Interactive comment on “Retrieval algorithm for CO₂ and CH₄ column abundances from short-wavelength infrared spectral observations by the Greenhouse Gases Observing Satellite” by Y. Yoshida et al.

Anonymous Referee #1

Received and published: 9 December 2010

The manuscript "Retrieval algorithm for CO2 and CH4 column abundances from shortwavelength infrared spectral observations by Greenhouse Gases Observing Satellite" from Yoshida et al. is the first detailed manuscript submitted to a peer-reviewed journal where the operational retrieval algorithm for GOSAT is described. It therefore covers an important topic which is highly relevant for AMT. The paper is well written and I recommend its publication in AMT after the comments given below have been considered by the authors.

=> Thank you for your careful reading of our paper. The followings are our reply to your comments. The words with "double line (~~—~~)" were removed and those with "under bar (___)" were added.

Abstract: It is stated that certain GOSAT results "agree well with the current state of knowledge" although no detailed evidence for this statement is given. I recommend to show at least model conparisons (as the authors have pointed out that a comparison with independent measurements will be shown elsewhere), e.g., using the NIES TM model which is used for the CO2 and CH4 a-priori profiles.

=> We add model comparison by using the NIES TM. Figures which show the monthly averaged global distribution (corresponding to Fig. 6) and the latitudinal distributions of zonal mean (corresponding to Fig. 7) are added. Followings are the revised sentences.

<p.4793, line 15>

"The interhemispherical differences and the temporal variation patterns of the retrieved column abundances ~~agree well with the current state of knowledge~~ show similar features with the atmospheric transport model."

<p. 4813, line 19>

"The global distributions ~~of retrieval results~~ and the latitudinal distributions of zonal averages of retrieval results and simulated results using the NIES TM are shown in Figs. A, B, and C ~~respectively~~. For comparison, the matched NIES TM data with the GOSAT retrieval is used.

The retrieved XCO_2 and XCH_4 show appropriate patterns of the latitudinal distributions and seasonal variations, although the retrieval results have biases and show ~~relatively~~ large variabilities as compared with the NIES TM. The variation of XCO_2 and XCH_4 in the longitudinal direction over the ocean is smaller than those over the land mainly due to the distributions and strengths of sources and sinks of these gases. Although the elements of the state vector are different for land cases and ocean cases, no clear gaps are found around the coastline."

<p.4815, line 7>

"The interhemispherical differences and the temporal variations of retrieved XCO_2 and XCH_4 ~~agree well with the current state of knowledge~~ show similar patterns with those simulated with the NIES TM, although there exist bias and amplitude difference."

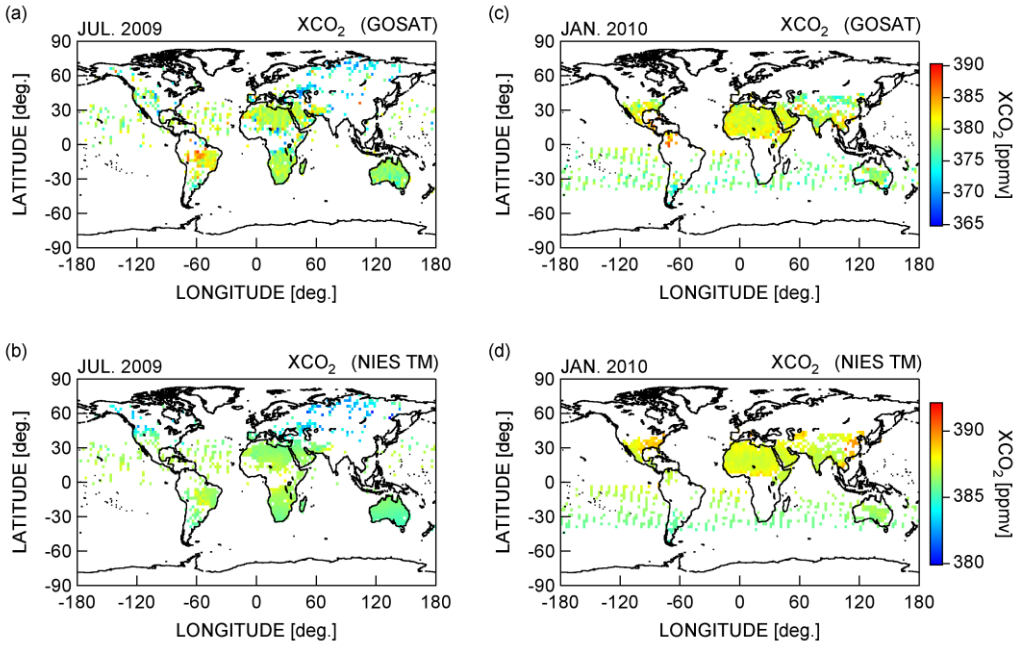


Fig. A Monthly average of the XCO_2 [ppmv] retrieved by GOSAT (a, c) and simulated by the NIES TM (b, d) within a 2.5 x 2.5-degree grid box. A blank indicates that no valid retrieval result was available within the grid box. Different color-scales are used for GOSAT retrieval and the NIES TM simulation.

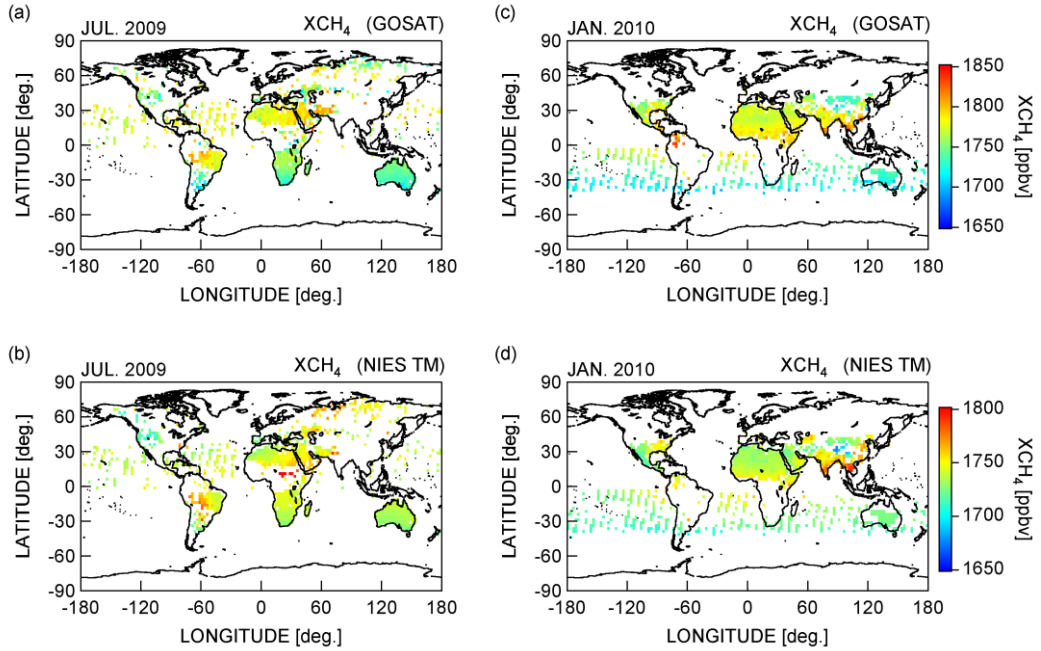


Fig. B Monthly average of the XCH_4 [ppbv] retrieved by GOSAT (a, c) and simulated by the NIES TM (b, d) within a 2.5 x 2.5-degree grid box. A blank indicates that no valid retrieval result was available within the grid box. Different color-scales are used for GOSAT retrieval and the NIES TM simulation.

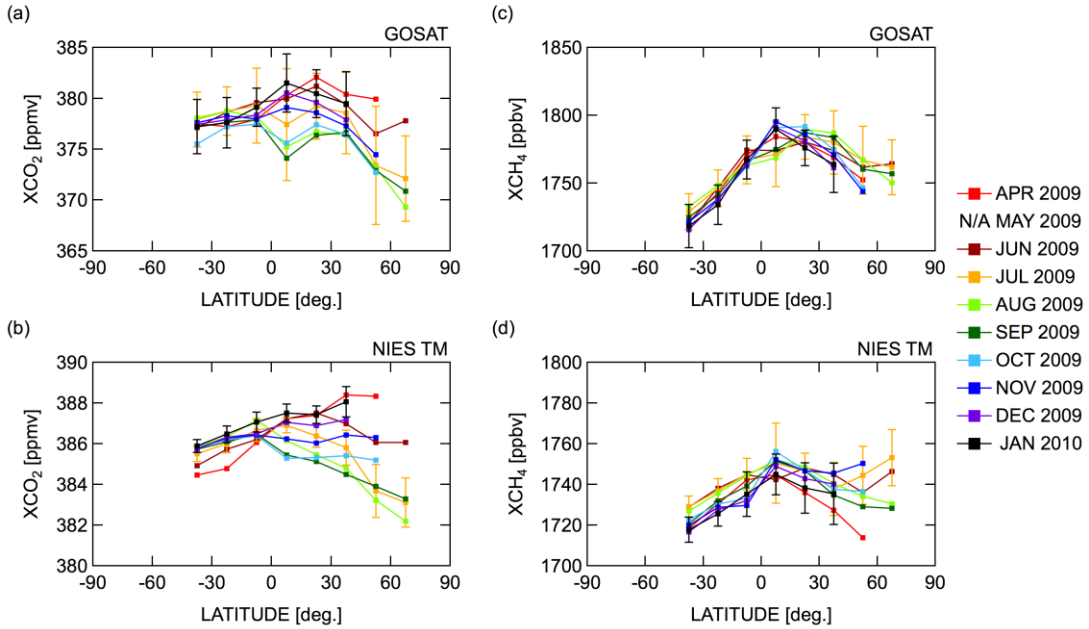


Fig. C Latitudinal distributions of zonal mean of the retrieved and simulated XCO_2 [ppmv] (a, b) and XCH_4 [ppbv] (c, d). The standard deviations of zonal variation for July 2009 and January 2010 are plotted as error bars.

Introduction, page 4794, line 25: The sentence as written gives the wrong impression that SCIAMACHY CO2 will not be precise and accurate enough for flux estimation. This however only refers to a certain data product (the product of Schneising et al., 2008) and this product may improve in the future e.g. using an improved version of the WFM-DOAS algorithm of Schneising et al., 2008, or using another algorithm such as the one of Reuter et al., 2010. This statement needs to be modified to take this into account.

=> We agree with you. Revised the sentence as follows.

<p. 4794, line 25>

"~~However, the~~ The precision (1 to 2%) and accuracy (-1.5%) of CO_2 column abundances by current SCIAMACHY retrieval method (Schneising et al., 2008) are still insufficient for flux estimation, although the improvement of the retrieval algorithm has been continuously carried out."

Introduction, page 4795, line 13: What is the difference between the different versions of the Level 2 algorithms ? Please add this information.

=> The different versions of the Level 2 product reflect the different versions of the Level 1B product (measured spectrum). The Level 2 algorithm itself is not changed. We add this information as follows.

<p. 4795, line 13>

"Note, (1) the different version indicates the different version of the input TANSO-FTS Level 1B product (measured spectrum); the corresponding Level 1B versions are V050.050, V080.080, and V100.100, respectively, and (2) the major differences in the Level 1B are the detection criteria for signal saturation and spike-noise which are attached as quality flags in the Level 1B product."

Introduction, page 4795, line 18 and following: The statement that the (standard) DOAS method works well when the measured signal is transmitted direct solar light is not correct. Standard DOAS strictly speaking requires essentially that the logarithm of the radiance (or transmission) can be expressed as a linear combination of (differential) gas absorption cross-sections plus a low order polynomial. This requires that the differential optical depth is "small enough" (or if not that this can be somehow been considered e.g. by using appropriate airmass factors) and that the absorption

cross-sections do not depend too strongly on temperature and pressure and that the absorption lines are resolved by the instrument. Therefore for line-absorbers such as CO2 and CH4 the standard DOAS method can typically not be used even if the measured signal is transmitted direct solar light.

=> Thank you for clear explanation about DOAS method. Here, we want to mention that the optical path modification due to aerosol/cloud brings large error. The revised sentences are shown after the following comment.

Introduction, page 4795, line 22 and following: The CO2 proxy method for SCIAMACHY XCH4 retrieval of Frankenberg et al., Science, 2005, needs to be cited. The algorithm deals with aerosol issues by using the CH4 to CO2 column ratio.

=> Done.

<p. 4795, line 15>

"Many algorithms have been developed to retrieve column abundances of trace gases. The differential optical absorption spectroscopy (DOAS) retrieval method has been widely used to retrieve the column abundances of trace gases (see Table 1 of Hönninger et al., 2004). ~~The DOAS method works well when the measured signal is transmitted direct solar light. However, if the measured signal is surface-scattered light, the path radiance component modifies the equivalent optical path length, leading to large retrieval errors.~~ For the retrieval of SCIAMACHY data, several DOAS-based algorithms have been developed (Buchwitz et al., 2000; Barkley et al., 2006; Frankenberg et al., 2005a). In those algorithms, however, aerosol scenarios and/or the surface albedo (two key parameters for the optical path length modification) are assumed. When the actual equivalent optical path length differs from the assumed one, it makes large errors in the retrieved results. Oshchepkov et al. (2008, 2009) proposed a new DOAS-based retrieval algorithm that simultaneously retrieves the photon path length probability density function parameters (Bril et al., 2007) to correct the optical path length modification effect. Focus on the methane retrieval, Frankenberg et al. (2005b) proposed a CO_2 proxy method that simultaneously retrieves the CO_2 and CH_4 column abundances with the no-aerosol assumption and takes the CH_4 to CO_2 column ratio to remove the most of the optical path length modification effect."

<reference>

" Frankenberg, C., Meirink, J. F., van Weele, M., Platt, U., and Wagner T.: Assessing methane emissions from global space-borne observations, Science, 308, 1010-1-1014, doi:10.1126/science.1106644, 2005b."

Section 2.1, page 4797, line 12: Does this mean that uncalibrated TANSO-FTS data have been used for this manuscript ? Please clarify.

=> No. We apply the correction for the radiometric degradation for TANSO-FTS as written in section 2.3 (p. 4799, line 4). We also mentioned about this at the end on section 2.1.

<p.4797, line 8>

"Details on TANSO-FTS and TANSO-CAI, along with the conversion method from raw interferograms to spectra (i.e., Level 1 processing) and pre-launch calibration results, are described by Kuze et al. (2009). Although the initial geometric and radiometric calibrations for TANSO-CAI have been performed, those for TANSO-FTS are still underway. The SWIR Level 2 V01.10, V01.20, and V01.30 only correct the radiometric degradation of the TANSO-FTS as a function of time."

Section 2.3, page 4799, line 10: Please explain how XCO2 and XCH4 are computed from VCO2 and VCH4.

=> See eqs. (10) and (11). The numerator of eq. (11) is the VCO2 or VCH4. Maybe following formula is easy to understand.

" $$X_{\text{target}} = \frac{\mathbf{h}^T \mathbf{x}_x}{\mathbf{h}^T \mathbf{1}} = \frac{V_{\text{target}}}{\mathbf{h}^T \mathbf{1}},$$ (11)"

Section 4.2, page 4805, line 17: I do not understand what "the target reflectance should be considered as retrieved". Please clarify.

=> Revised as follows.

<p.4805, line 15>

"The radiance level of the observed spectrum was highly variable according to the target reflectance, the solar zenith angle, and the satellite viewing angle. ~~Because~~ Although the last two angles are easily determined, the target reflectance varies with surface-type and time and should be ~~considered as~~ retrieved."

Fig. 1: This figure gives a nice overview about the GOSAT spectral coverage but it does not allow to see very much details. I recommend to add another figure where details of the spectral fits are shown including the fit residuals for the different conditions in the fitting windows used.

=> Add figures and description about the residual spectra.

<p.4813, line 18>

"**6.3 Retrieval results**

Before the discussion of the retrieval results, we briefly mentioned about the MAP iteration. The solution converges in less than six iterations for more than half of the measurement scenes. About 1.5 % of the measurement scenes can not converge. For the converged scenes, the residual spectra are enough small in general (see Figs. D, E, and F), and only 0.6 % of the measurement scenes can not passed the χ^2 value test. These non-converged or large-residual scenes tend to fail a fitting in O_2 sub-band, therefore, they might be contaminated by undetected clouds or elevated aerosols that are not taken into account in the current forward model. Focus on the residual spectra, several spectral points always show the large residual probably due to the error in the spectroscopic databases. Further, there remains a systematic residuals in O_2 sub-band, which may come from the differences in the O_2 absorption line shape and/or ILSF of the TANSO-FTS Band 1 (Note: the ILSF at the shorter wavelength region is more sensitive to the optical alignment and hard to determine accurately)."

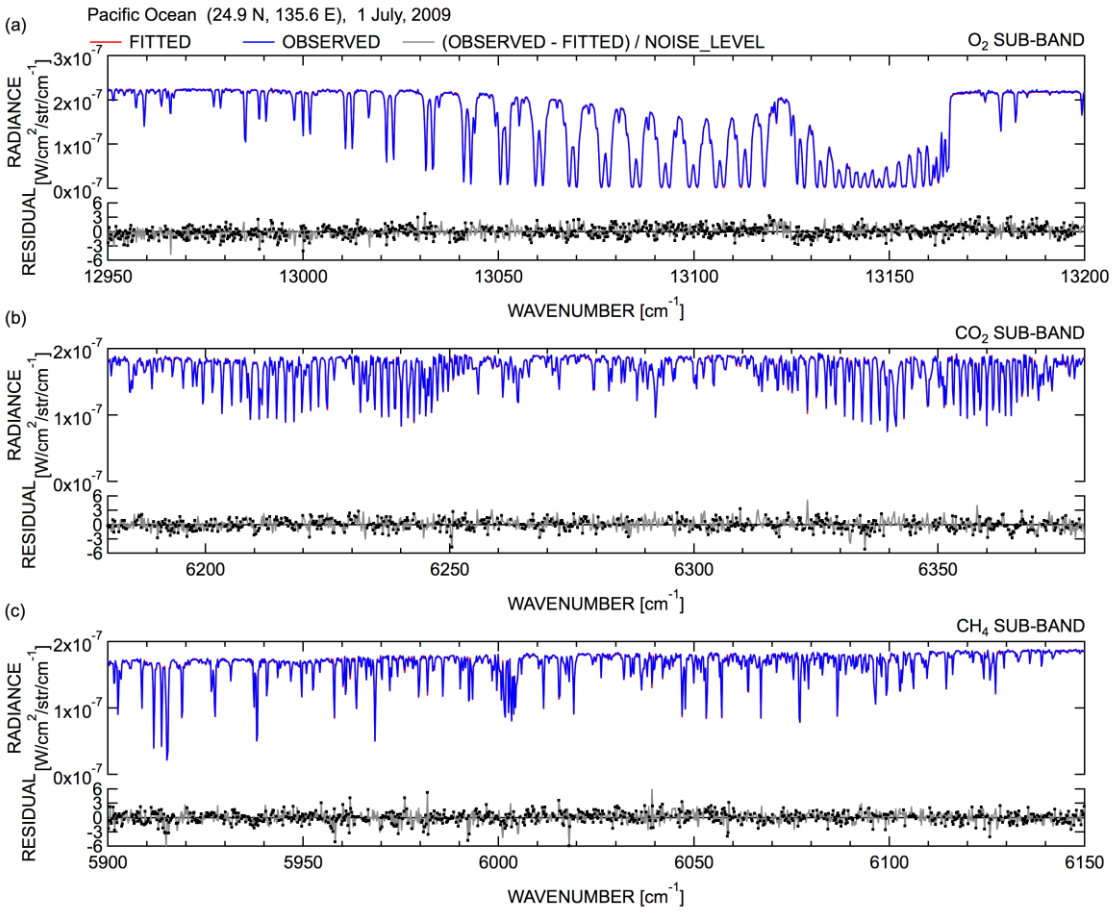


Fig. D Observed and fitted spectra and its residuals for O_2 sub-band (a), CO_2 sub-band (b), and CH_4 sub-band (c). Measurement was conducted over the Pacific ocean (24.9 N, 135.6 E) in 1 July 2009. Black dots in the residual plots indicate the channels used in the retrieval analysis; i.e., not contaminated by Fraunhofer lines.

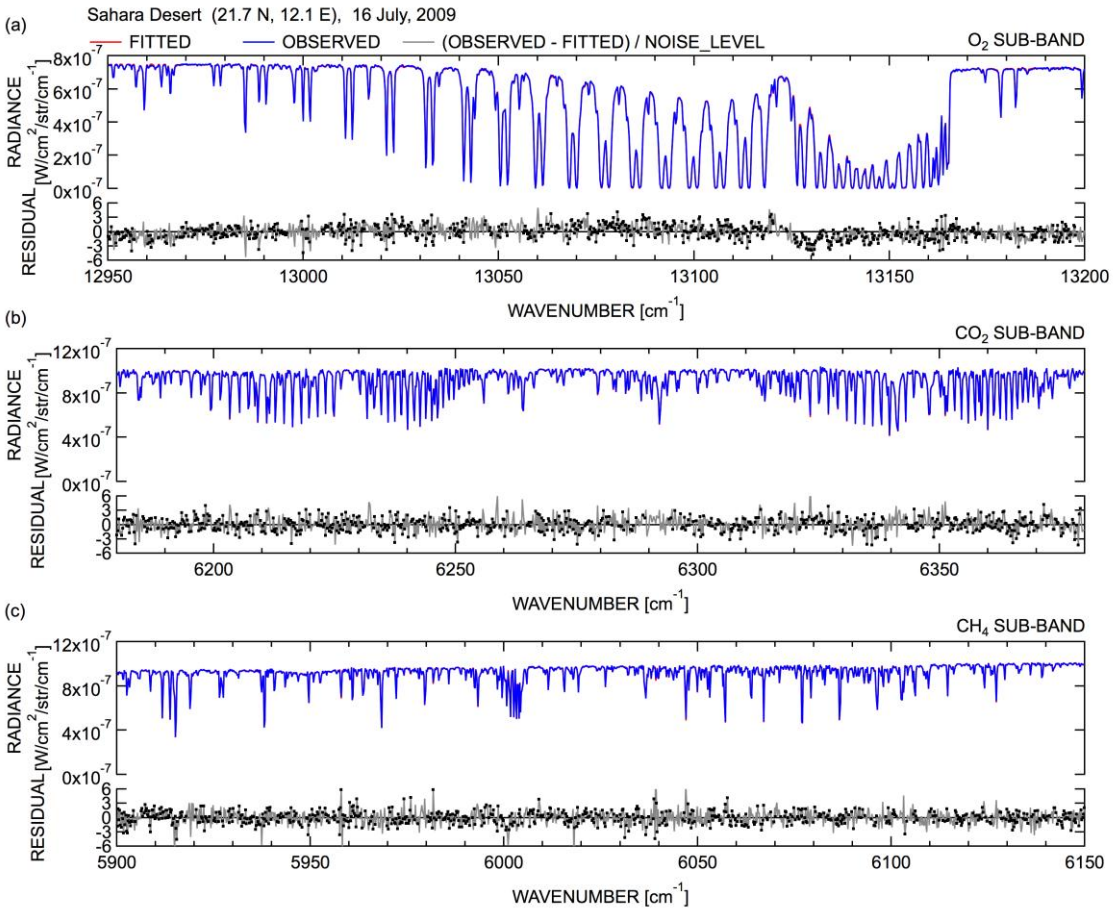


Fig. E Same as Fig. D but measurement was conducted over the Sahara desert (21.7 N, 12.1 E) in 16 July 2009.

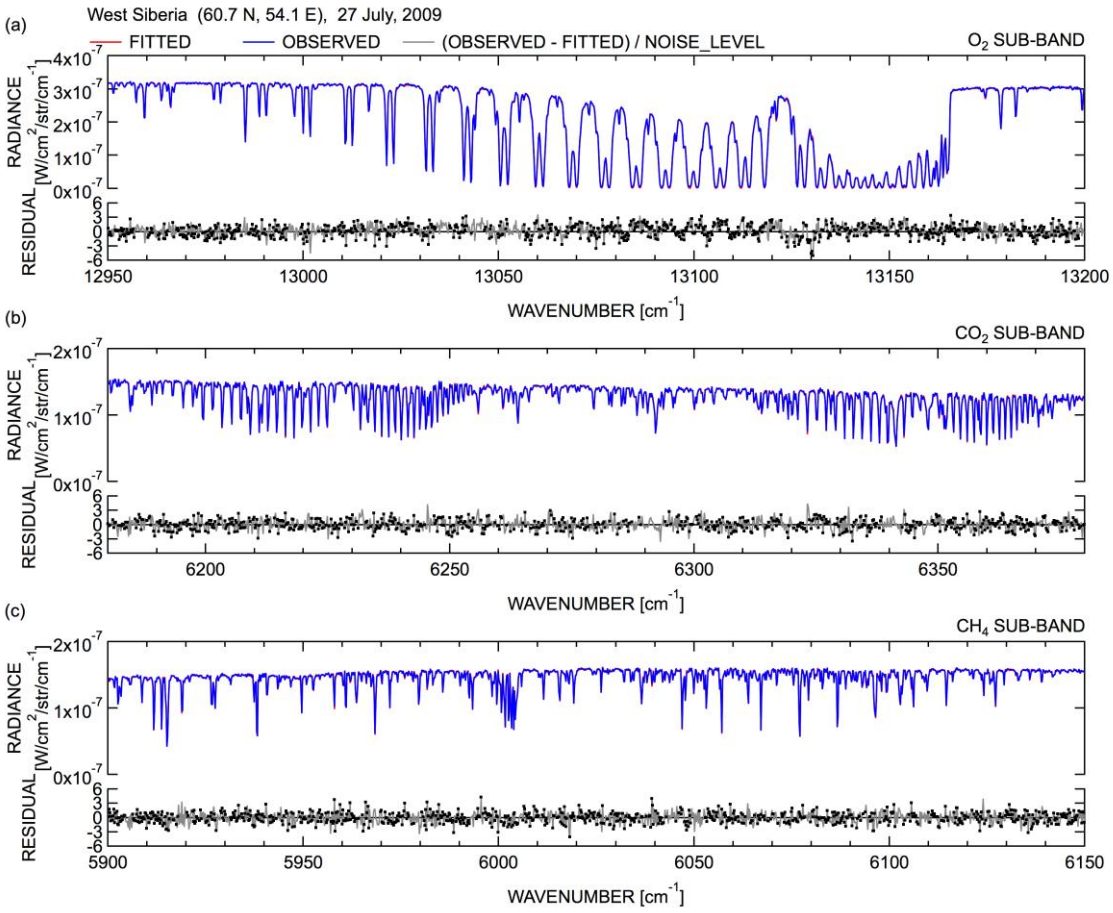
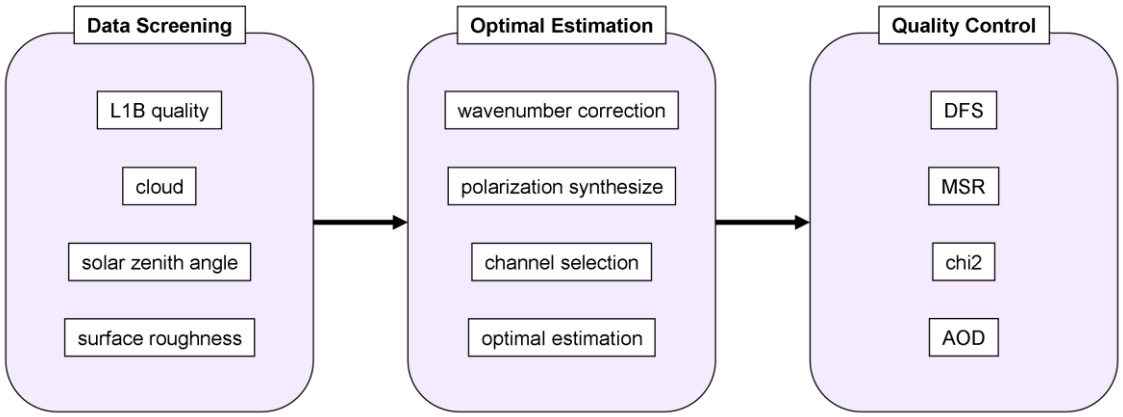


Fig. F Same as Fig. D but measurement was conducted over the west Siberia (60.7 N, 54.1 E) in 27 July 2009.

Fig. 2: Possible typo "synthsize". Please add to what quantity "root mean squares" refers.

=> We made a mistake about the explanation of "RMS". The previous (wrong) explanation is "the root mean squares (RMS) of the residual spectra for each retrieval sub-band", but the correct explanation is "the mean squares of the residual spectra for each retrieval sub-band". We changed an abbreviation "RMS" to "MSR (the Mean Squares of the Residual spectra)".



"Fig. 2 Schematic diagram of the retrieval processing flow of TANSO-FTS SWIR. "DFS," "MSR," and "AOD" indicate the degree of freedom for signals, mean squares of the residual spectra for each retrieval sub-band, and aerosol optical depth, respectively."

Fig. 3: It would be good if in addition the absolute number of measurements are shown.

=> The absolute number plot looks similar as the fraction plot, therefore, the absolute number of measurements is added into the text.

<p. 4812, line 4>

"The latitudinal range for retrieval moves north or south according to the seasonal change of solar declination. The region where the retrieval results are obtainable throughout the whole year is restricted over land, with a latitudinal range of 45 S to 45 N. No region over the ocean contains year-round retrievals because of the narrow latitudinal range of the sun-glint region for TANSO-FTS. The number of measurement scenes suitable for retrieval analysis are 9371 of 292810 for July 2009 and 7839 of 290369 for January 2010. The monthly mean fraction of the measurement scenes suitable for retrieval analysis is about 3%."

Fig. 5: Annotation Uncertainty Reduction. CO2 needs to be replaced by CH4.

=> Done.

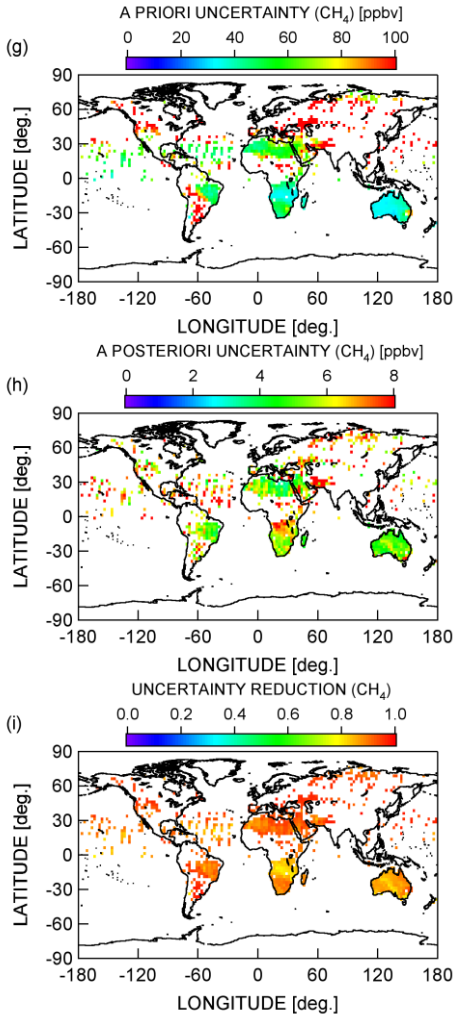


Fig. 7: The colors for certain months cannot be distinguished, e.g., July - Sept. I recommend to use a different color for each month.

=> Done. See Fig. C above.