Comments to referees

We appreciate the important and meaningful comments of the referees.

Referee #1

General comments:

(1) This paper describes first aircraft measurements over g-b FTS sites in Japan for comparisons of the g-b FTS and GOSAT with the aircraft measurements. We succeeded in completing all planned measurements. This aircraft campaign provided significant information on the total column estimates of both the g-b FTS and GOSAT in combination with estimated vertical stratospheric profiles.

The ceiling altitude of 7 km in this measurement was lower than the tropopause height. All referees pointed out our ceiling altitude; therefore, the authors estimated the error when calculating the total column amount from the aircraft measurement and GFIT a priori at the stratosphere. The stratospheric error is particularly critical because of its inclusion in the estimated stratospheric profile. The authors added the following text to section 4 according to the referee's comment:

"The errors resulted from the estimated stratospheric profile along with the surface and aircraft measurements, and they were evaluated when the aircraft measurement was integrated using the GFIT a priori stratosphere. The estimated total error is the square root of the sum of squares of these components. We estimated a total error of 0.5 ppm for CO_2 and 9 ppb for CH_4 in the same manner as in the TCCON calibration."

Referee #1 indicated that the difference between the aircraft and g-b FTS at Moshiri was larger than the TCCON validation result obtained during the aircraft measurement. Possible causes are noted in section 5.2. Although a somewhat large difference remains, we believe it is possible to use Moshiri data for the validation if we keep in mind the characteristics of retrieval results at Moshiri.

(2) Referee #1 indicated the possibility of using monthly average data of the satellite. We calculated the monthly averages and standard deviations of g-b FTS at Moshiri (8/2009) and Tsukuba (2/2010). These results are

listed in the table below:

Table. Monthly average and standard deviation of g-b FTS at Moshiri, Tsukuba and ACOS

	Moshiri (8/2009)		ACOS (8/2009)		Tsukuba (2/2010)	
CO_2	377.44	4.69	369.02	12.80	389.43	1.95
CH_4	1.771	0.029	--	--	1.788	0.010

The monthly average of ACOS B2.9 in August, 2009 is calculated using data from within 100 km of the Moshiri site shown in the above table. In August 2009, the monthly average of ACOS B2.9 was 8 ppm lower than that of the g-b FTS at Moshiri. This lower average compared to Moshiri FTS and large standard deviation was due to lack of data points. Using monthly averaged satellite data is one method for comparing the ground station measurements with the aircraft measurements and the satellite data. Conditions under which the average is obtained should be considered more seriously. In this study, the authors decided not to use the monthly average from this result.

General public user (GU) data are screened from the research announcement user (RA) data so that all GU data are included in RA data.

The bias calculated from GU data is not coincident with that from RA data.

Referee #1 suggested a usage of the monthly average of the ACOS B2.9 product for comparison with Taiki. Unfortunately, a specific point observation at Taiki on 30 August, 2009, was not retrieved for NIES and ACOS owing to fractional cloud coverage. We calculated the monthly average of both NIES and ACOS data, resulting in 377.25 and 375.64 ppm CO_2, respectively. These values are consistent with the results reported in Morino et al. (Atmos. Meas. Tech., 2011). Note that the total column from the aircraft observation at Taiki has to be calculated without the GFIT a priori because of the absence of a g-b FTS site. We do not mention the effect on the absence of the stratospheric profile for Taiki.

We understand from this measurement that negative bias remains after calibration. This small bias between the Tsukuba g-b FTS and the aircraft remained even after the standard TCCON calibration, which may be due to the effect of ghosts in section 5.2.

Scientific Comments

(1) P. 1846:

As pointed out by referee #1, the difference of the aircraft from the g-b FTS and GOSAT includes both bias and random errors. An assessment performed using the results of average differences was reported by Morino et al. (Atmos. Meas. Tech., 2011). In the first analysis, we evaluated our results to ensure consistency with those of Morino et al. (Atmos. Meas. Tech., 2011).

(2) P. 1850, Line 20:

The main reason for our choice in conducting the aircraft observation over Moshiri was that we were able to measure coincident with a ground-based FTS and meteorological instruments.

The Moshiri site is a normal observation point; Taiki was observed on August 30, 2009, as a special observation point. GOSAT observed both Moshiri and Taiki on path 5.

The surface albedo was retrieved with CO_2 and CH_4 concentration profiles simultaneously in addition to other auxiliary parameters. We believe the homogeneity and flatness of the Taiki area gave us an improvement of the retrieval algorithm in the initial analysis phase.

The text describing Hokkaido measurements was confusing. We revised the paragraph in p. 1851 Lines 3–12 as follows:

"In August 2009, we also carried out aircraft measurements over Moshiri and Taiki, Hokkaido. Both Moshiri and Taiki were observed on GOSAT's path 5. Tokachi-Obihiro Airport was used as a base camp for the Hokkaido measurements.

The aircraft measurements were carried out on 26 August 2009, over the Moshiri observatory in the Geospace Research Center of the Solar-Terrestrial Environment Laboratory of Nagoya University, which is located in northwestern Hokkaido. The Moshiri observatory, a GOSAT validation observational site, operates a g-b FTS and meteorological instruments.

A descent spiral flight over Taiki was carried out on 30 August 2009 in accordance with a GOSAT measurement. Despite the fact that there is no ground observation station at Taiki, located 200 km southeast of Moshiri, the flatness and homogeneity of its surface improved the GOSAT retrieval algorithm in the initial analysis phase. On 30 August 2009, GOSAT was not successful in retrieving XCO_2 or XCH_4 owing to clouds in its field of view."

(3) P. 1850, Line 26:

Although CO_2 concentration increases near the surface owing to human activities, profile uniformity is assumed in the free troposphere above the planetary boundary layer. We substituted the profile in the free troposphere measured at Kumagaya. The following sentence was added to the section 3:

“Vertical profiles measured at Kumagaya were used in the calculation of the total column amounts of CO_2 and CH_4 at Tsukuba, assuming uniformity of atmospheric concentrations of these compounds in the free troposphere above the planetary boundary layer over Tsukuba and Kumagaya.”

(4) P. 1852, Line 16:

We added a figure of column averaging kernels of g-b FTS (fig. 7) and the following description to section 4 according to referee's comment.

"The column averaging kernels for the g-b FTSs at Tsukuba and Moshiri are shown in Fig. 7. Column averaging kernels vary as a function of pressure and solar zenith angle."

(5) P. 1853, Line 8:

GU data were screened on several criteria. In the case of February 14, AOT at 1600 nm became larger than 0.5 (AOT = 0.9284).

(6) P. 1854, Line 20:

It is clear that the total columns retrieved from Moshiri FTS shows larger uncertainties than those at Tsukuba site owing to the lack of FVSI because it was partially cloudy on the observation day. The instrument stability installed in Moshiri might be a cause of the difference as well. These complex causes might explain the large difference.

(7) P. 1855, Line 18:

Uchino et al. (Atmos. Chem. Phys., 2012) reported the influence of high-altitude aerosols and thin cirrus clouds on GOSAT SWIR retrieval. We have added the following sentence to the section 5.2:

"These cirrus clouds give rise to a difference between the actual optical path and the assumed optical path, which affected the GOSAT SWIR retrieval."

(8) P. 1860–1863, Tables 1-4:

The difference between tables 1-2 and 3-4 was a result of using different average kernels. According to eq. (1) in p. 1852, the column averaging kernel ***a*** for the g-b FTS is used in tables 1 and 3 for the comparison between the aircraft and g-b FTS. On the other hand, the column averaging kernel ***a*** for GOSAT is used in tables 2 and 4. The authors have added a footnote in Tables 1–4 and the following sentence in section 4:

"The column averaging kernel ***a*** for the g-b FTS is used in tables 1 and 3. Another column averaging kernel ***a*** for GOSAT is used in tables 2 and 4."

(9) P. 1870, Fig. 7

The error bars of GOSAT data were plotted in Fig. 8 and 9 and the known bias was added in their captions of Fig. 8, Fig. 9. We only had a partial understanding of the difference between ACOS and NIES GOSAT data. Then, in this study, the authors decided to focus on comparing the aircraft measurements with g-b FTS and NIES GOSAT data.

Technical Comments

(1) P. 1851, Line 18:

We revised the sentence as follows:

"The GFIT algorithm, developed at the Jet Propulsion Laboratory (JPL), is a spectral fitting code for retrieving the column-averaged abundances of atmospheric trace gases from infrared solar absorption spectra (Wunch et al., 2011)."

(2) P. 1853, Line 3:

Mean squares have the same units of measurement as the square of the quantity being estimated. In our case, we observed radiance spectrum whose unit is $W/cm^2/str/cm^{-1}$

(3) P. 1854, Line 25:

The authors have incorporated the phrase "in the future."

Referee #2

Specific comments:

P. 1845, Line 24:

We replaced the reference from IPCC2007 to Greenhouse Gas Bulletin of the WMO in the Introduction according to the referee's comment.

P. 1846, Line 9:

There were no definite requirements on the monthly average accuracy of the column-averaged dry air mole fractions of both CO_2 and CH_4 for GOSAT. Kuze (App. Opt., 2009) mentioned the target of observation of CO_2 density in three-month averages with 0.3%–1% (1–4 ppmv) relative accuracy in 100–1000 km spatial resolution before the launch.

P. 1848, Line 27:

The authors stated typical duration during a spiral descent flight on P. 1847, Line 26–P. 1848, Line 1 in the text. The aircraft measurements were designed within GOSAT overpass ±30 min.

Here, the duration indicates the time between sampling start time and sampling end time. We substituted the intermediate time of the duration of each flight as the time of the aircraft measurement.

Sampling was conducted for 105 s during a level flight.

P. 1849, Line 28:

Referee #2 mentioned accuracy according to the aircraft in situ measurement because in situ data are used as “truth” when comparing the g-b FTS and GOSAT.

Before the aircraft measurements, we calibrated the NDIR by using standard commercial dry air gas and N_2 (for calibration of zero offset) with accuracy within ±1 ppm.

During the aircraft in situ measurement, CO_2 concentrations measured by NDIR were corrected by two standard gases introduced at regular intervals, as described in section 2.3. These gases were calibrated to WMO in situ trace-gas measurement scales. The authors were then able suppress the uncertainty within ±0.2 ppm including offset, linearity, and drift.

We revised the sentence in p. 1850, Line 2, as follows:

"..., analytical precision of the CME for the CO_2 concentration is within ±0.2 ppm including offset, linearity and drift for 10 s on average during the aircraft measurements."

P. 1850, Line 26:

Referee #1 mentioned a similar comment. Please refer to (3) P. 1850, Line 26 of referee #1.

P. 1851, Sect. 3:

We added following sentences to the end of section 3, according to the referee's comment:

"We conducted three flights over Tsukuba on February 14, 20, and 23, 2010, and one flight over Moshiri on August 30, 2009. We obtained four profiles to calculate XCO_2 and XCH_4."

P. 1852, Sect. 4:

Referee #2 pointed out the error associated with the a priori profile.

The error estimates arising from the profile over the aircraft ceiling altitude were summarized in the response to referee #1.

P. 1853, Line 25:

We understand that the thin cirrus clouds measured on February 14 led to larger differences, which is opposite of the smaller differences reported on other observation days. Considering the standard deviation of the average difference (0.46 ppm), the difference on February 14 becomes comparable.

Referee #3

General comments:

Referee #3 commented on a demand for repetition of instrumental detail and calibration results. The authors briefly interpreted these comments in the text in section 3 with the following additions:

"Direct sunlight is introduced into the g-b FTS by a sun tracker and gold-coated mirrors. The g-b FTS measures direct solar spectra in the near-infrared region, and column-averaged abundances of atmospheric constituents are retrieved from the spectra. Measurements with the high-resolution FTS are performed according to the TCCON data protocol. A CaF_2 beam splitter and an InGaAs detector are used for the 5500–10500 cm^{-1} spectral region. A spectral resolution of 0.02 cm^{-1}, aperture size of 0.5 mm, and scanner velocity of 10 kHz are used as standard parameters for the TCCON measurements. The pressure in the FTS is kept at 0.03 Torr by an oil-free scroll vacuum pump. The forward and backward scanned interferograms are separately integrated over a period of about 70 s.”

Referee #3 also mentioned the effect of the limited ceiling altitude of the aircraft observation. The author's response is summarized in response to referee #1's comment.

Specific comments:

P. 1850, Line 20:

Referee #1 mentioned a similar point. Please refer to the comment to referee #1

P. 1852, Line 1:

The detector did not have sensitivity at the spectral region of HF when we installed the instrument before joining the TCCON network. We then replaced the detector with sensitivity at the HF region.

P. 1852, Line3:

The tropopause height can be derived from meteorological parameters measured directly by radiosonde. In the case of an absence of radiosonde data, the temperature profile from NCEP is used to determine the tropopause height in the GFIT. The tropopause height is manually adjusted within a day using the CH_4-HF correlation.

The effect of the difference between “true” tropopause height and that assumed by GFIT algorithm is described in section 5.3.

P. 1854, Line 16:

The initial instrumental settings, including scan speed, were different from the TCCON norm at Moshiri. This is the only difference to the TCCON standard settings.

It is clear that the scatter in total columns retrieved from the Moshiri FTS resulted from the lack of FVSI because conditions were partially cloudy on the observation day. These complex factors may explain the large difference.

The authors added a figure of the time series of total column amounts measured at Moshiri according to referee's comment as Figure 10.

Tables 1–4:

In this paper, we focused on the calibration of g-b FTS in Japan and the validation of the GOSAT data. A comparison of the g-b FTS and GOSAT data with the aircraft considered both averaging kernels.

The authors revised the sign of difference in Tables 1-4 to be consistent with Morino et al. (Atmos. Meas. Tech., 2011).

Technical comments:

The authors revised XCO2 and XCH4 to X_subscript (CO2/CH4)

References

Kuze, A., Suto, H., Nakajima, M., and Hamazaki, T.: Thermal and near infrared sensor for carbon observation Fourier-transform spectrometer on the Greenhouse Gases Observing Satellite for greenhouse gases monitoring, App. Opt., pp. 6716–6733, 2009

Morino, I., Uchino, O., Inoue, M., Yoshida, Y., Yokota, T., Wennberg, P. O., Toon, G. C., Wunch, D., Roehl, C. M., Notholt, J., Warneke, T., Messerschmidt, J., Griffith, D. W. T., Deutscher, N. M., Sherlock, V., Connor, B., Robinson, J., Sussmann, R., and Rettinger, M.: Preliminary validation of column-averaged volume mixing ratios of carbon dioxide and methane retrieved from GOSAT short-wavelength infrared spectra, Atmos. Meas. Tech., 4, 1061–1076, doi:10.5194/amt-4-1061-2011, 2011.

Uchino, O., Kikuchi, N., Sakai, T., Morino, I., Yoshida, Y., Nagai, T., Shimizu, A., Shibata, T., Yamazaki, A., Uchiyama, A., Kikuchi, N., Oshchepkov, S., Bril, A., and Yokota, T.: Influence of aerosols and thin cirrus clouds on the GOSAT-observed CO_2: a case study over

Tsukuba, Atmos. Chem. Phys., 12, 3393-3404, 2012.

Wunch, D., Toon, G. C., Wennberg, P. O., Wofsy, S. C., Stephens, B. B., Fischer, M. L., Uchino, O., Abshire, J. B., Bernath, P., Biraud, S. C., Blavier, J.-F. L., Boone, C., Bowman, K. P., Browell, E. V., Campos, T., Connor, B. J., Daube, B. C., Deutscher, N. M., Diao, M., Elkins, 15 J. W., Gerbig, C., Gottlieb, E., Griffith, D. W. T., Hurst, D. F., Jime´nez, R., Keppel-Aleks, G., Kort, E. A., Macatangay, R., Machida, T., Matsueda, H., Moore, F., Morino, I., Park, S., Robinson, J., Roehl, C. M., Sawa, Y., Sherlock, V., Sweeney, C., Tanaka, T., and Zondlo, M. A.: Calibration of the Total Carbon Column Observing Network using aircraft profile data, Atmos. Meas. Tech., 3, 1351–1362, doi:10.5194/amt-3-1351-2010, 2010.