Review comment amt-2019-488-RC1

Reviewer: **Anonymous Referee #3**

Dear referee,

Thank you for your detailed review of our article. Our responses to your remarks, questions and considerations can be found in the table below. The performed changes to the manuscript are listed in the Section “Detailed Changes”.

Response

Item	Referee comment	Author’s response
Section 5	The text states that in-flight linearity deviates from on-ground by no more than 1%. This seems rather large. Is this a statistically significant deviation? This deserves more discussion.	The text states 1‰, which is not large. Have you maybe misread the sentence?
Section 7	This is an important topic, but the authors choose to devote only a short qualitative discussion to it. It would be helpful to the reader to provide some idea of the errors involved. At what error level does the flagging occur?	Added sentence on level of saturation flagging. As described, the blooming flag is not based on an error threshold but on a pixel filling value.
Section 8	The authors state they have only addressed geolocation in Bands 4-7. Geolocation in the shorter bands, esp. Band 3, are also important and validation should be possible except for Band 1. The authors should at least discuss what their plans are to validate these bands.	A more detailed discussion on the results, their consequences and future plans has been added.
Section 9	A similar comment about wavelength registration. The authors imply there is no source of wavelength information other than from L2 products and there are no products providing this information for Bands 1 & 2. Yet the spectral registration in these bands is no less important than at longer wavelengths. The authors can at least acknowledge the problem and discuss their plans to deal with it.	The L1 wavelength assignment is based on on-ground calibration. The key data can be updated as described. Added specifically that this can also be done once data for other bands is available.
Section 11	The discussion in this section (esp. the paragraph starting at line 260) was somewhat confusing. The authors should consider two alternatives	This section has already been adapted following the initial review comments.

Item	Referee comment	Author’s response
	to remedy this: provide a bit more explanation to the reader, or eliminate some of the details that are the source of the confusion. I recommend the latter because it’s not clear what is to be learned from these details.	
Section 12	In Line 285 the authors seem to throw cold water on any technique, other than on-board calibrations, to derive or validate radiometric change. It is quite reasonable that the authors have not had a chance to implement any of the well-documented techniques for validating the calibration, but they should refrain from suggesting these were omitted because they lack useful information. I think I follow the ’competing change’ argument described in Lines 330-335, but I doubt most readers will. The authors need to describe explicitly what about Figures 12 & 13 indicates increasing detector response competing with diffuser degradation.	Rephrased the sentence to make clear that it is about the operational L1b processor. Added a remark on validation of the correction with Earth targets. Rephrased to make the point clearer.
Table 3	These numbers appear to be in percent. The authors should say so explicitly	Added % to the header.
Section 13	The authors imply at the start of Section 12 that the reflectance calibration of TropOMI is an important quantity, but they fail to address its accuracy. If that is outside the purview of this paper, the authors should say so. The authors also fail to discuss in this section the effect that adjusting the irradiance calibration has on measured Earth TOA reflectances. Since the radiance calibration wasn’t mentioned, the reader is left to assume that all the adjustments described in Section 13 are being applied in inverse to the instrument’s reflectance calibration. What is the justification for doing so? The authors provide no insight as to why the pre-launch irradiance calibration might be so much in error. How do they know that the radiance calibrations are not in error by an equal or nearly equal amount?	Added explicitly that the reflectance is changing. As described in the beginning of Section 13, the on-ground calibration measurements for irradiance suffered from low SNR. As mentioned, the details about the on-ground calibration issues are discussed in Kleipool et al. (2018). Added more details on further comparison with on-ground sources.
Grammar comment	Use of the word "for" in connection with "corrected" should be accompanied by an object rather than a subject. "We correct for something" rather than "Something is corrected for."	Adapted.

Detailed changes

List of changes to version 2

The page and line numbering in the Table below is according to version 2 which was public on the discussion page. The comments on the version 1 (the one which was initially sent out to the reviewers) have already been included in version 2.

Item	Change
New figure	Added new figure and caption at the beginning of the article. It shows a functional schematic of TROPOMI. Added a reference to this figure in several places in the text.
Fig 1-3, 5-9, 11-22	Enlarged plots or adapted plots to increase fontsize and improve readability. Adapted captions and the references to the plots accordingly. For Fig.1 added "The triangles in the top panel show the gain ratio as derived from on-ground measurements."
p 1 l 13, abstract	Changed "processing from 2020 on" to "processing from late 2020 on".
p 1 l 22/23, Table 1	Adapted to be consistent with official PRF: 5.6-> 5.5, 7.2 ->7, 28.8->28
p2 l 27 ff	Replaced "The instrument is measuring the radiance on the day side of each orbit and once a day the irradiance via a dedicated solar port as described in detail in KNMI (2017) and Kleipool et al. (2018)." By " The instrument is measuring the radiance on the day side of each orbit and once a day the irradiance via a dedicated solar port as shown in Fig.1. Sun light passes through one of the two internal quasi volume diffusers (QVD1 and QVD2) and is coupled via the folding mirror into the telescope of the instrument. A detailed instrument description canbe found in KNMI (2017) and Kleipool et al. (2018)."
p 2 l 41, introduction	Changed "The timing and definition of the different orbit types was adapted to match the detected darkness of the eclipse. " to "The timing and definition for the measurement sequences of the different orbit types was adapted to match the detected darkness of the eclipse. "
p 3 l58	Added " All measurements described in this article were performed at the nominal temperatures with active thermal stabilization."
p 3 l 62	Added "when the radiant cooler points in a sub-optimal direction"
p 4 l 75 ff	Replaced "output" by "observed signal"and "detector response".
p 4 l 86	Added "Depending on the source and its location in the instrument, the listed values can contain contributions from degradation of the source, its specific optics, the diffusers, the folding mirror, the telescope and the spectrometers."
p 6 l 114	Added "or other housekeeping parameters" .
p 7 l 138, 141	Added " in the tropics". Changed "and" to "-". Added " In the tropics typically about 0.2-0.5% of the pixels are flagged for saturation in bands 4-6, other regions and bands are hardly ever affected."
p7 l 140	Added: " For the CCD detectors spatial binning is applied: the charge of several successive detector rows is added in the register and then read out."

Item	Change
p 7 l141	Replace “this” by “the saturation issue”
p 8 l143	Added:“ (spatial direction)”
p 9 l157	Added: “ ..., so only a narrow spectral range is available per UVN band.”
p 10 l 183ff	Changed “For the SWIR and UVIS detectors the same effect is observed, so a mechanical change within the instrument during launch seems unlikely.” to “For the SWIR, UVIS and NIR spectrometers the same effect is observed, so a mechanical change within the instrument itself during launch seems highly unlikely. For UV the signal to noise of the high resolution measurements with their small spectral range is too small to draw conclusions. The light for the UV and SWIR takes the same path up to and including the instrument slit and the UV spectrometer is part of the UVN optical bench as shown in Fig. 1. As the SWIR spectrometer shows the same effect as the UVIS and the NIR spectrometers and no difference is observed between UVIS and NIR, due to the instrument design it is highly unlikely that the UV spectrometer should behave differently.”
p 10 l 188	Added “ A further validation is not foreseen, as the nominal radiance measurements have a larger groundpixel size.”
p 11 l 204	Added “or data for other bands becomes available”
p 11 l 208	Added “(spatial direction)”
p 11 l 210	Changed “ Therefore not the main instrument slit but the slit in the UV spectrometer is most likely causing the feature. “ to “ From the instrument design as shown in Fig. 1 it can be seen that not the main instrument slit but the slit in the UV spectrometer is most likely causing the feature.”
p 11 l 214	Added “as shown in Fig. 1”
p 11 l 217	Added “ (columns)”
p 12 l 236	Changed “400 orbits” to “ 400 consecutive orbits (starting in orbit 1247)”
p 13 l 241	Added “ possible electronic drifts”
p 14 l 261	Added “The fitting window covers the natural yearly solar azimuth variation for the reference orbit with equator crossing time of 13:30 local solar time.”
p 14 l 263	Changed “ see also Section 12”to “see also Section 12 for the description of the residuals”
p 15 l 272	Added “The slew manoeuvres are included in the nominal operations baseline as described in Section 14. This reduces the measured azimuth range to less than $\pm 1^\circ$ around the reference angle.”
p 15 l286 ff	Changed to “To determine relative electronic drifts, the DLEDs which are situated close to the detectors are used. The optical path of the WLS includes additional elements which are not part of the optical path for light from the Earth or the Sun, and the WLS light does not pass through the QVDs. The internal light sources also show a decrease in output which cannot be separated from instrument degradation as described in Section 4. The internal light sources are therefore less suitable for the calibration of the degradation of the irradiance and radiance optical paths.

Item	Change
p 15 l 287	Changed to "Radiance measurements in general show much variability in themselves and would require too much input from atmospheric models to be useful for the derivation and regular update of an independent and sufficiently accurate degradation correction for operational L1b processing. In the future the derived correction needs to be validated by - for example - using sites with well known reflectance."
p 15 l 291	Changed from "the degradation of the diffusers (QVD1 and QVD2) used for irradiance measurements, a gradual spectrally dependent increase of the throughput in the UV spectrometer and a drift of the CCD gain for the UVN spectrometers." To "the degradation of the diffusers (QVD1 and QVD2) used for irradiance measurements, a drift of the CCD gain for the UVN spectrometers and a gradual spectrally dependent increase of the throughput in the UV spectrometer. This spectral ageing in the UV spectrometer is observed for irradiance, radiance and WLS data and cannot be found in on-ground data."
p 16 l 300	Changed "composed" to "modelled"
p 16 l 304	Changed "perfect" to "are best described"
p 16 l 315	Added "For UVN (SWIR) a super pixel stretches over 20 (12) rows in the spatial direction. In the spectral direction (columns) it is 5,10,20 and 20 pixels for UV, UVIS, NIR and SWIR respectively. Apart from the spectrometer degradation in the UV, the data is spatially and spectrally smooth, so the super-pixel size has no impact on the result apart from noise reduction."
p 16 l 316	Added "Following the postulate of the model, the"..
p 16 l 318	Added "If the residuals show in the future that the assumption of exponential decay is not justified anymore, a different fitting function can be used."
p 16 l 333ff	Rephrased to " In the left part of Fig.13 it can be seen that this spectrometer ageing is stronger than the signal decrease due to the diffuser degradation. In this way the UV spectrometer ageing nullifies the diffuser degradation."
p 17 l 347	Added "diffuser"
p 17 l 349	Added "The spectrometer specific degradation Dspec in the UV spectrometer is derived for the entire mission so far and the correction is applied to both the radiance and irradiance. The correction is also applied to the reference orbits for the absolute irradiance calibration"
p 17 l 350	Added " and that the steps occurring in the data around updates are minimal."
p 22 Table 4	Changed "The degradation per band per 1000 orbits as determined up to orbit 9748" to "The mean degradation per 1000 orbits as determined up to orbit 9748." Added % to the header.
p 23 l 362	Added "An investigation of various on-ground illumination sources via the Sun and the Earth port showed that the discontinuity is exclusively observed for the absolute irradiance calibration with the FEL lamp. The absolute radiance calibration with the FEL lamp is consistent with other calibration sources."
p 23 l 364	Added "The correction to the absolute irradiance is derived for orbits 2818 (QVD1) and 2819 (QVD2), the same orbits the diffuser degradation is tied to. The UV spectrometer specific degradation has been corrected in the used data, see Section 12."

Item	Change
p 23 l 365	Changed “A well-known solar reference is the high resolution Dobber spectrum (0.014 nm per pixel) (Dobber et al., 2008) and the Kurucz spectrum (Chance and Kurucz, 2010), which are high resolution composites of different solar measurement campaigns. It covers the spectral range of the TROPOMI instrument, but especially in the UV range it is unclear if it is reliable.” To “Well-known solar references are the high resolution Dobber spectrum (±0.014nm per pixel) (Dobber et al., 2008) and the Kurucz spectrum (Chance and Kurucz, 2010), which cover the spectral range of the TROPOMI instrument. They are both high resolution composites of different solar measurement campaigns and not based on a single instrument.”
p 23 l 375	Removed “independently calibrated”
p 23 l 376	Added two references: Seftor et al., 2014; NASA Goddard Space Flight Center, 2019
p 23 l 380	Replaced “spectral”by “radiometric”
p 24 l 402	Added “Adapting only the irradiance calibration for UV and UVIS changes the reflectance for these spectral ranges. Initial validations tests show that this has indeed a positive impact on the L2 retrievals. In the future a more extensive re-assessment of the radiometric accuracy can be performed and any potentially remaining inconsistencies in radiance and irradiance can be addressed.”
p 24 l 423/424	Adapted SSD to be consistent with table: 5.6-> 5.5, 7.2 ->7, 28.8->28
p 25, l 434/ 436	Changed v1 / v2 to version 1 /2
p 449	Changed “radiometry” to “radiometric”
References	Removed urls where doi is present, removed doi prefix in bib-file.
Language	Removed phrase “corrected for”.

Changes to initial version 1

The changes below have been performed to the initial version 1 sent out to the referees. These changes were already included in the version 2 which was published on the discussion page and are listed below for completeness.

Line number Fig/Table (version1/version2)	Original (version 1)	Update (version 2)
/Table 1		Added table on main characteristics.
24/ 24		Added " The main characteristics of TROPOMI are listed in Table 1. "
23/23	5.5km x 3.5km	Put non-rounded number to be consistent with new table: 5.6km x 3.6km

Line number Fig/Table (version1/version2)	Original (version 1)	Update (version 2)
420/423	"before it was approximately 7 km at nadir and it is now about 5.5 km. In across-track direction the minimal sampling distance at nadir is around 3.5km for bands 2–6, about 7km for bands 7–8 and around 28km for band 1."	Put non-rounded number to be consistent with new table: "before it was approximately 7.1km at nadir and it is now about 5.6km. In across-track direction the minimal sampling distance at nadir is around 3.6km for bands 2–6, about 7.2km for bands 7–8 and around 28.8km for band 1."
Caption Fig.5/Fig.5	"The differences for low and high row numbers are now mostly within the requirements and more symmetrical."	Added "(black lines)": "The differences for low and high row numbers are now mostly within the requirements (black lines) and more symmetrical."
208	335-–337	Changed to em-dash: "335–337"
Caption Fig.6/Fig.6	"Note that the row numbering is showing the binned count."	Changed to " Note that the binned row count is shown in the plots, the affected detector rows are rows 335--337."
220/221		Added: "Detector rows 335 and 336 correspond in this example to the binned row counter 144."
263/265	"For double processing, so re-analysing data that is corrected with the derived relative irradiance CKD, the standard deviation reduces to the order of ×10 −4 , this is an order of magnitude better than what was achieved with the on-ground data."	Re-phrased to: "To validate the integration of processor and key data, double processing is performed: data that has already been corrected with the derived CKD is re-analysed for remaining effects. Double processing irradiance data with the derived relative irradiance CKD reduces the standard deviation to the order of ×10 −4 . This result is an order of magnitude better than what was achieved with double processing of the CKD derived from on-ground calibration data."