

Interactive comment on “Quantification and mitigation of the impact of scene inhomogeneity on Sentinel-4 UVN UV-VIS retrievals” by S. Noël et al.

S. Noël et al.

stefan.noel@iup.physik.uni-bremen.de

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Reply to referee 1

We thank the referee very much for the overall positive and helpful comments. We have taken all the comments of the referee into account in developing our revised version of the manuscript.

Answers to specific comments:

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1. *Section 1. The following paper provides a nice and reasonably complete overview of the Sentinel-4 UVN instrument. Consider to add this reference. Ahlers, B. et al, "GMES Sentinel-4/UVN instrument concept and calibration approach", 20th CALCON Technical Conference proceeding, Logan, Utah, USA, 29 August – 1st September 2011.*

We will include this reference and also provide some more background information about UVN in the introduction.

2. *Page 2045, line 12: The wavelength shifts in OMI are reported to be up to 0.5 spectral pixel, which corresponds to 0.07 nm in UV2 and 0.10 nm in VIS. This shall be corrected.*

This is corrected.

3. *Page 2046, lines 5-12: Explain in more detail what the UVN instantaneous field of view is, how it scans from east to west over 8 km in about 6 seconds and what the convolution of the 2 looks like, since this is important to understand the impact of scene inhomogeneity of instrument spectral response.*

The typical UVN ground sample size is 8 km × 8 km. The spatial response function of the UVN instrument in east-west direction is shown in Fig. 1, giving the sensitivity of the instrument to light coming from different directions / spatial distances relative to the centre of the observed scene. As can be seen from this figure, the spatial response function is in the UV-VIS of trapezoidal (almost rectangular) shape with a full width at half maximum (FWHM) of about 8 km. During one integration time (about 6 s) the instantaneous field of view (IFOV) is moved about 8 km from the east to the west by the scan. By this the spatial response function is smeared, resulting in an almost triangular shape (but with similar FWHM).

This is added to the manuscript appropriately.

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4. Page 2049, lines 21-28. The description on how the OMI spectral assignment and calibration works is incorrect and shall be corrected. For OMI the situation is as follows:

- There are two independent algorithms: one for spectral assignment and one for spectral calibration. Both algorithms are operational at any time.
- The spectral calibration fits the solar Fraunhofer lines much in the way as described, using the wavelength-dependent spectral response functions for homogeneous illumination.
- The spectral assignment is based on a fixed set of polynomials per ground sample (providing a wavelength per pixel) and correction parameters to these polynomial parameters for optical bench temperature dependence and non-homogeneous illumination of the instrument entrance slit. The scene inhomogeneity is measured / derived from measurements with higher spatial (temporal) sampling at specific wavelengths. The mentioned polynomial correction parameters are derived from comparing the in-flight spectral assignment and spectral calibration data.
- Both algorithms have their own advantages and disadvantages: The spectral calibration is more accurate, but may fail in case of low input fluxes. The spectral assignment is more robust.

Many thanks for this detailed information. The corresponding section accordingly now reads as follows:

For OMI, there are two independent algorithms: one for spectral assignment and one for spectral calibration. The spectral calibration is determined for a number of irradiance spectra obtained at a reference temperature of the optical bench. This is done by fitting a reference solar spectrum to the measured irradiances. The spectral assignment is based on a fixed set of polynomials per ground sample (providing a wavelength per pixel) and correction parameters to these polynomial

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parameters for optical bench temperature dependence and non-homogeneous illumination of the instrument entrance slit. The scene inhomogeneity is derived from measurements with higher spatial (temporal) sampling at specific wavelengths. The polynomial correction parameters are derived from comparing the in-flight spectral assignment and spectral calibration data.

The wavelength calibration algorithm used in the present study is in fact very similar to the OMI spectral calibration in the sense that in both cases absorption features are fitted to the measured spectra. However, in the present case the spectral calibration fit is applied to each individual radiance and irradiance spectrum without sub-pixel knowledge instead of using a-posteriori corrections.

5. Page 2050, lines 11+12: Explain why the radiance and irradiance wavelength grids are usually slightly different.

Reasons for different wavelength grids are different Doppler shifts resulting from different viewing directions, small thermal changes of the instrument between the measurements or potentially slightly different illumination conditions (as addressed in the present paper). This is now explained in the text.

6. Page 2050, lines 20-22: Clarify that the high sampling interpolation method is used in 1-2 data processing.

The high sampling interpolation method is used to determine reflectances out of radiances and irradiances. These are then later used in the error mapping. Note that no 1-2 retrieval is performed, only an error mapping. We will clarify this in the text.

7. Section 2.5. There are almost no details on the used 1-2 retrieval techniques. One major deficiency in the paper (that needs to be improved): It needs to be better explained to what extent observed errors are originating from spectral errors in the level-1b data or from the used algorithms for the 1-2 retrievals. This is not as black and white as currently suggested by the paper.

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Section 2.5 has been rewritten to explain this in more detail. The updated text reads as follows:

The information content and error analysis approach is based on the Optimal Estimation retrieval scheme and performance assessment (see e.g. Rodgers, 2000). Optimal estimation combines the information from the measurement with a-priori information of the parameter to be retrieved.

Instead of a full retrieval, an error mapping is performed. We assume a moderately linear problem (i.e. neglecting non-linearities) to determine the errors. The formulas for this approach are given in Appendix C. As a-priori state, the simulated state of the atmosphere is used. The linearisation of the forward model is performed around this a-priori state. The forward and instrument model is used to simulate the a-priori radiance. Here, the instrument model is assumed to be insensitive to the inhomogeneity of the scene, i.e. we simulate a homogenous illumination of the slit and use the homogeneous ISRF to calculate the spectra from the mean radiance of the scene. The inhomogeneous ISRFs are then used in the instrument model to determine how the measurement of the radiance is disturbed by the inhomogeneous illumination of the slit. The difference between the erroneous radiance and the true radiance is then mapped to a difference between the true state (which is also the a-priori state) and the state a retrieval would determine from the erroneous radiance. This difference estimates the size of the systematic error we get from the inhomogeneous illumination of the slit and therefore from the inhomogeneity of the scene.

The systematic error would appear in a retrieval as a bias. The precision of an optimal estimation retrieval is determined by the covariance of the radiance measurement (i.e. the noise) and constrained by the a-priori covariance. In this manuscript emphasis is placed on the minimisation of the systematic errors.

In the error mapping model, four trace gases are considered: O₃ (fitting window

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305–330 nm), NO₂ (405–500 nm), SO₂ (308–325 nm), and HCHO (337–360 nm). For all quantities, the profiles of the scenario as specified in Tables 1 and 2 are used as a-priori with an associated error of 50 %.

Note, that the error mapping is always performed for only one of the trace gases. It is assumed in the analysis, that the atmospheric state is perfectly known for all parameters except the retrieved one. Potential impacts of scene inhomogeneity on other retrieval parameters are not considered in the context of the present study. The only instrumental effect taken into account is the inhomogeneous illumination of the slit. A small error for a geophysical parameter resulting from a single instrumental error does not necessarily mean that this parameter can be retrieved with the estimated error. A full error budget needs to be built up for all instrumental limitations, including errors, introduced by the imperfect knowledge of cloudiness, surface albedo or aerosol loading. Since such an error budget would depend on the actual retrieval method it is beyond the scope of the current study.

8. *Section 3. Explain how big the observed UVN spectral shifts are (that lead to the quoted results at level-2).*

Spectral shifts are different for each scene and also depend slightly on wavelength. The mean spectral shift for all scenes is close to zero, i.e. positive and negative shifts cancel on average. The mean absolute shift is about 0.005 nm, the maximum absolute shift is about 0.04 nm.

This is addressed in the text.

9. *Section 4: The conclusions are rather qualitative, where the paper itself presents many quantitative results.*

Line 7: "significant tropospheric column errors". How significant?

Line 10: "largely reduced". By how much?

Line 11: "good measure". How good?

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We will quantify the tropospheric column errors (about 5% mean error, 50% maximum error) and also the error reduction due to spectral calibration (up to a factor of about 10 for the mean error, resulting in mean errors well below 1%). Especially, we will also mention in both the conclusions and the abstract the standard deviation of the errors (up to 8% before, 1.5% or less after wavelength calibration), as this is a measure for the additional uncertainty of a derived product introduced by the inhomogeneous illumination conditions. The quality of the reflectance ratio as a measure to characterise inhomogeneous illumination can not be easily quantified, as there is no reference measure for inhomogeneity. Therefore we will mention the correlation between the derived errors and the reflectance ratio (correlation coefficient ± 0.7) in this context.

10. *Page 2054, lines 17-24: This paragraph is not understood and not in line with the rest of the paper, i.e. it comes a bit out of the blue. Since these conclusions seem to make sense, this means that this paragraph has to be better introduced (in the paper, not in the conclusions) and explained:*

- *Applying spectral calibrations with the homogeneous ISRF mitigates nearly all problems associated with inhomogeneous scenes. Why then is it still necessary to calibrate the inhomogeneous ISRFs?*
- *It is my understanding that the spectral calibration uses only the homogeneous ISRF. Is this correct? How are then the inhomogeneous ISRFs used? The above needs to be taken into account. Maybe I misunderstood something, but then this needs to be clarified.*

In the context of the present study the inhomogeneous ISRFs are only used to derive representative radiances from inhomogeneous scenes. In the spectral calibration and the error mapping only the homogeneous ISRFs are used. For the simulations described here this is sufficient to significantly reduce the errors of the tropospheric columns. However, the characteristics of the real instrument, which

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will be determined during on-ground calibration, will probably differ from the ones assumed in this study. Another aspect is that the actual retrieval method used to determine the tropospheric columns (in contrast to the simple error mapping approach used in the present study) might introduce additional uncertainties, e.g. due to limited knowledge of surface albedo or cloudiness and the inhomogeneity of these quantities over the observed scene. Therefore it is recommended to repeat this analysis once the real instrument properties are known. If in this case the spectral calibration will turn out to be less efficient, additional mitigation strategies need to be considered. One of these strategies could be to estimate inhomogeneous ISRFs for a specific scene based on sub-pixel information obtained in-flight during the scan. These estimated ISRFs could then be used in the retrieval instead of the homogeneous ISRFs.

We will add a paragraph in section 3 explaining these issues a bit more and also reformulate the conclusions accordingly.

Answers to Technical corrections / minor points:

11. *Page 2044, lines 24+25: "... will be homogeneously illuminated, ...". Clarify that homogeneously applies to the entrance slit dimension that affects the spectral resolution, i.e. the slit width.*

Inhomogeneous illumination occurs in principle in both directions of the slit (spectral and spatial). However, in the present case we indeed concentrate on the effect of inhomogeneous illumination in the spectral direction. This is possible, because the UVN UV-VIS band has been designed such that there is almost no smile, i.e. (i.e. no variation of spectral calibration in spatial direction). We will clarify this in the text.

12. *Page 2044, line 25: slit function refers to spectral response function, or spectral response function in the spectral domain. Consider to clarify this once or twice at the beginning of the paper, like here.*

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Will be done.

13. Page 2045, line 28. Explain acronym MTG the first time it is used.

Will be done.

14. Page 2046, line 5: Consider to change to "The typical UVN ground pixel size is 8 km x 8 km, which is considerably smaller than currently operational similar earth atmosphere observation instrumentation in low-earth orbits".

Will be done.

15. Page 2049, line 11: Typo "ration".

Will be corrected.

16. Page 2050, line 3: Consider to change to "... in both cases solar Fraunhofer absorption features are filled to the measured spectra."

The spectral calibration of radiances described in the present paper uses both Fraunhofer lines and atmospheric (ozone) absorption features. Therefore we will stick to the original formulation which is more general.

17. Page 2052, line 20: Consider to change to "With spectral calibration with instrument spectral response function for homogeneous illumination the errors ...".

Will be done.

18. Page 2054, line 5: tropospheric O3, NO2, SO2, HCHO.

Will be changed.

Interactive comment on Atmos. Meas. Tech. Discuss., 5, 2043, 2012.

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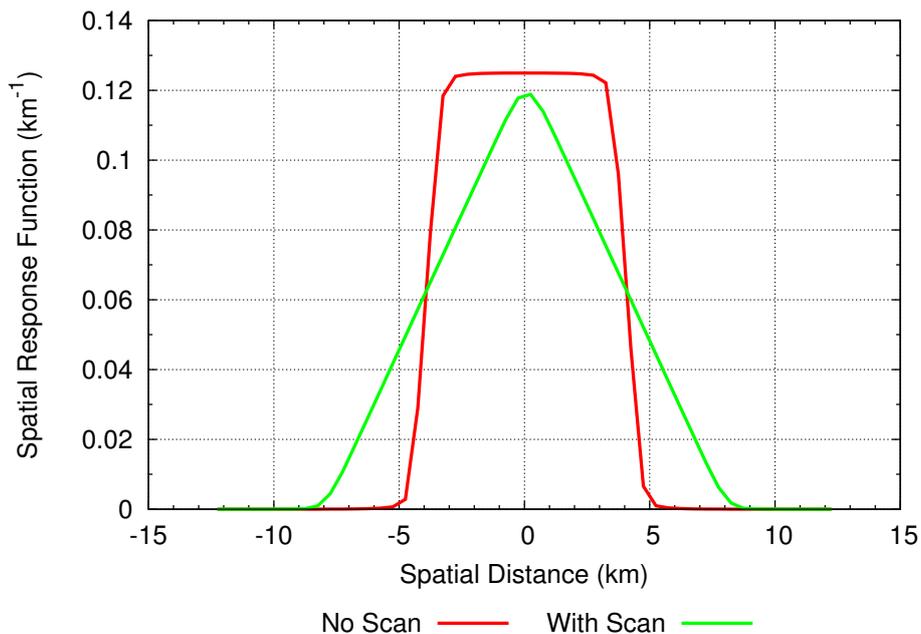


Fig. 1. Normalised spatial response function for the UV-VIS in east-west direction in ground coordinates. Red: Without scan. Green: With scan.

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