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Atmospheric Measurement Techniques Discussions

Interactive comment on "Level 1 algorithms for TANSO on GOSAT: processing and on-orbit calibrations" *by* A. Kuze et al.

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<Response to Referee #2>

We thank the reviewer for carefully reading our manuscript and for providing important comments. We address the comments below. Our responses are in bold and red in the supplement version. Updated figures are included in the supplement PDF file.

<Response to the general comment>

We asked an English native speaker, who is familiar with FTS technology, to edit our manuscript extensively. We will add him as a co-author. We have modified the English of our entire manuscript.

<Specific Comments>.

(1) Page 2960, line 4: Change: "In this paper, first, the most recent operational Level 1 algorithms to produce the spectral radiance from the acquired interferogram are described." To "In this paper, we first describe the most recent operational Level 1 algorithms that produce radiance spectra from the acquired interferograms."

A: We have modified as follows. "In this paper, we first describe the version V150.151 operational Level 1 algorithms that produce spectral radiance from the acquired interferograms."

(2) Page 2960, Line 12: Change: "However, the Level 1B algorithms of TANSO-CAI are not mentioned, here in this paper." To "The Level 1B algorithms of TANSO-CAI, however, are not described in this paper.

A: We have modified as follows. "The Level 1B algorithms of TANSO-CAI, however, are not a subject of this paper."

(3) Page 2960, Lines 20-24: Comment: It isn't clear whether the two orthogonal polarizations apply to all bands, or to just the CH4 (band 2). Perhaps describe the polarization properties in a separate sentence.

A: We have modified as follows. "TANSO-FTS measures reflected solar radiance in the oxygen (O2) A band region at 0.76 μm (Band 1) and in the weak and strong CO2 bands at 1.6 μm (Band 2) and 2.0 μm (Band 3), and also CH4 bands at 1.67 μm (Band 2) all with two orthogonal linear polarizations, designated "P" and "S"."

(4) Page 2961, lines 5-10: Comment: This sentence is too long – break into two sentences. For example, "JAXA is responsible for producing the Level 1A (raw interferogram) and the Level 1B (spectral radiance) products of TANSO-FTS and the Level 1A (raw digital number) product of TANSO-CAI. NIES provides the Level 2 (CO2 and CH4 concentrations from each Level 1B spectra), the Level 3 (global distribution of CO2 and CH4 concentrations by interpolating the Level 2 products), and the Level 4 (net CO2

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sources and sinks) products of TANSO-FTS and the Levels 1B, 1B+, 2, and 3 products of TANSO-CAI."

A: We have broken into two sentences as suggested above.

(5) Page 2961, Line 10: Comment: What is level "1B+" ? Why isn't it mentioned in Table 1? Either define level 1B+ or don't mention it.

A: We have mentioned Level 1B+ in the main text as follows "Levels 1B (radiometric and geometric conversion), 1B+ (spatially resampled data), 2 (with cloud flag), and 3 (global distribution) products". As the CAI Level 1B is not a subject of this paper, it is not mentioned in Table 1.

(6) Page 2961, line 23: Change: "The camera (CAM) data is not processed ..." To "The camera (CAM) data are not processed . . .."

A: We have modified as suggested above.

(7) Page 2961, line 24: Comment: " . . .the camera was originally installed to check alignment onboard." What alignment? The interferometer, the pointing mirror?

A: We have modified as follows: "to check pointing mirror alignment onboard after launch between the actual viewing position and the calculated value from the resolver angles of the pointing mirror."

(8) Page 2962, lines 3-5 state: "The two axes optical mirror pointing mechanism has pointing and image motion compensation functions and the views of the earth and the calibration sources". Comment: Perhaps re-write as: "The two-axis optical mirror pointing mechanism has pointing and image motion compensation functions, allowing precise viewing of the earth and the calibration sources."??

A: We have modified as follows. "The two-axis optical mirror pointing mechanism has pointing and image motion compensation functions, allowing precise viewing of the earth and the calibration sources."

(9) Page 2962, Line 6: states: "the grid points". Comment: What grid points? You haven't introduced figure 2 yet. The grid points are not described until the next section (1.3). Suggest you modify this sentence to "the earth close to nadir", or introduce the grid point concept earlier.

A: We have introduced Fig. 2 earlier as follows. "In nominal observation mode, the pointing mirror views predefined grid points of the earth close to nadir as illustrate in Fig. 2."

(10) Page 2962, line 9: Change: "an actuator rotary voice-coil" to "a rotary voice-coil actuator".

A: We have removed detailed technical description. We have modified as follows. "The FTS scan mechanism sweeps the optical path difference (OPD) of the interferometer."

(11) Page 2962, lines 10-11: Change: "The performance of these two mechanisms on orbit has to be carefully characterized and the performance is described in Sects. 2.2.3 and 3.4." to "The performance of these two mechanisms on orbit has been carefully characterized and is described in Sects. 2.2.3 and 3.4."

A: We have re-written as suggested above.

(12) Page 2962, lines 15-16: Change: "During the day time both SWIR and TIR of TANSOFTS and TANSO-CAI data are acquired and during the night time only TANSO-FTS TIR data is acquired" to "During the day time both SWIR and TIR of TANSO-FTS and TANSO-CAI data are acquired. During the night time only TANSO-FTS TIR data are acquired"

A: We have re-written as suggested above.

(13) Page 2962: lines 19: Change: "On orbit the response change with time has been monitored for three years and characterized in this paper. To "The on-orbit response changes have been monitored for three years and their characterization is described in this paper.

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A: We have re-written as suggested above.

(14) Page 2962, line 21: Change: "performances" to "performance"

A: We have re-written as suggested above.

(15) Page 2963, lines 11-13: Change: "GOSAT has a 3-day revisit orbit cycle and a 12-day operation cycle. There are three operation patterns on how to insert the target observations to the nominal grid observations." to "GOSAT has a 3-day revisit orbit cycle and a 12-day operation cycle. Three different operational patterns have been employed to insert target observations into the nominal grid observations."

A: We have re-written as suggested above.

(16) Page 2963, lines 24-25: Change: "The FTS mechanism controller counts laser fringes for uniform-speed scans within the maximum optical path difference (MOPD) and then drives the FTS-mechanism scan-arm to motion. Turnaround is a loss of observation time, which needs to be minimized" To "The FTS mechanism scan arm is servo controlled using the laser fringes. This achieves uniform scan speeds within the maximum optical path difference (MOPD) followed by rapid reversal of the scan-arm motion (turn-around). Since no useful data are acquired during turn-around, its duration is minimized."

A: We have re-written as follows. "The FTS mechanism scan arm is servo-controlled using the laser fringes. This achieves uniform-speed scanning within the OPD range followed by rapid reversal of the scan-arm motion (turn-around). The fringe count is also used to trigger the turnaround of the scan mechanism at precisely repeatable scan distance from ZPD. This is done by up and down counting according to scan direction.

(17) Page 2964, lines 6-21: Comment:. I don't understand how the M-shaped scan pattern avoids the along-track dead bands. Perhaps add the location of these dead bands to figure 2.

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A: We have modified the sentence for explanation as follows: “The 2nd and 4th of the original five cross-track (CT) points shown in Fig. 2(a) are close to dead-band angles and they have large biases:”

(18) Page 2964, line 25: Change “a total of 56 000 points globally” to “a total of 56 000 soundings globally”. A more general comment is that the word “point” is over-used in the manuscript. It is used to mean several different things: an interferogram sample, the number of difference places on the earth that are viewed (grid-points), the number of times that the earth is viewed every 3 days. I strongly suggest that different words (e.g. soundings, samples) are used to replace some of the usages of “points”, avoiding over-use.

A: We appreciate suggestions. We have changed several portions from “point” to “soundings” and “fringes (interferogram sample)”

(19) Page 2966, line 6: Change: “Step S2: Correction of spike noise detection caused by cosmic rays onto the detector” to “Step S2: Correction of spikes caused by cosmic rays hitting the detector”

A: We have re-written as suggested above.

(20) Page 2967, line 12: ”65400”. Question: Why is this different from 2ËĘ16 = 65536?

A: We have modifies as follows for clarification: “the digital number exceeds 65,400, which is the value including margin slightly lower than the actual dynamic range.”

(21) Page 2968, line 25: Comment: Don’t say: “the most recent version. . .”. Instead, state the current version number. Otherwise, somebody reading this paper in a few years will be mis-led if you subsequently re-instate the ADC non-linearity correction.

A: We have changed from “the most recent version” to “V150.151”. We have removed all the “the most recent version”.

(22) Page 2979, line 23: Change: “The vertical lines in the figures represent the time of

the vicarious campaigns." To "The three vertical lines in each panel of figure 8 represent the times of the vicarious campaigns."

A: We have modified as follows. "The three vertical lines in each panel of Fig. 8 represent the times of the vicarious calibration campaigns."

(23) Page 2969, line 26 states: " TANSO-FTS has. . . two 1.31 μm distributed-feedback (DFB) lasers, which have much longer life time than a conventionally used HeNe laser". Comment: I'm surprised to see lifetime cited as the main advantage of diode lasers. I would have thought it more important that they are much smaller, more robust, and their low voltage power supplies don't arc azt low pressure.

A: There are several advantages to use DFB lasers as mentioned above. The most critical reason for GOSAT is life time. It must be longer than 10 years. We had to demonstrate in early stage of the GOSAT development. We had completed the life time test of DFB lasers before launch. But it is not a main subject of this paper. We have re-written simply as follows. "The metrology wavelength of TANSO-FTS is 1.31μm. Even sampling the OPD at half the wavelength by means of up-and-down zero-crossings of laser-fringes, the wavelength of Band 1 is still shorter than twice the sampling interval and hence Band 1 frequencies are aliased to low frequencies."

(24) Page 2969 line 27 to page 2970 line 6. Comment: This needs to be re-written. The reason for the Band 1 being AC-coupled is not adequately explained.

A: We have re-written as follows. "Even sampling the OPD at half the wavelength by means of up-and-down zero-crossings of laser-fringes, the wavelength of Band 1 is still shorter than twice the sampling interval and hence Band 1 frequencies are aliased to low frequencies. Both optical and electrical filters are employed to minimize aliased signal and noise mixing. This also results in the AC coupling of the signal to the ADC and hence preventing the data quality determination as is done for bands 2 and 3."

(25) Page 2970, line 11: "Scene signal modulation". Question: Is this the interferomet-

ric modulation, or something else?

A: We have modified the sentence as follows: “lower than the scene signal modulation of the interferometer, which is the order of 10 KHz.”.

(26) Page 2971, line 15-20: Change: ”The high gain of Band 1 has high amplitude and its high-gain amplifier uses . . ..” To “The high gain amplifier of Band 1 uses a Chebyshev filter with a sharply peaked gain and cut-off to avoid aliasing of noise. Unfortunately, its gain is sensitive to the capacitance in the circuit, which varies with input voltage, temperature, and time. For the other bands, Butterworth filters are used, which have much flatter responses, so capacitance change results only in small shifts in their cut-off.

A:ãĂĂWe have modified as follows. “The high gain of Band 1 uses a Chebyshev filter with much sharper gain peak and cut-off than the other bands to avoid aliasing of noise. Unfortunately, its gain is sensitive to the capacitance in the circuit, which varies with input voltage, temperature, and time. Apart from the high gain Band 1, all bands use Butterworth filters, which have flat response. Their feedback capacitance changes result only in small shifts in their cut-off.”

(27) Page 29712, line 12 states: “As the difference is constant with time on orbit, this nonuniformity is corrected by resampling the interferogram.”. Comment: Since the sampling interval varies with OPD and scan direction, which are continually changing, it cannot be “constant with time”. It is, however, reproducible/predictable, which allows a correction to be made once you have established the functional form. But how was this done on orbit?

A: We have re-written as follows. “The deviation on orbit can be estimated by analyzing the onboard ILSF calibration laser data. As the deviation is reproducible on orbit, this non-uniformity is corrected by resampling the interferogram.”

(28) Page 2973, line 10: Question: What is this “background radiation”? Is it the

instrument self-emission?

A: We have added description as follows: “the background radiation mainly from the aft optics”.

(29) Page 2973, line 19 states: “the exact maximum OPD are 1309.742nm×76 336/2=±2.4995 cm” This is confusing. The sampling interval is 1309.742 / 2 nm because TANSO-FTS samples twice per laser wavelength. I suggest rewriting as “the exact OPD maxima are 1309.742 / 2 nm × ±38168 = ±2.4995 cm”. To me this is more intuitive and numerically correct”

A: We have corrected as suggested above.

(30) Page 2972, line 22-23: Comment: You state that a prime number IFFT is employed to save computation time. How much faster is a 76545-point prime factor FFT than a 2ˆ17-point FFT? I suspect that the difference is small. The real advantage of the prime factor FFT is that the size of the resulting spectrum is minimized without any loss of information.

A: The above comment is correct. We have modified as follows: “to save computation time instead of using 76,336 (38,168) and to minimize the resulting spectrum size instead of using 131,072 (=2ˆ17).”

(31) Page 2980, line 4: Change: “solar the zenith angle” to “the solar zenith angle”.

A: We have modified as suggested above.

(32) Page 2983, line 10 states: “There is no stable onboard white light source available today for radiometric calibration purposes. Therefore, SNR cannot be measured explicitly. It is estimated from the imaginary spectra or out-of-the band real spectra.” Comment: Isn’t the sun a stable white light source? Please explain the desire for an on-board white light source. Which kinds of spectra are used for estimating the SNR? Deep space, glint, nadir, spectralon?

A: We have added explanation as follows: "There is no stable onboard white light source available today for radiometric calibration purposes to estimate noise level that is proportional to signal level." We are estimating SNR indirectly by checking imaginary spectra or out-of-band spectra

(33) Page 2983, lines 15-22 state: "There are two dominant noise sources for TANSO-FTS bands 1, 2, and 3. One is the detector and its electronics noise, which is independent of the input signal level and proportional to the square root of the band width. The performance can be measured with dark input data and can be expressed with specific detectivity (D*). The second source is the shot noise, which is proportional to the square root of the total number of input photons. Band 2 has wide band width of 5800–6400 $cm{-}1$ to cover CO_2, CH_4 and H_2O lines, while the shot noise contribution is larger than in the other two bands." Question: Why is the shot noise contribution larger in Band 2 larger than in the other two bands? It is stated that both the detector/electrical and the shot noise scale as the square root of the band width. So the larger band width of Band 2 will increase ALL noise terms. So why is the relative shot noise contribution larger in band 2? Perhaps the "band width" on line 17 is not the same thing as the "band width" on line 20.

A: To avoid confusion, we modified the first one to "electric band width" and the second one to "optical band width".

(34) Page 2984, line 15, Suggestion: Please describe the nature of the "monochromatic light". Is this the same thing as the "onboard diode laser" mentioned in the figure 10 caption?

A. Before launch, we used tunable diode lasers for ILSF characterization test, which are much more powerful than the onboard diode laser. We have described as follows: "the pre-launch tests with monochromatic light from tunable diode lasers"

(35) Page 2984, lines 25-27, Question: What is the wavelength of the ILSF calibration laser? Does the laser fill the finite FOV of the interferometer.

A. The wavelength of the on-board diode laser is 6460 cm-1. As the onboard diode laser illuminates the solar diffuser, the laser can fill the entire FOV, but it is difficult to illuminate uniformly. So we are monitoring relative change before and after launch. We have modified as follows. “Fig. 10 (b) shows the long term stability of the data using onboard ILSF calibration laser of which wavelength is 6460 cm-1. Although the wavelength of the onboard diode laser without temperature control is not constant and the laser cannot illuminate the solar diffuser plate uniformly, the ILSF shape itself has been very stable since launch: this indicates that no significant spectral resolution change has been observed.”

(36) Page 2985, line 7: Change “%” to “ppm”.

A: % is correct. It is not a wavelength shift. To avoid confusion we have added the explanation as follows. “The degradation of laser signal detection level is exponential and smaller than 10% in one year.”

(37) Page 2985, line 8: Change: “We expect the laser has sufficient level of control after 10 yr of operation.” To “We expect the laser will still have a sufficient level of control after 10 yr of operation.”

A: We have modified as suggested above.

(38) Page 2985, lines 5-6 state: “. . .we have observed a gradual decrease of the laser signal detection level and an increase of the apparent wavenumber of the Fraunhofer lines”. Question: Are these two things related? If so, please explain how.

A: Yes, we consider two items are related. The illumination on the laser detector has become weaker, maximum OPD has become larger, and spectral resolution has become slightly higher.

(39) Page 2985, lines 9-10 state:” Because all the bands of 1, 2 and 3 have the constant wavenumber shift, the most probable cause is the optical alignment change of the laser beam on orbit”. Comment: A change in the alignment of the laser beam would cause

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a shift that was proportional to wavenumber (i.e., a stretch), not constant.

A: We have modified as follows: “Because the band all have the same spectral calibration factors”.

(40) Page 2985, lines 10-12 state: “..the most probable cause is the optical alignment change of the laser beam on orbit as illustrated in Fig. 11. Consequently, MOPD has become larger and spectral resolution has become slightly higher.” Comment: I’m struggling to reconcile this statement with figure 11, which illustrates that the misaligned laser OPD is *shorter* than the well-aligned laser path. Since the MODP actually got *larger*, does this mean that the laser alignment has improved since the start of the mission?

A: No. As the laser is the standard of FTS system, the laser path length (which is the laser wavelength multiplied by total number of fringes) is the same even if the laser alignment changes. The laser alignment becomes worse since the start of the mission. To avoid the confusion, we have modified Fig. 11.

(41) Page 2985, lines 20-21: Change: “The optical mirror pointing mechanism has two different speed motions; IMC and pointing of the earth surface during turnarounds.” To During interferogram scans, the optical pointing mirror is turned very slowly to perform IMC. Then, during turnarounds, it quickly steps to the next point of the grid pattern.”

A: We have modified as follows. “During interferogram scans, the pointing mirror is turned very slowly to perform IMC. Then, during turnarounds, it quickly steps to the next point of the grid pattern.”

(42) Page 2986, line 19-20 states: “The protection coating on the pointing mirror made of silver surface has a polarization phase.” Comment: In this sentence it isn’t clear whether the term “made of a silver surface” refers to the protection coating or the pointing mirror. Usually, protective coatings are made from a dielectric, not silver. Or perhaps the authors mean “reflective coating”, not “protection coating”.

A: We have modified expression simpler as follows. “The protection coating on the silver pointing mirror surface has a polarization phase.”

(43) Page 2988, lines 9-15: Change: “The quality flag of spike noise flag in the Level 1B product shows both fluctuation of the interferogram and spike caused by the cosmic rays. For the last three years after the launch, no spike caused by the cosmic ray has been detected. The FTS mechanism scan speed instabilities larger than 2% are to be detected by monitoring the passing time of the 10 different OPD positions. However, the stability on orbit is much better than 1% and the speed instability has never been detected since the launch.” to “The noise spike quality flag in the Level 1B product can be triggered by rapid fluctuation of the interferogram intensity and by spikes caused by cosmic rays. For the three years since launch, no spikes caused by cosmic rays have been detected. FTS mechanism scan speed instabilities larger than 2% would be detected by monitoring the passing times of 10 different OPD positions. However, the stability on orbit has so far been much better than 1% and so the speed instability flag has not yet been triggered.

A: We have modified as follows as suggested above.

(44) Page 2988 lines 21-23: Comment: I’m surprised to read that the TANSO spectra are corrected for the ILS broadening due to the finite-FOV-effect. What is the advantage of doing this in the case of TANSO? I understand that in the case of AERI this allows a more direct comparison of spectra from instruments having different FOV’s, but this advantage does not seem to apply to TANSO.

A: There is no advantage in case of CO2 and CH4 retrieval. We additionally correct Band 4 thermal radiation data for metrological users. We have added the following sentence: “Only Band 4 data additionally corrected for meteorological application.”

(45) Page 2990, lines 14-15 state: “Radiation from the aperture of the integrating sphere has angular distribution especially for bands 1 (UV) and 4 (SWIR).” Comment: Ignoring the missing article before “angular”, what does this sentence mean? The ra-

diation must have an angular distribution for all bands. What is special about bands 1 and 4? Perhaps the authors mean that "Radiation emanating from the aperture of the integrating sphere has a non-Lambertian angular distribution, especially for bands 1 (UV) and 4 (SWIR)."

A: We have modified as follows. "Radiation emanating from the aperture of the integrating sphere has a non-Lambertian angular distribution, especially for bands 1 (UV) and 4 (SWIR)."

(46) Page 2990, lines 20-21: Question: What is this "limb darkening"? This term usually refers to the solar disk, but in this case it is evidently something else.

A: We have changed from "limb darkening" to "vignetting" (optical vignetting + natural vignetting (illumination falloff)).

(47) Page 2991, lines 12: Explain briefly how an airplane (v=0.25 km/s) stays in formation with GOSAT (v=7 km/s).

A: The speed of the airplane and satellite is not the same. We have changed from "formation" to "simultaneous".

(48) Page 2991, lines 16-18: Change: "First, we selected the site data where standard deviation of the measured earth albedo between 3 by 3 pixels of TANSO CAI was lower than 0.005." To "First, we selected the site data where the measured earth albedo was uniform to better than 0.5% across the 9 (3 by 3) pixels of TANSO-CAI."

A: We have modified as suggested above.

(49) Page 2991, lines 19-20: Change: ". . .degradation of. . ." to ". . .degradation over. . .". Comment: It is not the site that is degrading, it is TANSO.

A: We have modified as suggested above.

(50) Page 2992, line 11: Change: "THETA_atc and THETA_atc are the AT and CT angles from the nadir" To "THETA_atc and THETA_ctc are the AT and CT angles from

the nadir”

A: We have corrected typo.

(51) Page 2998, Table 2: Comment: It is not clear whether the Notes apply to FTS, CAI or both. And what is the meaning of the “>” symbols in the notes?

A: We have updated the notes to clarify the application. We have changed the expression from “>” to “from *** to ***”.

(52) Page 3003, Figure 1: Suggestions: Add blue arrow from Spectralon Diffuser to Pointing mirror. Change “After Optics” to “Aft Optics”.

A: We have modified Figure 1 as follows.

(53) Page 3005, Comment: In Figure 3 the spectral radiance units are denoted as “V/cm-1”. Elsewhere in the paper the units are denoted as “V cm”, which is the same thing, but in my opinion less intuitive. You should express the spectral units consistently throughout the paper.

A: We have modified Figure 3 and Table 2

(54) Page 3010, Figure 8: Suggestion: Add labels (a) and (b) to the appropriate panels.

A: We have added (a) and (b) again to figures 6, 8, 9, 13 and 14. It was typesetting error.

(55) Page 3011, Figure 9: Questions: Why does the y-axis annotation say “Jun-Jul”. I thought that the ratio was for June 2009 and June 2010. And why does site “Sahara 8”have ratios of 1.00 for all bands? Is this just a coincidence, or has some normalization taken place?

A: One month period data of TANSO-FTS over the Sahara is limited. We use both June-July data. Sahara 8 data is not the exactly 1.00. This is just a coincidence. We have added the following note in Table 4. “As the data available is limited, Sahara

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Desert includes July data."

(56) Page 3012, Figure 10: Suggestion: Add labels (a) and (b) to the appropriate panels. Specify the wavelength of the on-board diode laser.

A: We have added (a) and (b) again. The wavelength of the on-board diode laser is 6460 cm-1.

(57) Page 3018: Figure 16: Suggestions: Add labels (a) and (b) to the panels. Also, change: "Fig. 16. (a) TANSO-CAI degradation in one year between 2009 and 2010 over the Sahara and Arabian deserts in June. (b) The same as (a) but for between 2010 and 2011." to "Fig. 16. TANSO-CAI degradation over the Sahara and Arabian deserts. (a) between June 2009 and 2010, (b) between June 2010 and 2011.

A: We have added (a) and (b) again. For figure caption, we have modified as suggested above.

Please also note the supplement to this comment:
http://www.atmos-meas-tech-discuss.net/5/C1620/2012/amtd-5-C1620-2012-supplement.pdf

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