

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 #4

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This paper describes the details of the CO₂ and CH₄ GOSAT SWIR retrievals produced by the GOSAT team. This documentation is important for users of these products. AMT is an appropriate journal for this article. The paper is clearly written and should be published. The comments below should be addressed before publication.

=> 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.

There should be more detail in the paper, enough such that others can reproduce results or make detailed comparisons. For example, it would be useful to show one or more spectra in standard units of intensity. The details of the locations of such spectra should be given. In addition, the spectral fits (broken out by the different retrieved parameters), radiance residuals, etc., should also be shown. It would be helpful to see spectral biases in the fits and values of auxiliary parameters retrieved, especially aerosol AOD and surface pressure (for example, do the retrieved values make sense?). It would also be nice to show the Jacobians so that readers get an idea of their spectral dependence.

=> Add figures and description about the residual spectra and Jacobians. Broken out plot is not suitable for TANSO-FTS spectrum, because the observed spectrum is the reflected light and it depends on the surface reflectance which also retrieved simultaneously.

<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 O₂ 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 O₂ sub-band, which may come from the differences in the O₂ 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)."

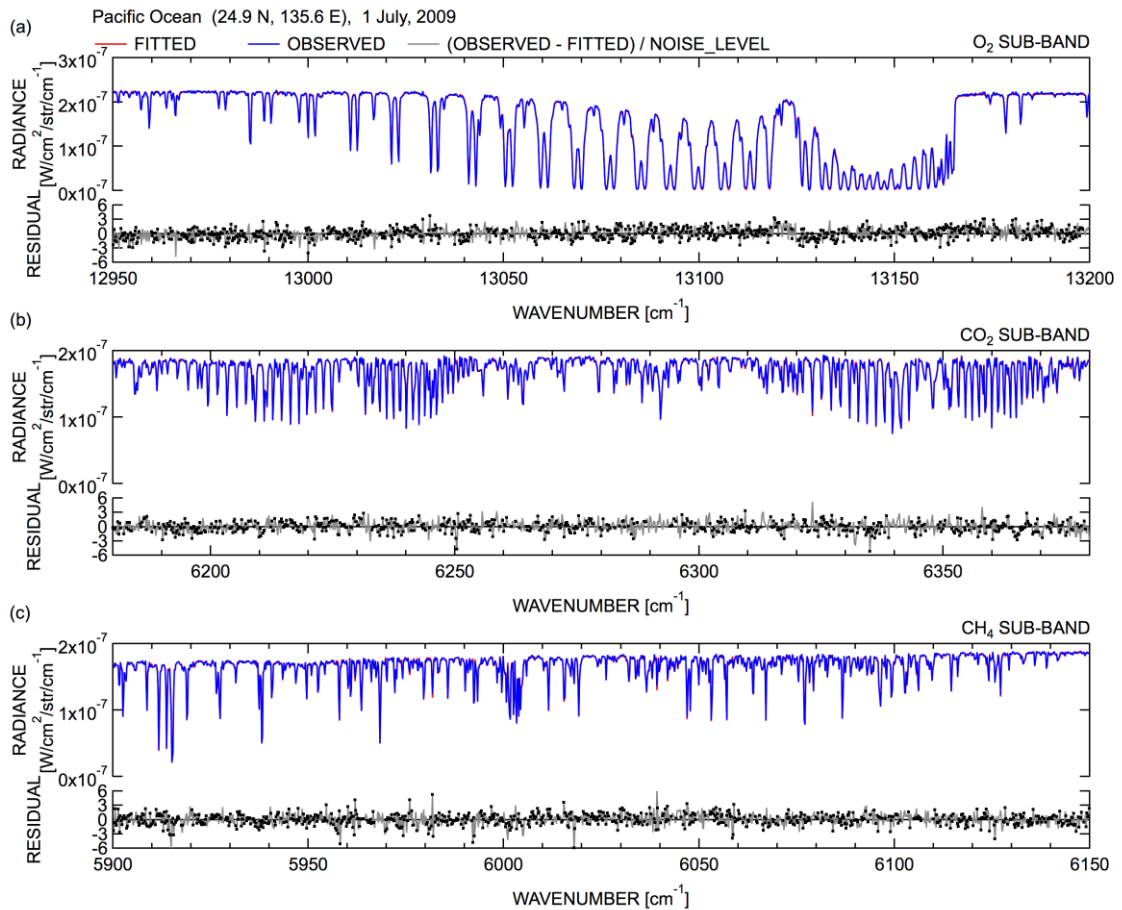


Fig. D Observed and fitted spectra and its residuals for O₂ sub-band (a), CO₂ sub-band (b), and CH₄ sub-band (c). Measurement was conducted over the Pacific ocean (24.9 N, 135.6 E) in 1 July 2009. Black dots in the residual plots indicate the channels used in the retrieval analysis; i.e., not contaminated by Fraunhofer lines.

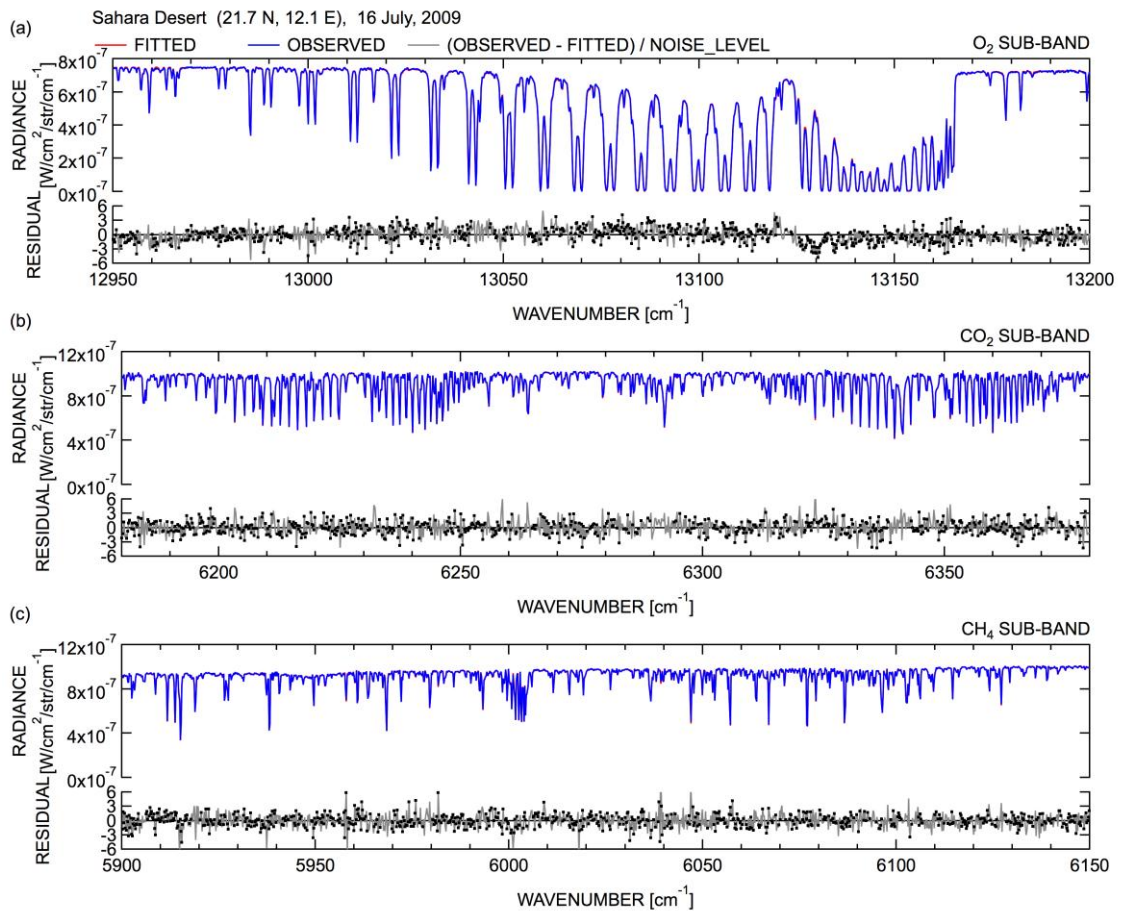


Fig. E Same as Fig. D but measurement was conducted over the Sahara desert (21.7 N, 12.1 E) in 16 July 2009.

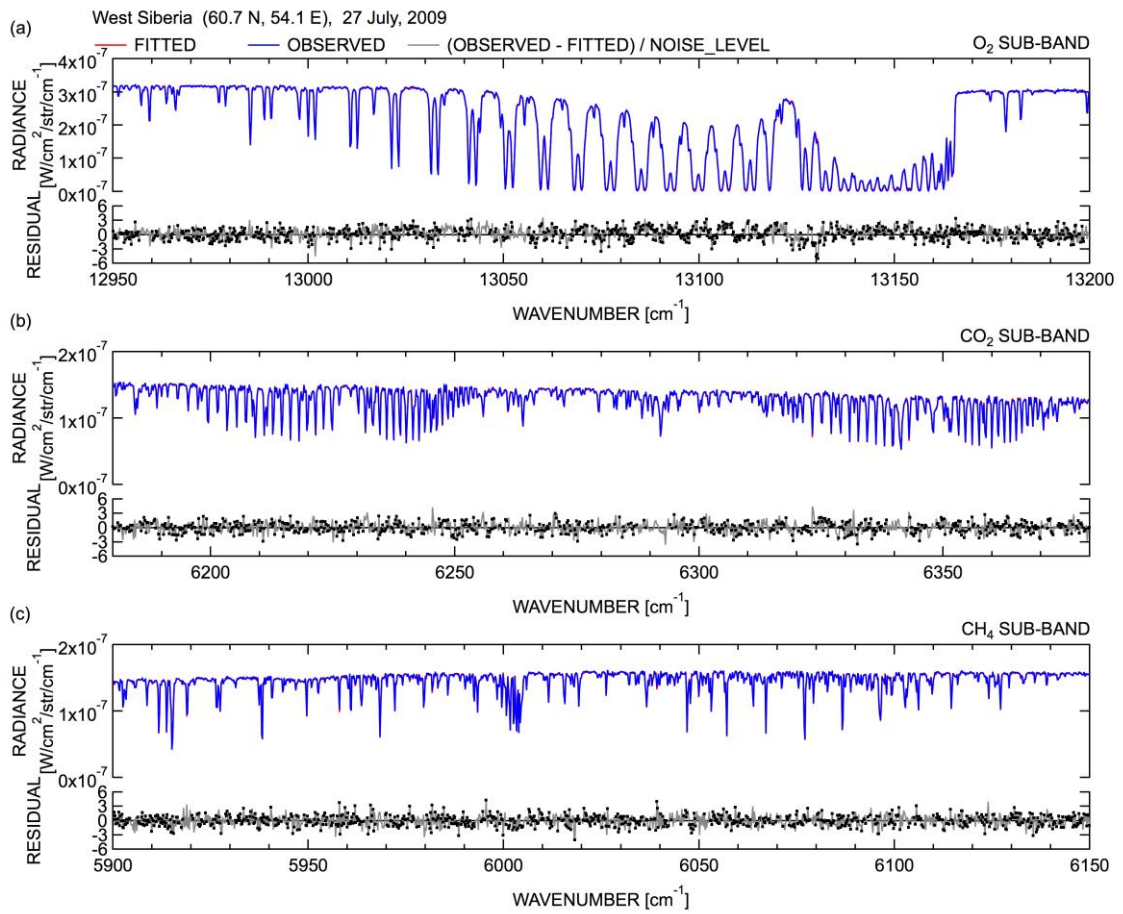
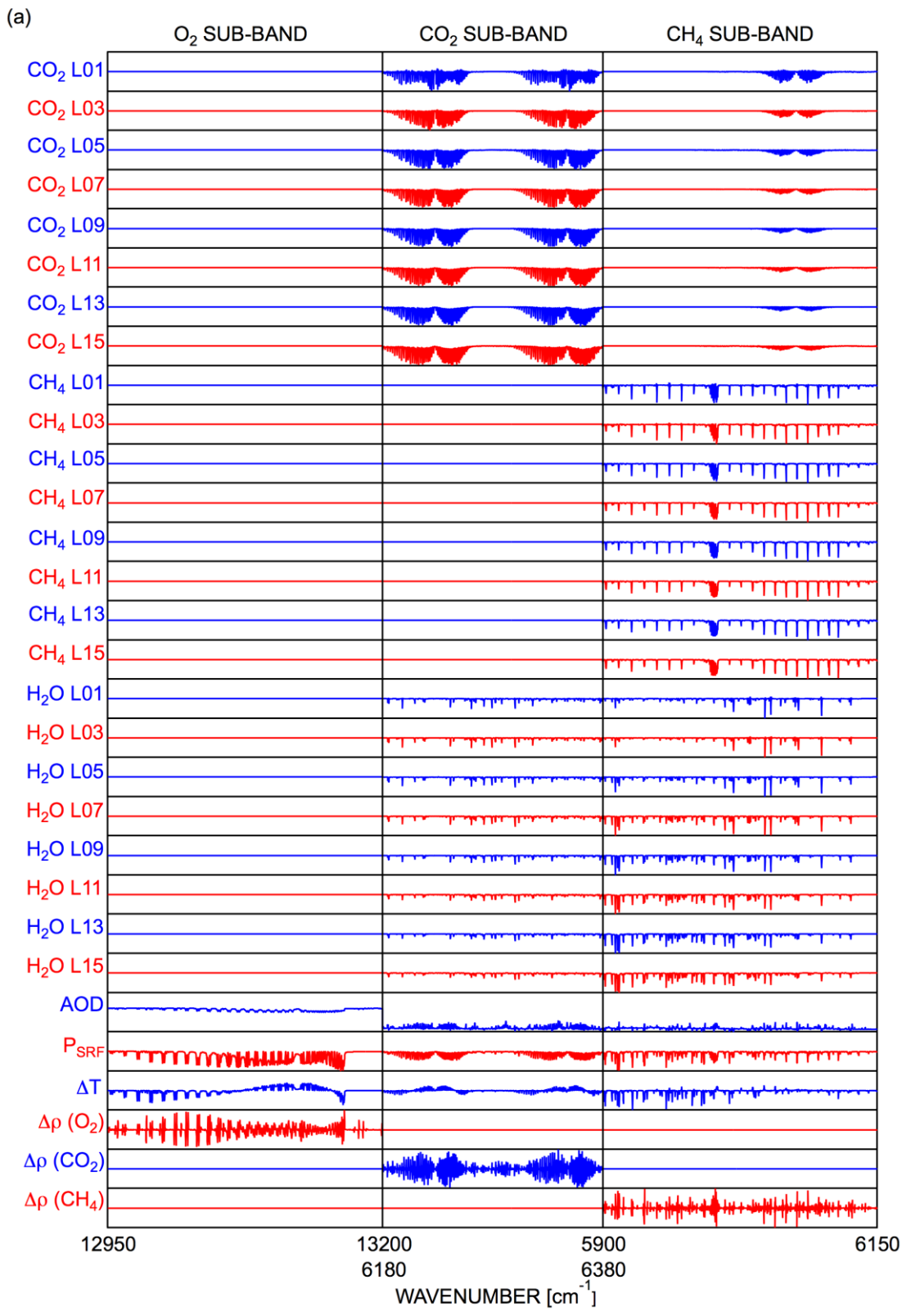


Fig. F Same as Fig. D but measurement was conducted over the west Siberia (60.7 N, 54.1 E) in 27 July 2009.



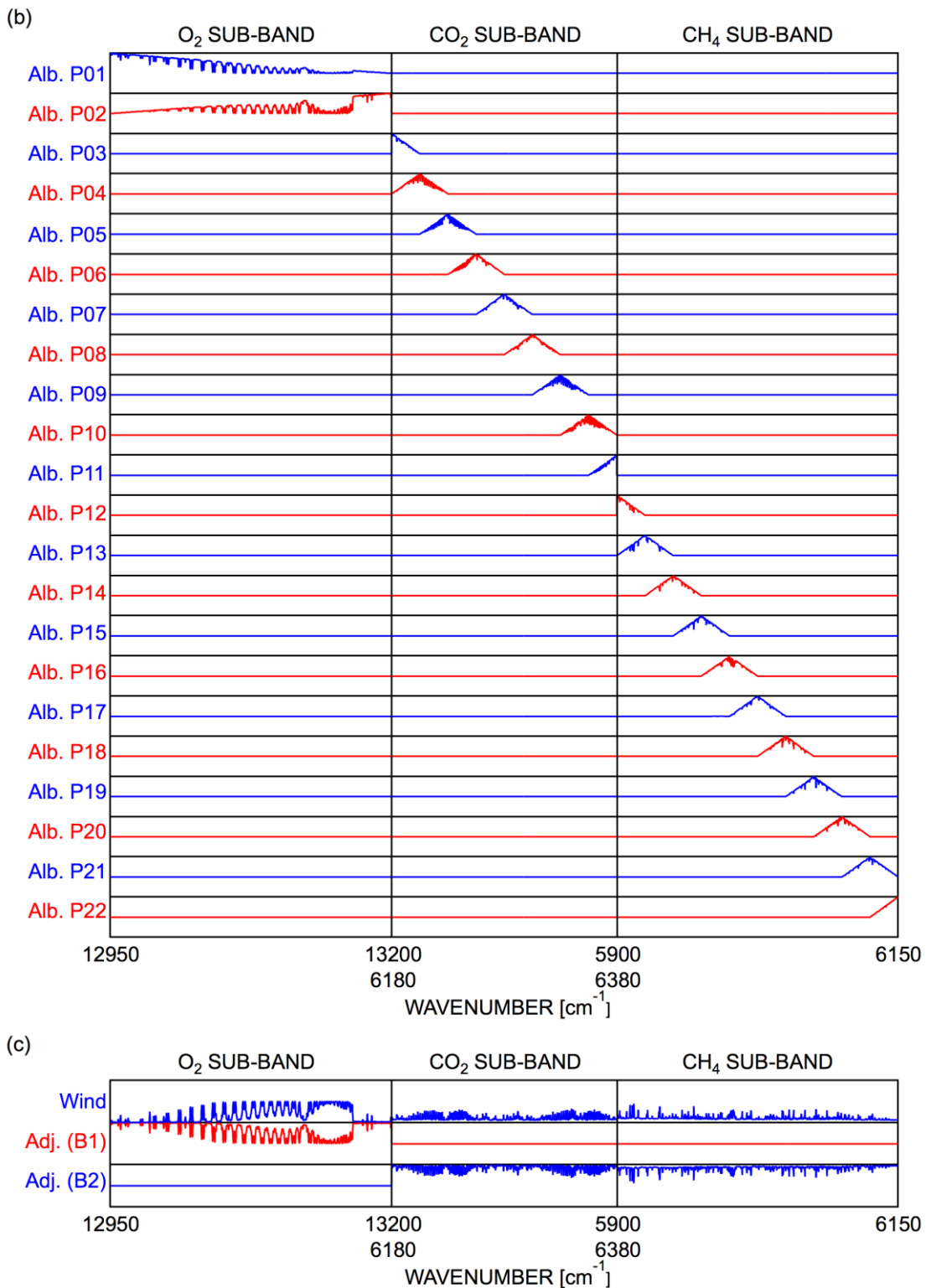


Fig. G Jacobians (scaled to the same amplitude) of common retrieval parameters both for land and ocean (a), only for land (b), and only for ocean (c). Jacobians of CO_2 , CH_4 , and H_2O profiles are plotted every other layer. The vertical layer is ordered from the top of the

atmosphere ("L01") to the surface ("L15"). "AOD", "P_{SRF}", "ΔT", "Δρ", "Alb.", "Wind", and "Adj." indicate the aerosol optical depth, surface pressure, temperature profile bias, wavenumber dispersion, surface albedo, wind speed, and adjustment factor. "(O₂", "(CO₂", and "(CH₄") indicate those parameters for O₂/CO₂/CH₄ sub-bands, and "(B1)" and "(B2)" indicate those parameters for TANSO-FTS Band 1/2.

More discussion of sunglint retrievals over ocean would be helpful.

=> As for the retrieval results, we add the comparison with the NIES TM. See following comment and response.

As for the retrieval algorithm, there is no special configuration for the "sunglint" condition. The elements of the state vector is decided only from the surface type (land or water), and does not depends on the sun-target-satellite geometry. The explanation about the ocean reflectance was insufficient, therefore, we revised as follows.

<p. 4806, line 2>

~~"Over ocean, the wavenumber dependency of water reflectance is related to that of the refractive index of water, and the surface wind speed can determine the reflectance magnitude over the whole spectral range.~~ The assumption of the Lambertian surface is not adequate for water surface. The bidirectional reflectance distribution function for water surface is calculated based on the slope probability distribution function proposed by Cox and Munk (1954). The Cox-Munk assumption can determine the reflectance of water surface over the whole spectral range with single parameter of a surface wind speed."

<Reference>

"Cox, C., and Munk, W.: Measurement of the roughness of the sea surface from photographs of the Sun's glitter, J. Opt. Soc. Am., 44, 838-850, 1954."

Realizing that the scope of the paper does not include validation, the CO₂ and CH₄ results show some interesting features such as the high CO₂ and CH₄ values near the Amazon region of South America. The CO₂ and CH₄ are highly correlated. Can the authors make a comment about this. Do you believe these are real features or are they perhaps due to aerosol contamination?

=> We checked the relatively high XCO₂ and XCH₄ data near the Amazon. Simultaneously retrieved surface pressure for these data were more than 10 hPa smaller than the a priori values. It makes the artificial correlation between retrieved XCO₂ and XCH₄. Maybe this small

surface pressure is due to the aerosol (or undetected cloud) contamination, but we can't conclude.

Minor comments

Abstract and elsewhere: "agree well": As noted by the other reviewers, this is subjective and open to alternative interpretations.

=> 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 XCO₂ and XCH₄ 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 XCO₂ and XCH₄ 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 XCO₂ and XCH₄ ~~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."

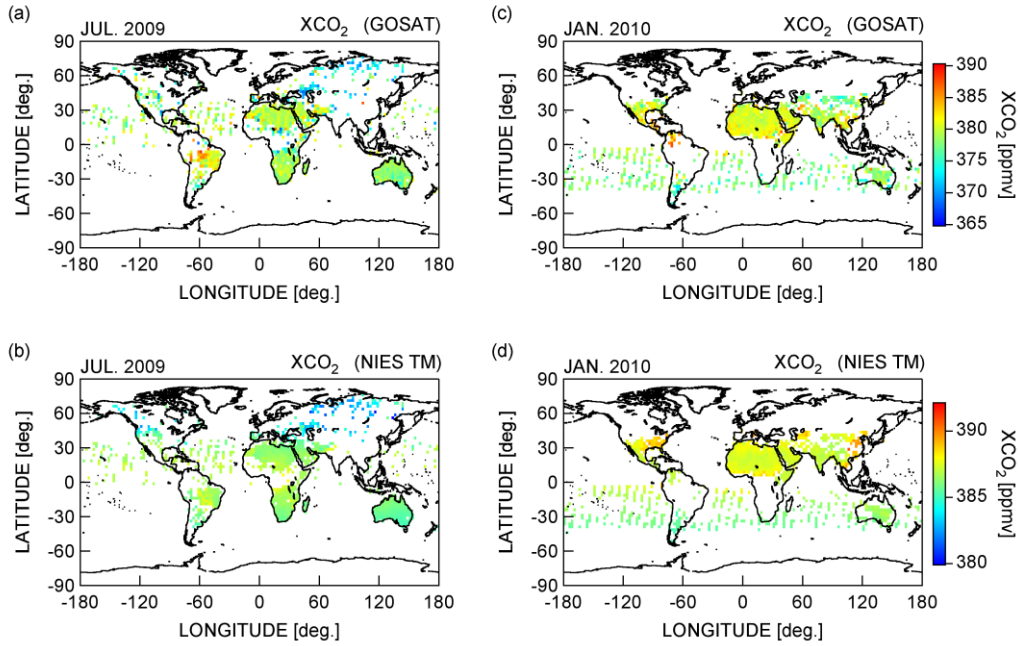


Fig. A Monthly average of the XCO_2 [ppmv] retrieved by GOSAT (a, c) and simulated by the NIES TM (b, d) within a 2.5×2.5 -degree grid box. A blank indicates that no valid retrieval result was available within the grid box. Different color-scales are used for GOSAT retrieval and the NIES TM simulation.

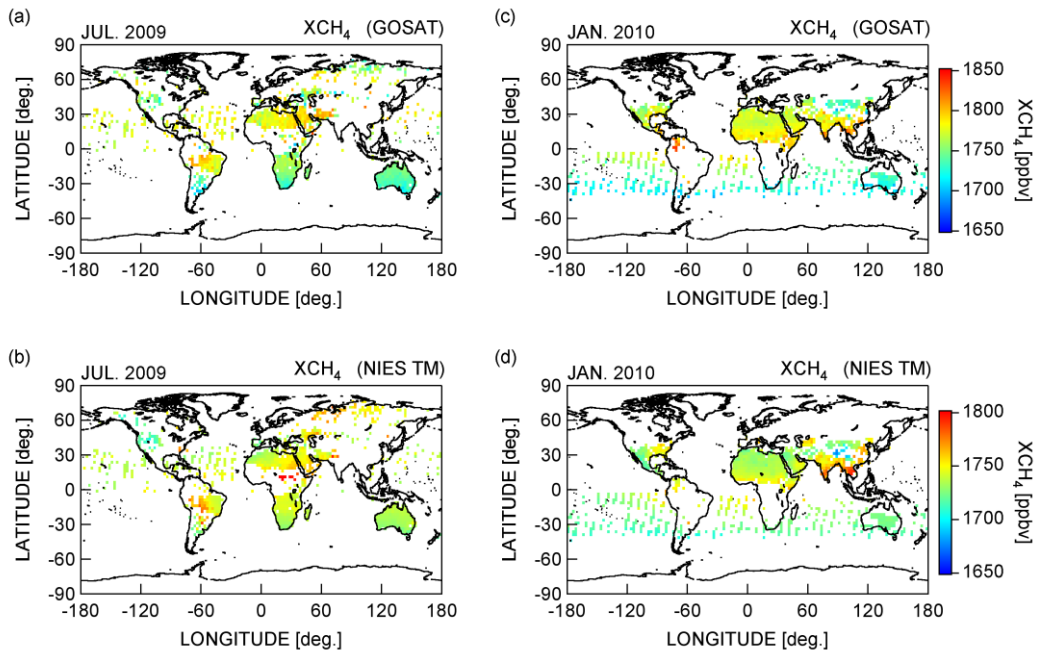


Fig. B Monthly average of the XCH_4 [ppbv] retrieved by GOSAT (a, c) and simulated by the NIES TM (b, d) within a 2.5×2.5 -degree grid box. A blank indicates that no valid retrieval result was available within the grid box. Different color-scales are used for GOSAT retrieval

and the NIES TM simulation.

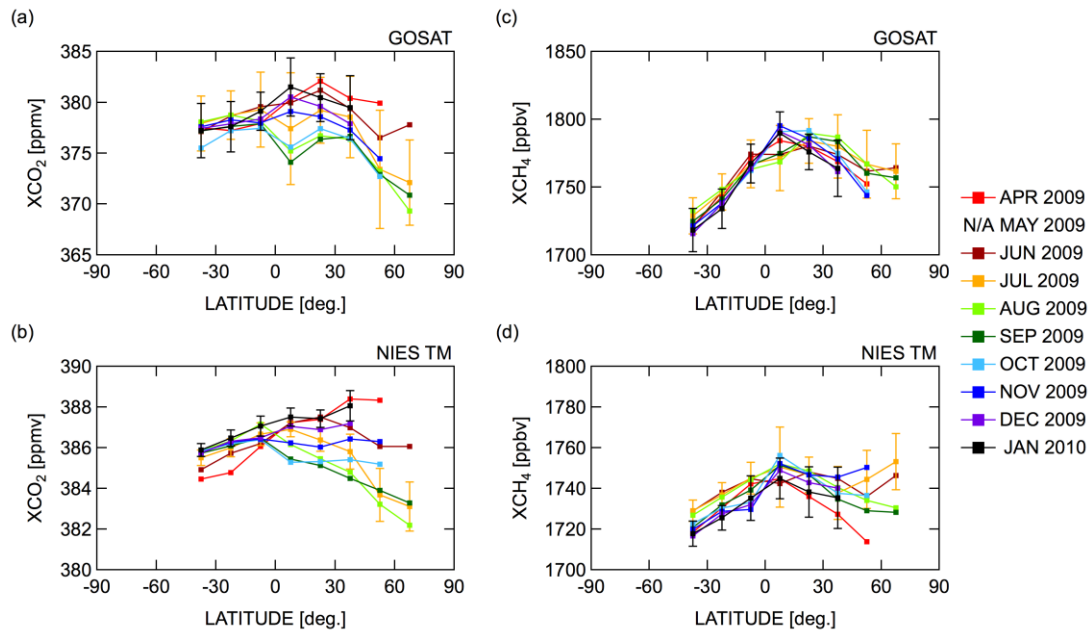


Fig. C Latitudinal distributions of zonal mean of the retrieved and simulated XCO₂ [ppmv] (a, b) and XCH₄ [ppbv] (c, d). The standard deviations of zonal variation for July 2009 and January 2010 are plotted as error bars.

p. 4794, L9: Please clarify (also noted by another reviewer), SWIR observations are sensitive to the total column gas abundance.

=> Revised as follows.

<p.4794, line 8>

"TIR observations are sensitive to CO₂ and CH₄ in the middle to upper troposphere, whereas SWIR observations are also sensitive to gas abundances near the surface."

p. 4794, L15: Please clarify, "spatially and temporally averaged data...", on what spatial and temporal scales?

=> Revised as follows.

<p.4794, line 15>

"For spatially (few hundreds to thousands square kilometers) and temporally (weekly to

monthly) averaged data, a precision of 1% order or better in CO₂ column abundances is required to improve our current knowledge of the surface CO₂ fluxes (Rayner and O'Brien, 2001; Houweling et al., 2004; Patra et al., 2003)."

Sect. 3.1: Have the authors considered using TIR channels to screen cirrus or is the 2 um check sufficient?

=> We are just preparing the cloud-detection methods from TIR spectrum.

Sect. 4.1: Please spell out MAP at its first occurrence (Subsection title).

=> Done.

<p.4802, line 11>

"4.1 Formulation of the MAP (maximum a posteriori) retrieval"

Sect. 4.2 and elsewhere: It would be helpful to state the spectral ranges in terms of wavelength for those who are more used to those units.

=> We put the wavelength ranges at its first occurrence.

<p.4798, line 24>

"The spectral region of the 1.6- μm CO₂ absorption band (spectral wavenumber/wavelength range from 6180 to 6380 cm^{-1} / 1.567 to 1.618 μm), the 1.67- μm CH₄ absorption band (5900 to 6150 cm^{-1} / 1.626 to 1.695 μm), and the 0.76- μm O₂ absorption band (12950 to 13200 cm^{-1} / 0.7576 to 0.7752 μm) were used for the retrieval."

<p.4800, line 23>

"The TANSO-FTS 2- μm -band test looks for the existence of elevated scattering particles (mainly cirrus cloud) using the measurement radiance of the strong water vapor (H₂O) absorption band (5150 to 5200 cm^{-1} / 1.923 to 1.942 μm) included in the TANSO-FTS 2- μm band (TANSO-FTS Band 3)."

p.4804, L17: Is the atmospheric layering (15 layers) used for the radiative transfer as well as the retrieval? I am a bit confused about how the radiative transfer table lookup is implemented. For

example, how are model temperatures used in the table lookup (is linear interpolation used for both temperature and pressure)? More detail on this would be helpful.

=> Yes. We used 15 layers for the radiative transfer calculations. However, each 15 layer is divided into 12 sub-layers (i.e., 180 layers) to calculate the optical thickness due to the gaseous absorption. In the table lookup, linear interpolated temperature and pressure for each sub-layer are used. Considering the paper flow, we revised the section 2.3 as follows.

<p.4798, line 27>

"To suppress the computational costs in the operational processing, the number of layers for the forward model is minimized. As described in section 4.2, the number of layers for retrieval is 15. To consider the temperature and pressure dependencies of the gaseous absorption, each layer is divided into 12 sub-layers, and the optical thickness due to the gaseous absorption is calculated for each sub-layer. The cumulative optical thickness for each layer is used in the forward model. Further, the P and S polarization components of the observed spectra were synthesized to produce a total intensity spectrum (see Appendix A)."

Is there any evidence for a constant temperature bias from the GPV model?

=> We don't have any evidence for a constant temperature bias for GPV. For a stability of the retrieval calculation, we set a single parameter of a constant temperature bias. A temperature profile can be estimated from the TIR spectrum. It may be possible to use or simultaneously retrieve a temperature profile from the TIR spectrum in future.

p.4806: Can you give more details about the modeled aerosols. Since the singlescattering albedo (and phase functions) are assumed as fixed, have there been comparisons with other data such as AERONET to verify the accuracy of the model?

=> The comparison of single-scattering albedo between SPRINTARS and AERONET is given in Takemura et al. (2002). They summarized that the mean difference between the simulation and observation is less than 0.05 for the single-scattering albedo in most regions.

<p.4806, line 18>

"The aerosol optical properties are calculated for every observed day by an offline three-dimensional aerosol transport model, the Spectral Radiation-Transport Model for Aerosol Species (SPRINTARS; Takemura et al., 2000, 2002). The SPRINTARS calculates

the mass concentration distribution of soil dust, carbonaceous, sulfate, and sea-salt aerosols. The optical depth, single-scattering albedo, and phase function of aerosols are calculated taking into account the size distribution and composition. The calculated single-scattering albedo and phase function are treated as fixed model parameters. The aerosols are assumed to be uniformly distributed within a 2-km layer from the surface. Takemura et al. (2002) compared the optical depth and single-scattering albedo simulated by SPRINTARS with those obtained by satellite and ground-based observation network using the sunphotometer. The mean difference between the simulation and observations was less than 30 % for the optical depth and less than 0.05 for the single-scattering albedo in most regions. In future, we plan to use aerosol optical properties derived from TANSO-CAI."

<Reference>

"Takemura, T., Nakajima, T., Dubovik, O., Holben, B. N., and Kinne, S.: Single-scattering albedo and radiative forcing of various aerosol species with a global three-dimensional model, J. Climate, 15, 333-352, 2002."

p.4815: "...interference error due to auxiliary parameters is relatively small." What about aerosol - it appears to have a significant impact? Have the authors compared retrieved AOD with other measurements, satellite or ground-based?

=> The interference error is the projection of the radiance response due to the possible variability of auxiliary parameters onto the a posteriori variability of target parameters. Differences between retrieved and true auxiliary parameters make a bias error in the target parameter, but this bias error is not included into the interference error. Of course, AOD has a significant impact on the retrieved XCO₂ and XCH₄, but it does not mean that AOD has a significant impact on the precision of the retrieved XCO₂ and XCH₄.

Intensive comparisons of retrieved AOD with other measurements are not conducted yet, but we plan to compare them with AERONET and MODIS in future.