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Atmospheric Measurement Techniques Discussions

Interactive comment on "Preliminary validation of column-averaged volume mixing ratios of carbon dioxide and methane retrieved from GOSAT short-wavelength infrared spectra" by I. Morino et al.

Anonymous Referee #2
Received and published: 6 January 2011
The present manuscript aims at the validation of atmospheric CO2 and CH4 total column concentrations retrieved from solar backscatter measurements by the TANSO-FTS aboard GOSAT. The satellite retrievals are compared to ground-based observations by the TCCON network. The topic is highly relevant for researchers working on remote sensing of greenhouse gases from space and inverse modelling of the respective sources and sinks. Therefore, the study is suitable for publication in AMT.

However, the paper requires revisions – in particular a more thorough discussion of the results. In its present shape, the paper is a status report of the current official GOSAT processor. This is a valid topic for AMT in particular since GOSAT is a new, challenging, and promising satellite sensor. Unfortunately, the authors put little effort in going beyond a mere reporting of numbers. More discussion is required on why data quality is still unsatisfactory, on how data quality has been improved in the past, on how data quality can be improved in the future, and on how the validation results relate to GOSAT's overall goal to facilitate inverse estimates of sources and sinks.

We added the next sentences in page 5624, line 7:
The earlier version (Ver.00.xx) used only band 2 of TANSO-FTS and retrieved CO2 and CH4

columns separately and estimates XCO2 and XCH4 using dry-air column calculated from meteorological data analyzed by the Japan Meteorological Agency. Over the Sahara Desert and Arabian Peninsula and their surrounding areas, apparent high values of XCO2 and XCH4 were retrieved due to the influences of dust particles. In Ver.01.xx released in August 2010, bands 1 and 2 of TANSO-FTS were used for simultaneous retrieval of CO2 and CH4 columns with surface pressure. Therefore the apparent high values of XCO2 and XCH4 disappeared almost over the Sahara Desert and their surrounding areas thanks to the correction of the extended optical paths by the elevated dust particles.

We added the next sentence in page 5624, line 26:
Therefore it is important to examine further the spectroscopic parameters of O2 and CO2.

We added the next sentence in page 5625, line 6.
In the retrieval algorithm of Ver.01.xx, aerosols are assumed to exist homogeneously below 2-km altitude. In the near future retrieval algorithm, the vertical profiles of aerosols will be simultaneously retrieved with XCO2 and XCH4. This could decrease the standard deviation of the scatter of the GOSAT XCO2 and XCH4.

Based on this validation, the bias-corrected GOSAT XCO2 values were used in a preliminary estimation CO2 fluxes of 64-regions using the NIES inversion model. The uncertainty of the CO2 fluxes are expected to decrease in regions where ground-based CO2 monitoring stations are sparsely located (Shamil Maksyutov and Hiroshi Takagi, private communication).

Major comments

1. The number of GOSAT data used for comparison with TCCON seems very low (e.g. Fig. 4, 5, 7, and 8). For some of the validation sites, only 2 coincident GOSAT measurements are identified during _1 year of satellite operation.

- The authors should investigate if less stringent filtering of the satellite data or relaxed coincidence criteria can help to increase the number of GOSAT data for comparison. For example, I would consider a 30 min coincidence criterion between GOSAT overpass and TCCON measurement rather stringent given that CO2 and CH4 total column concentrations show very little variability on this timescale. The same holds for the spatial variability on _1 to 3 degree latitude/longitude.
- In cases with only a few data, it is useless to calculate the error statistics (e.g. Table 2, 3).

We relaxed coincidence criteria. We compared the mean values of g-b FTS data measured within ± 1 hour of GOSAT overpass time with the GOSAT data retrieved within ±2 or ±5degree latitude/longitude box centered at each g-b FTS site. The g-b FTS data which we obtained from some g-b FTS sites were limited within ± 1 hour of GOSAT overpass time.
Coincidence data increased to 256 for ±2degree latitude/longitude, and 966 for ±5 degree latitude/longitude. The results are shown in Tables 4-7 and are summarized as follows:

For ±2 degree latitude/longitude, the GOSAT XCO_2 and XCH_4 are biased low by 8.57±4.44 ppm (-2.2±1.2%) and 15.8±22.3 ppb (0.89±1.26%), respectively.
For ±5 degree latitude/longitude, the GOSAT XCO_2 and XCH_4 are biased low by 8.25±3.97 ppm (-2.1±1.0%) and 14.8±22.6 ppb (0.83±1.27%), respectively.
These results are nearly equal to those in Tables 2 and 3.

Table 4. The averages and one standard deviations of the differences between GOSAT X_{CO2} and g-b FTS X_{CO2} and the percentages of GOSAT X_{CO2} divided by the g-b FTS X_{CO2} (±2 degrees, GOSAT overpass time ±60 min).

Sites	(GOSAT SWIR X_{CO2}) – (g-b FTS X_{CO2})			(GOSAT SWIR X_{CO2}) – (g-b FTS X_{CO2}) / (g-b FTS X_{CO2})	
	Number of data	Average (ppm)	1σ (ppm)	Average (%)	1σ (%)
Bialystok	3	-6.68	10.04	-1.72	2.61
Orleans	18	-13.01	3.59	-3.37	0.93
Garmisch	3	-7.71	3.24	-1.98	0.82
Park Falls	14	-7.72	4.11	-1.99	1.06
Lamont	126	-8.28	3.88	-2.13	1.00
Tsukuba	23	-6.09	2.77	-1.57	0.71
Darwin	9	-7.83	3.39	-2.03	0.88
Wollongong	57	-9.24	5.38	-2.39	1.39
Lauder	3	-9.70	3.86	-2.52	0.99
Total	256	-8.57	4.44	-2.21	1.15

Table 5. The averages and one standard deviations of the differences between GOSAT X_{CH4} and g-b FTS X_{CH4} and the percentages of GOSAT X_{CH4} divided by the g-b FTS X_{CH4} (±2 degrees, GOSAT overpass time ±60 min).

Sites	(GOSAT SWIR X_{CH4}) – (g-b FTS X_{CH4})			(GOSAT SWIR X_{CH4}) – (g-b FTS X_{CH4}) / (g-b FTS X_{CH4})	
	Number of data	Average (ppm)	1σ (ppm)	Average (%)	1σ (%)
Bialystok	3	-0.0107	0.0306	-0.61	1.73
Orleans	18	-0.0383	0.0191	-2.14	1.07
Garmisch	3	-0.0111	0.0170	-0.62	0.95
Park Falls	14	-0.0116	0.0213	-0.65	1.19
Lamont	126	-0.0108	0.0213	-0.60	1.18
Tsukuba	23	-0.0101	0.0135	-0.57	0.75
Darwin	9	-0.0153	0.0141	-0.87	0.80
Wollongong	57	-0.0237	0.0243	-1.36	1.39
Lauder	3	-0.0170	0.0179	-0.98	1.03
Total	256	-0.0158	0.0223	-0.89	1.26

Table 6. The averages and one standard deviations of the differences between GOSAT X_{CO2} and g-b FTS X_{CO2} and the percentages of GOSAT X_{CO2} divided by the g-b FTS X_{CO2} (±5 degrees, GOSAT overpass time ±60 min).

Sites	(GOSAT SWIR X_{CO2}) – (g-b FTS X_{CO2})			((GOSAT SWIR X_{CO2}) – (g-b FTS X_{CO2})) / (g-b FTS X_{CO2})	
	Number of data	Average (ppm)	1σ (ppm)	Average (%)	1σ (%)
Bialystok	26	-6.76	4.38	-1.75	1.13
Orleans	59	-10.24	3.75	-2.65	0.97
Garmisch	15	-6.58	2.35	-1.71	0.60
Park Falls	104	-8.24	4.07	-2.13	1.05
Lamont	513	-8.29	3.60	-2.14	0.92
Tsukuba	29	-5.61	3.33	-1.44	0.86
Darwin	72	-7.41	3.04	-1.92	0.79
Wollongong	143	-8.72	5.22	-2.26	1.35
Lauder	5	-7.02	4.57	-1.83	1.18
Total	966	-8.25	3.97	-2.10	1.02

Table 7. The averages and one standard deviations of the differences between GOSAT X_{CH4} and g-b FTS X_{CH4} and the percentages of GOSAT X_{CH4} divided by the g-b FTS X_{CH4} (±5 degrees, GOSAT overpass time ±60 min).

Sites	(GOSAT SWIR X_{CH4}) – (g-b FTS X_{CH4})			((GOSAT SWIR X_{CH4}) – (g-b FTS X_{CH4})) / (g-b FTS X_{CH4})	
	Number of data	Average (ppm)	1σ (ppm)	Average (%)	1σ (%)
Bialystok	26	-0.0072	0.0238	-0.41	1.35
Orleans	59	-0.0230	0.0183	-1.29	1.03
Garmisch	15	0.0032	0.0152	0.18	0.85
Park Falls	104	-0.0166	0.0225	-0.92	1.25
Lamont	513	-0.0132	0.0230	-0.73	1.28
Tsukuba	29	-0.0077	0.0165	-0.43	0.92
Darwin	72	-0.0140	0.0123	-0.80	0.70
Wollongong	143	-0.0218	0.0253	-1.25	1.45
Lauder	5	-0.0030	0.0230	-0.17	1.33
Total	966	-0.0148	0.0226	-0.83	1.27

2. The paper requires significant more discussion on the results. The paper finds, that GOSAT CO_2 and CH_4 retrievals are globally low-biased and that the apparent precision is 1% (as calculated from very few data, see comment 1).

- There is no discussion on why the bias varies from site to site by more than 3% (e.g. Table 2,3). Regionally varying biases are probably the most detrimental issue to inverse modelling of sources and sinks. A global low-bias, however, is not really worrisome given that also the TCCON data are globally scaled to match the in-situ standards.

As anonymous referee suggested, we added the next sentences after line 17 in page 5623.
It must be noted that it is useless to calculate the error statistics for a few data in Tables 2 and 3. We have to consider statistically all data (62) in Tables 2 and 3. For Orleans, Lamont, Tsukuba and Wollongong where the numbers of data are more than 10 in Table 2, respective biases exist barely within mutual standard deviations. Therefore we could say the bias does not vary from site to site from this preliminary validation. However we have to investigate this further.

- The GOSAT retrievals scatter substantially more than the TCCON data. This should be addressed in the discussion. How does the scatter compare to the noise error? Due to the scatter (and due to sparse data coverage), the Northern-hemisphere seasonal cycle of CO_2 cannot be clearly identified in time series of individual GOSAT observations (figures 4,5). This is quite disappointing in my opinion.

We changed from line 1 in page 5625.
The one standard deviation of the scatter of the GOSAT SWIR XCO_2 and XCH_4 is about 1% after correction of negative biases of XCO_2 and XCH_4 by 8.85 ppm and 20.4 ppb, respectively and it is larger than those of the g-b FTS data (~0.3%).

- Potential reasons for scatter and bias are not discussed except for a very vague and short speculation in section 5. What is the impact of spectroscopy errors in the various bands (O_2, CO_2, CH_4)? What are the instrument related uncertainties? I would expect some detailed information on instrument issues (which have certainly been discovered since launch of the satellite). What is the potential impact of residual aerosol and cirrus interference in particular since retrieved scattering properties are mostly representative for the O2A band, not for the CO_2 and CH_4 bands? To what extent are some validation sites "easier" than others? Garmisch for example seems a very tough site for satellite validation due to rough topography.

We added the following sentences after line 26 in page 5624:
Therefore it is important to study further improvements for the spectroscopic line parameters of O_2 and CO_2.

We add the following sentences after line 26 in page 5624:
Some instrumental issues occurred since the launch of GOSAT. Sampling laser wavelength of TANSO-FTS shifted in time probably due to the change of the 1.31-um distributed-feedback laser cavity length. The sensitivity of band 1 was decreased after the launch. These effects are considered before the retrieval of TANSO-FTS SWIR. The pointing error of the TANSO-FTS occurred when the pointing mirror has moved largely to the along track direction. This error causes the mismatch of the field of views between CAI and TANSO-FTS and misleads the cloud screenings. However in the case of the special point observation mode of TANSO-FTS to g-b FTS sites, the mismatch might be small.

We add the following sentences after line 6 in page 5625:
In the retrieval algorithm of Ver.01.xx, the aerosols are assumed to exist homogeneously below 2-km altitude. In the near future retrieval algorithm, vertical profiles of aerosols will be simultaneously retrieved with XCO_2 and XCH_4. This might decrease the scatters of XCO_2 and XCH_4.
Although topographies in the surrounding of g-b FTS sites may influence the data quality, it is not clear at present. We plan to investigate further this effect for the future.

3. Section 4.2 covers global maps of CO_2 and CH_4 for two months of the year 2009. This is useless for the purpose of validation if no comparison data is shown. Moreover, similar plots have been featured in Yoshida et al., AMTD, 2010. Either remove section 4.2 or evaluate the global distributions against a validation dataset (e.g. model data).

First of all, we changed Figs. 2 and 3 to the global distribution of the gridded data of GOSAT SWIR XCO_2 and XCH_4 monthly averaged over 1.5 by 1.5 degrees in April and October 2009. From these figures, we see the information on seasonal variations of XCO_2 and XCH_4 and where these values are mainly observed. These figures are also based on the calculation of latitudinal distributions of XCO_2 and XCH_4. Therefore we will save section 4.2. The comparison with models such as the NIES transport model has been made in the paper by the Yoshida et al., AMTD, 2010 and CarbonTracker will be made in the future.

Further comments

- The introduction is biased toward CO_2. I recommend some more introductory discussion on CH_4.

We added the following sentences as suggested:

Page 5615, line 26:

Methane in the atmosphere is determined by a balance between emission from the surface and loss by OH radicals in the atmosphere. After almost a decade of near-zero growth, globally averaged atmospheric methane increased during 2007 and 2008. This increase could be due to natural climate variability and not melting of Arctic permafrost and hydrates (Dlugokencky et al., 2009). To accurately predict future atmospheric CO_2 and CH_4 concentrations and their impacts on climate, it is necessary to clarify the distributions and variations of those sources and sinks.

Page 5616, line 11:

To reduce the uncertainty in monthly, sub-continental (about 500 km) methane source strengths from satellite measurements, the precision of the column-averaged volume mixing ratios of methane is required to be 1-2% without systematic biases (Meirink et al., 2006).

- Sections 2 and 4.2 provide a basic overview about the GOSAT instruments and the retrieval method. For the latter, the paper mostly refers to Yoshida et al., AMTD, 2010. While this is a valid reference, I recommend to add some information on the aspects relevant for validation: spectroscopic databases, meteorological input, calculation of mixing ratios from total columns. Maybe a table would help here.

We inserted the next sentences between line 7 and line 8 in Page 5621:

Table 1A summarizes the spectroscopic databases of CO_2, CH_4, H_2O, and O_2 and the parameters retrieved from bands 1and 2 of TANSO-FTS. The grid point values of the meteorological data analyzed by the Japan Meteorological Agency are interpolated to the retrieval points.

Table 1a. (a) Spectroscopies for CO_2, CH_4, H_2O and O_2 and (b) parameters retrieved from bands 1 and 2 of the TANSO FTS in the Ver.01.xx

(a)

	absorption line profile	Reference
CO_2	Voigt + Line mixing	Lamouroux et al. (2010)
CH_4	Voigt	HITRAN 2008
H_2O	Voigt	HITRAN 2008
O_2	Voigt + Line mixing and collision-induced absorption	Tran et al. (2006) Tran and Hartmann (2008)

(b)

Land	CO_2	CH_4	H_2O	AOD	surface press.	temp. profile bias	wavenumber dispersion	surface albedo	
Ocean								surface wind speed	radiance adjust. Factor

- From section 2, the reader might get the impression that also the thermal infrared and 2-micron CO2 bands are used for retrieval (p.5619, l 13). This should be avoided.

We corrected as follows:
p.5619, l.6 Briefly, absorption spectra at bands 1 and 2 are used
l.12 On the other hand, the TIR absorption
l.14 The retrieval from TIR spectra and validation of their products will be presented in a different papers.

- Section 3.2 is quite short and could be merged into Section 3.1.
Section 3.2 was merged into Section 3.1.

- p.5615,l.23: total warming effect -> total anthropogenic warming effect
We corrected as suggested:
total anthropogenic warming effect

- p.5617,l.13: several thousand square kilometers -?-> several hundred thousand

square kilometers
We corrected as suggested:
several hundred square kilometers

- p.5621,l.16: the latest retrieved value was overwritten: Why are data overwritten and not averaged?
We exchanged with averaged values of XCO_2 and XCH_4.

- p.5622,l.16: Figs. 4 and 5g,h -?-> Figs. 4 and 5
We corrected as suggested:
Figs. 4 and 5

- p.5624,l.13: though a striking difference is seen near 50-60degree N. : I would not see a striking difference given the generally large scatter of the GOSAT data. Further, there is an at least equally 'striking' difference in the zonal average CO_2. If this is an attempt to hint at high-latitude CH_4 emission from wetlands or thawing permafrost, it first needs to be proven that the observed difference is not a retrieval artefact. In my opinion, this has not been achieved here. I recommend to remove the statement.

We removed the statement : though a striking difference is seen near 50-60degree N.

- Figs. 2 through 11 should be presented on the same CO_2 and CH_4 scales for easy comparison. The CO_2 range [350, 410] ppm used in Figs. 4 and 5, for example, seems rather large and tends to mask detail. The CO_2 range [360,400] ppm used in Fig. 6 seems better.

We presented the same XCO_2 and XCH_4 scales for easy comparison: XCO_2 range [360, 400] ppm and XCH_4 range [1.6, 1.9] ppm.