Interactive comment on "On-orbit radiometric calibration of SWIR bands of TANSO-FTS onboard GOSAT" by Y. Yoshida et al.
Anonymous Referee #1
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The paper by Yoshida reports on an updated and refined radiometric degradation model for backscatter radiance spectra collected by the Greenhouse Gases Observing Satellite (GOSAT). Using direct solar spectra, degradation coefficients are reevaluated and fed into a time, wavelength, and polarization dependent degradation model. The study is an important contribution to characterizing GOSAT measurements and improving the respective greenhouse gas retrievals. It is suitable for publication in AMT after considering a few comments.

> => Thank you for your careful reading of our paper. The followings are our reply to your comments. The revised part is marked with "double line (═══; removed)" or "under bar (___; added)".

Comments:

The paper lacks a clear recipe how to apply the proposed degradation correction to GOSAT L1b data. I would recommend providing such a recipe at a prominent place in the manuscript. In particular, it is not clear how the spectral dependence of the degradation model is to be implemented in a GOSAT retrieval algorithm since the manuscript only provides numbers at few wavenumber points and a graphical illustration (figure 8). Equation (6) parameterizes the time dependence of the degradation model. In the limit of t=0, equation (6) reduces to "dP/S+eP/S" which is close (but not identical) to 1 when using the numbers in table 3. What is t=0? Is it 4 March 2009, which would be different from the previous version of the degradation model? Is there an offset to be considered at t=0 or is this offset already included when using the calibration dataset available from GOSAT support?

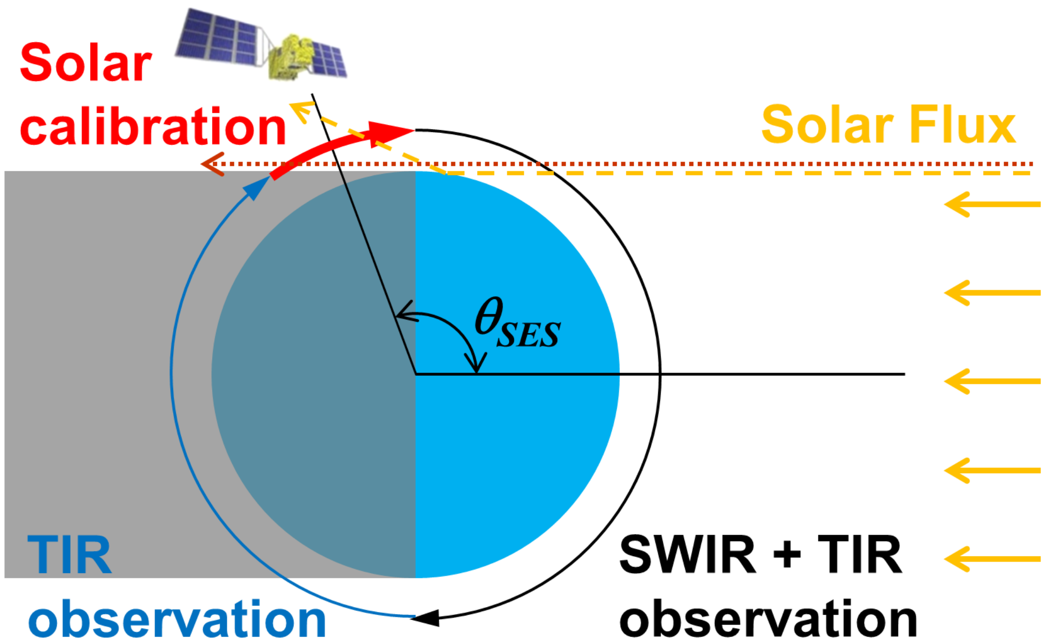
> => According to your suggestion, we added a new section about the implementation of the improved degradation model (see below). As written in the p.4715 Line 25, "t" is a day after the launch, so t = 0 indicates 23 January 2009. This is the same definition of the previous degradation model.
>
> "**Application of the improved degradation model**
> Since Eq. (6) gives a radiometric degradation relative to the reference date, we should evaluate the absolute radiometric degradation. In this paper, we used the results of vicarious calibration campaign (Table IV of Kuze et al., 2011). By substituting the mean value of the evaluated sensitivity-change relative to the pre-launch calibration data as an absolute degradation $A_{P/S}(\nu,t)$ (0.893, 0.881, 0.986, 0.975, 0.975, and 0.963 for Band 1P, 1S, 2P, 2S, 3P, and 3S, respectively) and t = 157 (29 June 2009; mid-day of the campaign) into Eq. (6), we can calculate the absolute degradation at $t = t_0$ = 40 (4 March 2009) $A_{P/S}(\nu,t_0)$. Note that the absolute degradation at t = 0 (23 January 2009) is not unity due to several reasons; (i) sensitivity-change between before and after the launch, (ii) fitting error of Eqs. (4) and (6), (iii) error in the pre-launch calibration data.
> The degradation model is applied as follows. First, calculate the absolute degradation $A_{P/S}(\nu,t)$ of each wavenumber grid for a given observation date. Then, interpolate them to the target wavenumber by using a cubic-spline. Finally,

divide the interpolated absolute degradations into the observed spectra, and you get the radiometric calibrated spectra."

p.4715,l.10: : :, figure 3, figure 4: I do not understand why telluric O2 absorption contaminates the solar spectra for small theta_SES. Shouldn't the contamination effect become more important the greater theta_SES. Looking at figure 3, I would conclude that telluric contamination is largest when the sun rises at the satellite (theta_SES>105 deg) causing a long tangent lightpath through the Earth's atmosphere. For smaller theta_SES the tangent lightpath gets smaller and essentially vanishes for theta_SES=90 deg. On the other hand figure 4 seems to confirm the present rationale in the manuscript. Please clarify.

=> There exists two possible contamination sources; one is the transmitted light through the terrestrial atmosphere and the other is the reflected/scattered light by earth's surface/atmosphere. Only the solar calibration data obtained 4 March 2009 covered the full-range of the red-arc in Fig. 3. Other solar calibration data covered the latter half part of the red-arc. This is why the contamination source you mentioned was not important. We added the explanation and revised Fig. 3 as follows.

"In this study, we used the solar calibration data taken with the back side diffuser plate, because it is expected to have suffered less degradation than the front side diffuser (Kuze et al., 2012). Table 1 summarizes the solar calibration data observed by the back side diffuser plate. ~~Furthermore, to discard the data that were contaminated by weak absorption of the terrestrial atmosphere, we selected the solar calibration data with the following criterion. We used the sun-earth-satellite angle θ_{SES} (see Fig. 3) to specify the scan from a series obtained in a single solar calibration.~~ The solar calibration data which were contaminated by weak absorption of the terrestrial atmosphere should be discarded. When the sun-earth-satellite angle θ_{SES} (see Fig. 3) is large, TANSO-FTS may receive a solar radiation directly transmitted through the terrestrial atmosphere (dotted line of Fig. 3). Also, TANSO-FTS may receive a solar radiation reflected/scattered by earth's surface/atmosphere as a stray light, because an aperture of TANSO-FTS always faces to the nadir direction (dashed-line of Fig. 3). The former/latter effect is expected to be large when θ_{SES} is large/small. Except for the case of 4 March 2009, solar calibration data were obtained during the GOSAT passing the latter-half part of the red-arc in Fig. 3 (see θ_{SES} range in Table 1). Therefore, the latter contamination was expected to be dominant. To discover the fine absorption structure, the observed solar spectra were averaged over certain θ_{SES} regions and then their differences were checked (Fig. 4). The absorption structure due to terrestrial atmospheric molecular oxygen can be seen when θ_{SES} is smaller than about 105 degrees probably due to the contamination of the reflected/scattered light. By also considering the data availability (see the range of θ_{SES} in Table 1), we used the data with θ_{SES} just above 105 degrees for each solar calibration in the following analysis."



"Figure 3. On-orbit operation of GOSAT. Solar calibration is conducted when the satellite passes over the northern polar region. Dotted and dashed lines are possible optical paths when observed solar radiation is contaminated by the terrestrial atmospheric absorption."

p.4716, section 4.1, 4.2: Table 1 lists the measurements used to fit an empirical relation of the diffuser reflectivity with incidence angle theta. The observation at small theta collected on 2009/03/04, _18:46, seems quite far off the other measurements. In section 4.2, measurements at large theta are then excluded from the empirical degradation model because they do not seem to fit well. Did you test if the empirical relationships for the diffuser reflectivity and the degradation model change significantly with/without considering this one data point at small theta?

=> We didn't check it precisely, but the rejection of the data point didn't make the fitting better.

Figure 9c: The refined degradation model removes the trend from the ratio of the band1 and band2 radiance calibration factors. One would expect that these calibration factors are not needed given a good degradation model. So, are these radiance calibration factors actually close to 1? There is still considerable scatter of the data. Is the scatter noise driven or is there other contributions?

=> The retrieved radiance adjustment factors were close to unity. The retrieved radiance adjustment factor of Band 1 showed relatively large scatter than those of Band 2. This was probably due to the simple assumption of the aerosol in the retrieval (i.e., single-layered aerosol with single type). Because the radiance adjustment factor was introduced to adjust the inter-band calibration error, we focused on their ratio, not on each factor.

Minor:

p.4712,l.5: measures short-wavelength infrared (SWIR) spectrum, and its radiometric accuracy : : : -> measures the short-wavelength infrared (SWIR) spectrum. Radiometric accuracy : : :

=> Done.

p.4712,l.10: parameter -> parameters

=> Done.

p.4712,l.15: evaluated -> found

=> Done.

p.4713,l.6: designated “P” and “S”, as well as thermal radiation : : : -> designated “P” and “S”. It further collects thermal radiation : : :

=> Done.

p.4713,l.15: : :: The sentence reads as if accurate radiometric calibration was not required if surface reflectivity did not affect scattering-related lightpath effects. Even if surface reflectivity was not a player or was independent of wavelength, accurate interband radiometric calibration would be crucial since particle scattering properties depend on wavelength.

=> We revised the sentences as follows.

"The strength of the optical path modification differs with wavenumber, because it depends ~~not only~~ on both the amount of scattering particles ~~but also on~~ and the surface reflectance. Therefore, ~~precise~~ accurate radiometric calibration of TANSO-FTS is needed to retrieve accurate estimates of XCO_2 and XCH_4."

p.4713,l.22: “large deviations” Deviations from what? Do you mean “was found deficient”.

=> We revised the sentence as follows.

"However, this degradation model ~~has been shown to produce large deviations~~ predicts faster degradation than the actual one, especially for Band 1 (Kuze et al., 2011, 2012)."

p.4714,l.2: : :: Define chi2 as used in figure 2 here. This will help clarify what is meant by “residual”.

=> Following equation and explanation was added.

$$\chi^2 = \frac{[\mathbf{y} - \mathbf{F}(\mathbf{x})]^T \mathbf{S}_\varepsilon^{-1} [\mathbf{y} - \mathbf{F}(\mathbf{x})]}{m}$$

"where $\mathbf{y}$ is the measured spectrum, $\mathbf{F}(\mathbf{x})$ is a forward model, $\mathbf{S}_\varepsilon$ is the error covariance matrix, and m is a number of channels."

p.4714,l.6: : :: The ratio between which radiance adjustment factors changed? Do you refer to ratioing the factors derived from different bands?

=> To make it clear, we revised the sentence as follows.

"*ISSUE-2*: the ratio between the radiance adjustment factor~~s~~ of Band 1 and that of Band 2 (see below for definition) changed with time (Fig. 2c)."

p.4714,l.10: What is the meaning of "rough spectra" in this context?

=> To make it clear, we added the explanation.

"Rough ~~spectra~~ spectrum structure of ground surface albedo in each band, which was represented by several grid-point values and varied linearly from one grid to the next, were retrieved for the land case, whereas the surface wind speed and radiance adjustment factor were retrieved for the ocean case."

p.4715,l.4: : :: I suggest adding a comment that the operational (nadir, glint) optical path inside the instrument is the same as for solar calibration except for the solar diffuser.

=> We added the sentence at the beginning part of the section 3.

"The solar radiation reflected by the onboard Spectralon diffuser plate is introduced into the TANSO-FTS when the satellite passes over the northern polar region. Except for the diffuser plate, the optical path inside the TANSO-FTS instrument is the same for both earth observation (nadir, sunglint, and target) and solar calibration (see Fig. 1 of Kuze et al., 2012). Around 35~50 scans (about 3~4 min converted into the data acquisition time) of solar calibration data were obtained for each orbit (Fig. 3)."

p.4719,l.2: evaluated -> improved

=> Done.

Table 1: observing -> observed; the data suitable for the analysis was not available -> no suitable data were available

=> Done.

Table 2: Coefficients a, b, and c of (a) Band 1, (b) 2, and (c) 3 to represent the reflectance of the diffuser plate. -> Coefficients a, b, and c of (a) band 1, (b) band 2, and (c) band 3 to model the diffuser reflectivity as a function of incidence angle.

=> Done.

Fig.2: Mention that the data are ocean-glint scenes.

=> Done.

Fig.4: As for the reference -> For reference

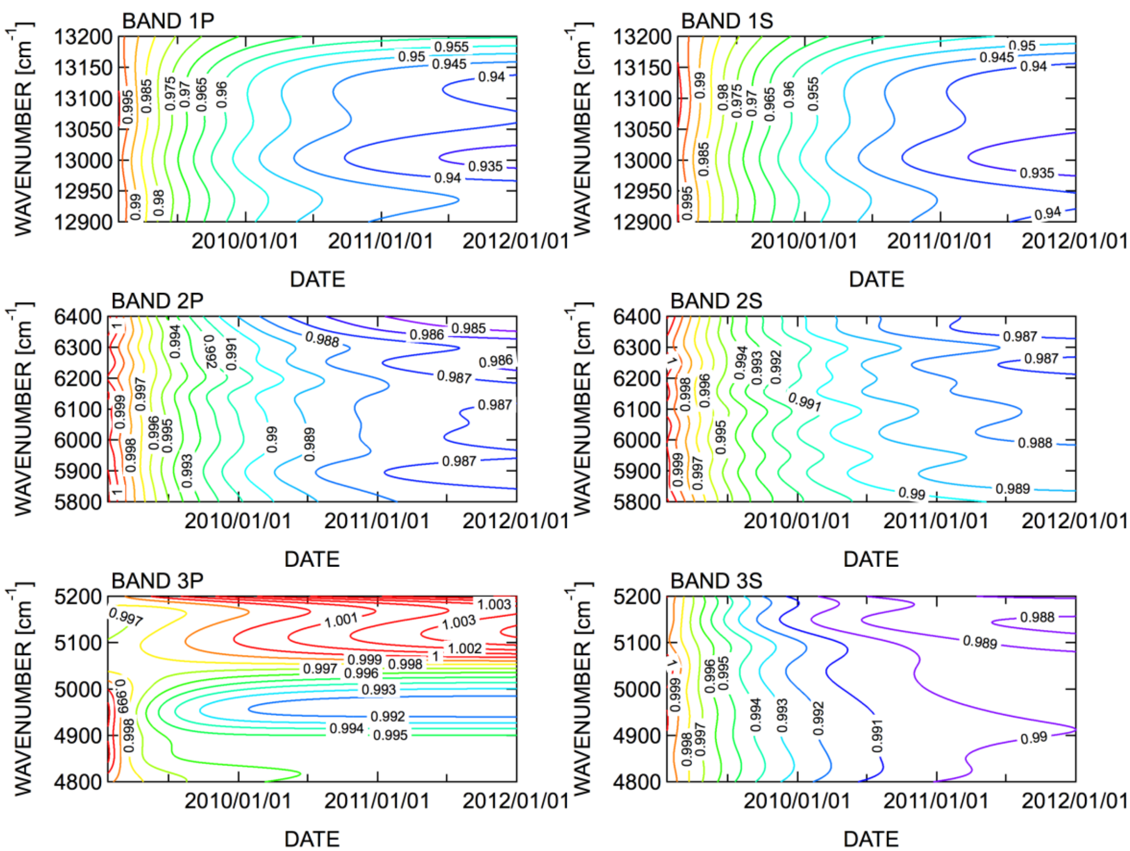
=> Done.

Fig.7: cross -> crosses; square –> squares

=> Done.

Fig.8: Predictions up to mid 2014 seem daring to me. I suggest shortening the prediction period in order to highlight degradation during the past and current mission.

=> Fig. 8 was revised to show the modeled degradation until the end of 2011.



"Figure 8. The TANSO-FTS radiometric degradation ~~over 5.5 yr~~ in various spectral bands calculated from the radiometric degradation model evaluated in this study."