACOS, NIES, OCFP, SRFP) in Eastern China with large anthropogenic CO2 emissions, can promote us to detect the anthropogenic enhancement of CO2 concentrations using these XCO2 data with confidence, and the result, the existing problems in deserts likely influenced by albedo and AOD, is expected to get attentions and improvement.

Table 1. Summaries of our analyses for uncertainty of XCO2 retrievals obtained by GOSAT via inter-comparison of multi-algorithms above, including characteristics of regional emissions, albedo, aerosol optical depth, and summary of differences between algorithms and bias compared to GEOS-Chem.

Characteristics of regions and summary of algorithms		Cells from 80 °E to 115 °E within 37°N-42°N							
Characteristics of regions	Regions Left longitude (°E)	80	85	90	95	100	105	110	115
	CO_2 emissions (Tg/year)*1	Low emissions (1.2-57.1)					High emissions (515.2-**821.9**)		
	Property of aerosol (AOD)*2	Dust (0.22-**0.53)**		Clear (0.10-0.28)				Urban (0.10-0.37))	
	Surface types (albedo)	Sand desert with high brightness (0.20-**0.26**)			Gobi and grassland (0.19-0.22)			Cropland and built-up (0.14-0.17)	
Summary of uncertainty	Consistency of algorithms (pairwise mean absolute differences)	Less Consistency (1.0-1.6 ppm)					Good consistency (0.7-1.1 ppm)		

	Bias compared to GEOS-Chem (bias range)	Large biases (1.2-3.1 ppm)	lesser biases excluding NIES (0.0-0.5 ppm)
	General performance of algorithms in spatio-temporal patterns of XCO_2 compared to GEOS-Chem	ACOS presents the lowest bias (-0.1±1.9 ppm); SRFP is next (-0.2±2.2 ppm) NIES presents the greatest -2.0±2.2 ppm)	

*[1] represents the total emissions of CO_2 from CHRED in each cell in 2012. *[2] is the range of averaged seasonal aerosol optical depth over a year.

-The discussion on the aerosol and albedo effect stays qualitative while a more quantitative analysis would be of interest here. I suggest to revise the paper to include a more quantitative analysis of the effect of aerosols and albedo on differences in retrieved XCO2 between different algorithms. This analysis should show to what extend the differences between algorithms, and between retrieved and models XCO2, are correlated with AOD and surface albedo. When such an analysis is included I recommend publication of the manuscript in AMT.

According to your suggestion, we added a quantitative analysis about the effect of aerosols and albedo in the discussion section from in the revised manuscript. It is also shown as follows:

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 °E -90 °E 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 °E -90 °E), 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.

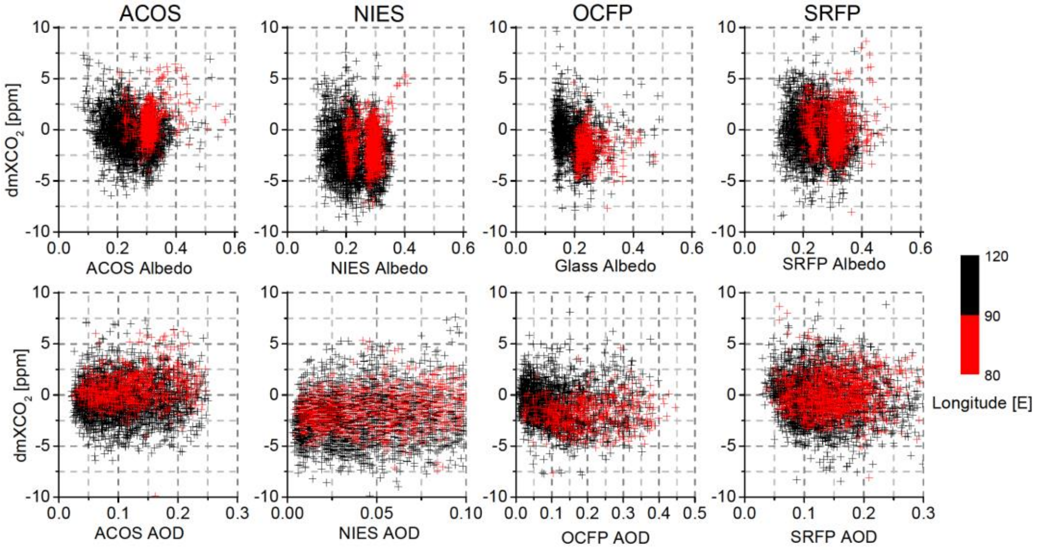

Fig. 1: Scatter plots of the differences ($dmXCO_2$) between GEOS-XCO_2 to ACOS, NIES, OCFP and SRFP respectively, with respect to albedo (the upper panels) and AOD (the lower panels). Colored points represent the data from different cells: red-[80 °E, 105 °E], black-[105 °E, 120 °E] in the study latitude 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 ±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.

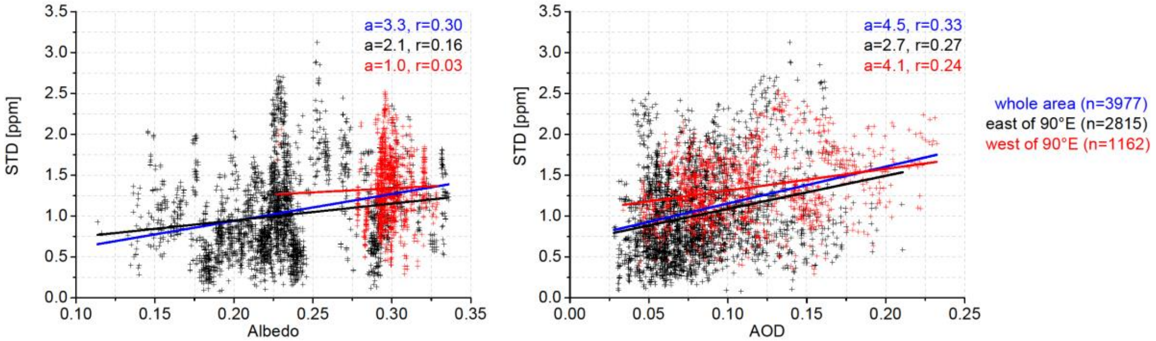

Fig. 2: Scatter plots of the standard deviation (STD) of XCO_2 from the four algorithms to albedo (the left panel) and AOD (the right panel). Colored points represent different cells: red-[80 °E, 105 °E], black-[105 °E, 120 °E] in the latitude zone [37 °N, 42 °N]. Colored solid lines display the corresponding 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.

-Other points:

--How accurate are the XCO2 values modeled by GEOS-CHEM? The paper would benefit from a demonstration of the capability of GEOS-CHEM, for example from comparions with TCCON (albeit outside the study region).

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 2.

Table 2. 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 2 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.

-- EMMA should be excluded from the analysis in this paper as it is not a retrieval algorithm itself but is composed from the different algorithms that are also analyzed in the present study. In fact, each EMMA value is the XCO2 retrieved by one of the algorithms that is closest to the median value for a given grid box. By including it in this study it correlates algorithm to itself.

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 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)

-- A proper reference should be made to EMMA as a tool to study consistency between different algorithms, like is being done in the present study.

Thanks for this suggestion. We will study the consistency of algorithms for EMMA in further when a proper reference is available.

--Line 132 states: " The recommended bias corrections are applied to the collected XCO2 data from ACOS, OCFP and SRFP". What is meant here? The files for both products already contain bias corrected products. Have these been used?

This is our incorrect expression. Modified to: “The collected XCO2 data from ACOS, OCFP and SRFP are products after bias correction.” .

-- Line 364 stated:" while Aerosol Optical Depth (AOD) is greatly affected by high surface albedo because of the optical lengthening effect.". What is meant here? AOD is not affected by surface albedo.

It is our incorrect expression. Modified to: “while estimations of Aerosol Optical Depth (AOD) in GOSAT full physics CO2 retrieval algorithms are greatly affected by high surface albedo because of atmospheric multiple scattering of light and the optical lengthening effect” .

-- The additional analysis of the new ACOS V7.3 product is confusing. It should either be used in the full analysis or the discussion should be shortened by only stating to what extend the conclusions would be different if the ACOS V7.3 product would have been used. The more detailed analysis could be moved to an appendix.

We shortened the part on the new version of ACOS, and moved part of it to an 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 are not exactly the newer version of ACOS products.