Review comment amt-2019-488-RC2

Reviewer: **Anonymous Referee #2**

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
Fig 1-3,5,6,11-22	The used fonts are to small, enlarge	The plots have been adapted or enlarged. Captions have been adapted accordingly.
Fig. 7-9	At least the numbers at the color scales need to be larger. For not so young eyes, the numbers and labels in the printed paper are difficult to read. Please change.	The plots have been adapted or enlarged. Captions have been adapted accordingly.
p1 l13, abstract	"processing from 2020 on". From my knowledge, late 2020 is the current foreseen start for the version 2 L1b processor. Please adapt the date, also in the conclusions.	Yes, that is correct. Currently the planning is for *late* 2020. Adapted both occurrences.
p2 l41, introduction	please define the term "orbit types" (probably the measurement sequence along the orbit.)	Adapted.
P3 , introduction	Please add (at the end of the introduction) a sketch of the instrument design, it would be very useful for the following paragraphs: Where is the calibration unit, what are the light paths, where are the diffuser etc. Please also add a paragraph or a sketch to the detector layout: row and column is frequently used in the text, but nowhere the spatial and spectral direction is explicitly stated.	Added a new figure with the functional schematic of TROPOMI. The spatial and spectral direction is now added to the text several times.
Section 2 Thermal stability	It is observed, that the thermal stability is reduced after orbital manoeuvres. Is there a reason or at least an educated guess for this behaviour? If yes, please add.	Added. The thermal stability is reduced when the pointing of the radiant cooler is not optimal as can be the case during manoeuvres.

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Section 7 Pixel saturation, blooming	Are there estimations available, how frequently saturation and charge blooming occur? Which are the suspect conditions (snow? tropical clouds? something else?). Please add.	Information on the pixel saturation has been added. For the blooming we do not have detailed statistics yet as the new version is not in use yet.
Section 8 Geolocation	p9 l161: ..or along-rack.. -> or along-track	Adapted.
Section 9 Spectral annotation	It is stated, that the calibration key data for the wavelength calibration are updated according to the wavelength fits in the Level 2 algorithms. Are the key data directly used as wavelength axis? There is no Level 1 wavelength calibration?	Currently there is no online Level 1 wavelength calibration. The L1 key data is based on on-ground calibration and adapted with the in-flight insights. L2 retrieval algorithms perform their own wavelength fitting where the L1 wavelength assignment is used as a starting point.
Section 10 Slit irregularity	Especially for this section, the definition of rows/columns versus spatial/spectral direction in the introduction would be very useful!	Adapted.
Figure 6	Change y-axis name to 'binned row counter' (this is the used name in the text). Please add in the caption, that the row 335-337 corresponds to the binned counter 144.	This has already been adapted following the initial review comments.
p 16 l 303 ff Section 12 absolute radiometry and instrument degradation	"The specific degradation curves ... are perfect exponential curves". Here it is assumed, that the degradation behaves exponential, so write something like: "It is assumed, that the diffuser degradation behaves exponential with time. Therefore, the specific degradation curves ... are modelled as exponential curves". Also the exponential behaviour of D_{com} is an assumption and should be stated as such.	It was found that the exponential fits resulted in a better fit than other functions. We made this clearer in the text that this is the model.
P 16 l 315 ff Section 12 absolute radiometry and instrument degradation	"For each of these super pixels the linear system in Eq. (1) is solved. For the UVIS, NIR and SWIR no spectrometer degradation D_{spec} could be determined and this term is therefore set to unity." I think, this is the wrong order: For UVIS, NIR, and SWIR, no spectrometer degradation can be derived, therefore D_{spec} is set to 1.0 for theses channels. With this assumption, the linear equations system is solved for each super pixel if UVIS, NIR and SWIR. Right? Please also give a number, how many pixels are in one super-pixel.	For UVIS, NIR and SWIR no spectrometer degradation was found so the term was set to 1. Added the size of the super pixels and some more explanation on it.

Item	Referee comment	Author's response
p 16 l 317 Section 12 absolute radiometry and instrument degradation	"The solutions for D_{q1} , D_{q2} and D_{com} are all three exponential decay functions and perfectly smooth in the temporal dimension." Your model fits exponential decay functions for this quantities, therefore this is trivial message. What could be stated here is something like: The assumption of an exponential decay for D_{q1}, D_{q2} and D_{com} is approved by the small residuals R_k/P_k, as shown by the right plots in Fig 12-14. The explanation for estimating D_{spec} for the UV leaves a few questions open: D_{com} is extrapolated to the UV region. What about D_{q1}/D_{q2}? What type of extrapolation do you use, so what are the assumptions made? Towards shorter wavelengths, the degradation is expected to increase. According to the left plot in Fig. 11, this is not the case for D_{spec}.	The phrasing has been changed to make clear that the exponential decay is the model. For the ratio of Dq1/q2 the assumption is made, that the degradation is exposure based, so we use the total time of usage as input. The spectral ageing Dspec of the UV spectrometer does indeed behave different than the diffuser degradation. The signal increases with time.
P 17, l 347-352	For the forward processing, an extrapolation of the degradation parameters is used. It is stated, that this new degradation parameters will be regularly updated by incorporating the recent measurements. With the update, also the extrapolation will change. This might introduce jumps in the irradiance time series, which might be an issue for users. Is there a strategy to monitor and/or avoid this? Please add some information about the details here.	Added remark on jumps in the data.
P 22, Table 4	The *mean* degradation per Band is given, right? Please clarify.	Yes for the bands/ wavelength it's the mean degradation. Rephrased the caption.
13 Absolute irradiance calibration:	Why is the OMPS irradiance measurement choosen as the reference measurement for the radiometric calibration? To my knowledge, OMPS is an unusual solar reference measurement. OMPS does not even distribute there irradiance measurements as regular product. The cited literature [Jaross 2014] gives no information about the absolute radiometric calibration except a plot together with an unnamed "synthetic" spectrum. If possible, at a reference for the radiometric calibration of the OMPS irradiance. Recently re-calibrated and published solar spectra are SOLSPEC (Meftah et al 2018) or SCIAMACHY (Hilbig et al, 2018), which would be a better choice. Both are also independent from other reference spectra. Nothing is said about the radiance calibration. Is the discontinuity observed in the overlap region also visible in radiances? What about the reflectance? The light path is the same for radiance and irradiance except the QVD. The QVD is the same for the the UV / UVIS overlap and cannot	The OMPS solar irradiance is not distributed as a separate product, but is part of every L1b file, we added additional references. We now added explicitly that the reflectance is changing, and explained the observed inconsistencies from on-ground calibration. The OMPS spectrum was chosen for several reasons: it has similar instrument characteristics, it is an active mission and a single instrument spectrum and not a composite spectrum. This point is made clearer in the text now. As shown in the paper we compared the results to different references.

Item	Referee comment	Author's response
	cause the discontinuity. Therefore, in the reflectance the discontinuity should cancel. If only the irradiance is mitigated here, the discontinuity is introduced in the reflectance. The radiance calibration and the impact of the irradiance mitigation on the reflectance needs to be discussed here.	
Conclusions p 25, l 434/ 436: p 25, l 449	'v1' / 'v2' change to 'version 1' / 'version 2', radiometry -> radiometric	Adapted.
References	Many references contain both the the DOI based URL and a direct URL. Only the DOI URL as permanent URL is needed, skip the second URL (which is also not added consistently...).	Corrected.
References	For Ingmann et al. The URL is erroneous	Corrected.

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

Item	Change
	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.”
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.”

Item	Change
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 ±1 ◦ 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.
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."

Item	Change
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."
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.

Item	Change
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
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	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 $\times 10^{-4}$. This

Line number Fig/Table (version1/version2)	Original (version 1)	Update (version 2)
	the order of ×10 −4 , this is an order of magnitude better than what was achieved with the on-ground data."	result is an order of magnitude better than what was achieved with double processing of the CKD derived from on-ground calibration data."