RESULTS OF A NEW STRAYLIGHT CORRECTION FOR SCIAMACHY

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ABSTRACT

In this paper, we present first results of a new straylight correction algorithm for SCIAMACHY, to be implemented in the operational Level 0-to-1 processing software. A re-analysis of the on-ground calibration data (Calibration Keydata) is currently on-going at SRON. We present interesting graphical results from this re-analysis activity, and show the improvement of the new straylight Keydata, coupled to a new straylight correction algorithm, on atmospheric spectra measured with the SCIAMACHY instrument.

1. INTRODUCTION

SCIAMACHY is a medium-resolution UV-VIS-NIR grating spectrometer, fed by a small telescope behind a scan unit which enables across-track scanning in Nadir and Limb, as well as sideways viewing for solar occultation and for calibration measurements of Sun and Moon. The scan unit employs mirrors for atmospheric and lunar observations, but also contains diffusers for solar measurements. The spectrometer contains 8 optical channels, which focus the spectrum on linear detector arrays of 1024 pixels each.

SCIAMACHY has been designed with stringent requirements on straylight in mind. Nevertheless, straylight needs to be corrected to reach the very high signal to noise ratios required for the retrieval of weak tracegas absorbers in the Earth's atmosphere.

Straylight may be described as a redistribution of input light at each wavelength, to all detector pixels in the instrument - in this case 8x1024=8192 pixels. Early in the design phase for instrument calibration, it was considered to deliver the full 8192 x 8192 straylight matrix as input to Level 0-to-1 processing. However, it quickly became clear that evaluating such big matrices for each measurement (typically 4 - 8 per second for each of 8 channels) is not feasible in operational processing.

The current straylight calibration concept of SCIAMACHY uses a simplified approach with two components [1]:

- uniform straylight, independent of the shape of the input spectrum
- a set of ghosts, where the straylight onto a pixel is derived from a limited number of input wavelengths
- cross-channel straylight is neglected, except for channel 1 where a broadband contribution from channels 2-5 is taken into account, and for a ghost from channel 7 into channel 8

Re-analysis of the on-ground calibration data, by SRON, confirms that in the current Calibration Keydata the level of uniform straylight was specified near the lowest straylight level in a channel (this to prevent negative signals after straylight correction). From another side, independent DOAS tracegas retrievals in the framework of the operational Level 1-to-2 verification, indicated that residual straylight levels up to a few percent may be present in calibrated SCIAMACHY data in channel 2 [2].

In this paper, we will present an overview of SCIAMACHY straylight properties based on on-ground calibration measurements. We present a preliminary straylight calibration algorithm for channel 2, and first results of Level 0-to-1 processing with the new straylight correction algorithtm.

2. ON-GROUND STRAY LIGHT MEASUREMENTS

Before launch, the SCIAMACHY instrument was carefully characterised under flight-representative thermal vacuum conditions. One of the types of measurements consisted of a wavelength scan using a double monochromator (having very low internal straylight levels) with linearly polarised light. Over the on-ground calibration period, many such scans were made, with a total of 4 different polarisation directions. The current stray light analysis was done using the total of these measurements.

Each scan was corrected for dark signal and memory effect, after which all measurements were added, on a common wavelength grid. After normalisation with the signal measured by SCIAMACHY, this resulted in an instrument response matrix on a grid of approximately 1000 input monochromator wavelengths, with a spacing of 1 to 2 nm, and 8192 output pixels (see Fig. 1).

The following features can be noted in the figure (see also Fig. 2 for more detailed views):

- there is no real uniform stray light, the level depends on the position of the parent peak
- channels 1 and 2 show smooth stray light behaviour, typical for holographic gratings. The ghosts in the other channels are mostly rowland ghosts, typical for ruled gratings with periodic errors resulting from the grating ruling machine
- a low level of stray light outside the channel where the monochromator peak falls

The following assumptions were made to arrive from the response matrix to a straylight matrix which is usable for instrument calibration:

- an arbitrary spectrum can be described as a weighted sum of the approximately 1000 input wavelengths between 240 and 2400 nm (neglecting wavelengths not measured by SCIAMACHY)
- cross-channel stray light is negligible (with the exception of channel 1 and a few discrete cross-channel ghosts coupled to different orders of the gratings in the infra-red channels)
- stray light behaviour varies smoothly with the pixel number within a channel, except for the ghosts
- based on instrument design considerations, ghosts are expected to be sharply focussed wavelengths

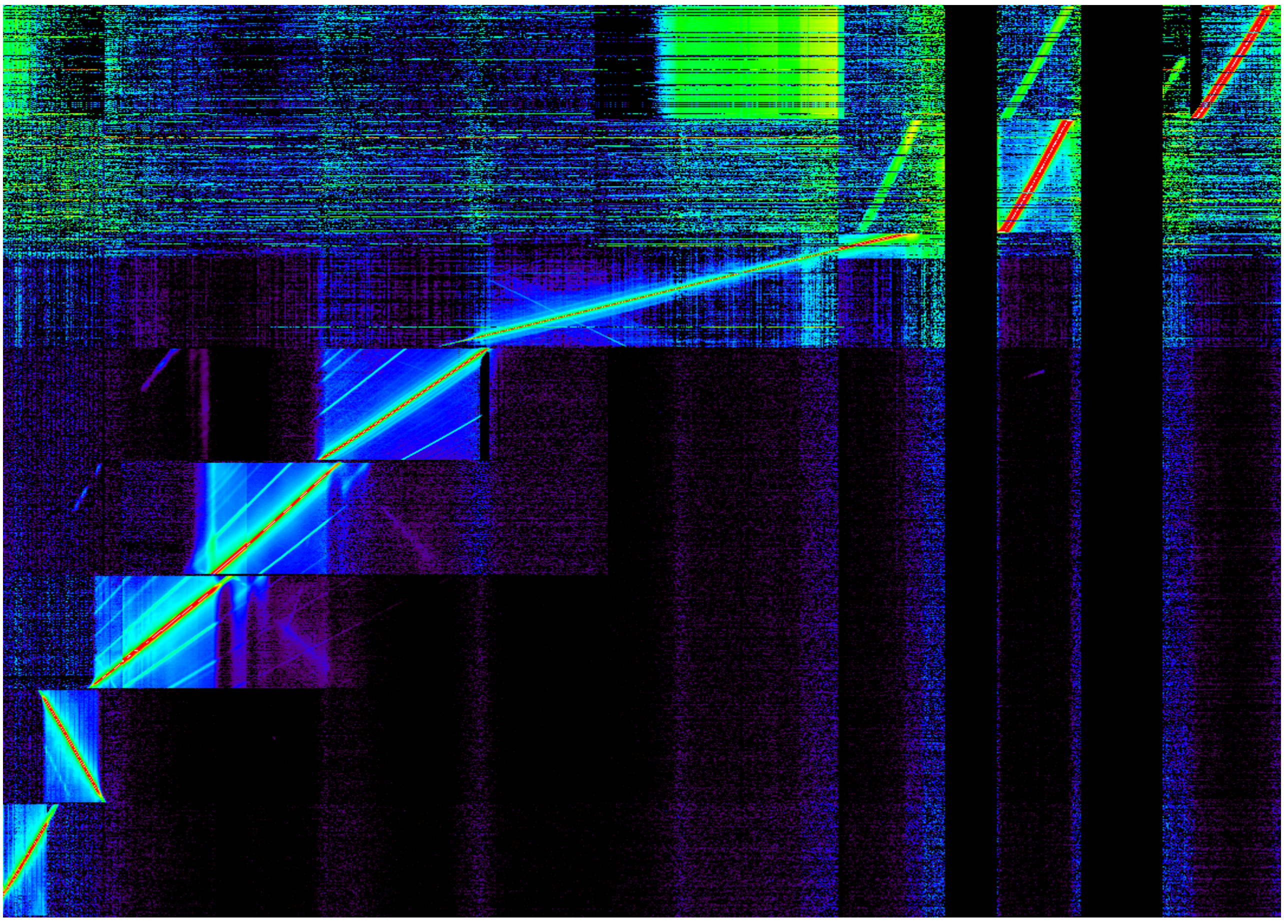

Figure 1: Preliminary instrument response matrix for Monochromator scans.
X-axis: input wavelength (240-2400 nm) Y-axis: detector pixel (8 x 1024).
The background correction in the NIR channels 6-8 (upper three blocks) needs improvement

(although this can not be readily seen at the monochromator resolution used)

- An upper cut-off limit for the stray light is set at the level where the contribution of the monochromator peak is negligible compared to the stray light. Any value in the matrix above this level is assumed to be direct light (contained in the instrument slit function) and the matrix value is set to zero.

The assumptions allow a reduced matrix description of the stray light within a channel. The wavelength parameter used as input for the full stray light matrix was converted to pixel positions using the wavelength

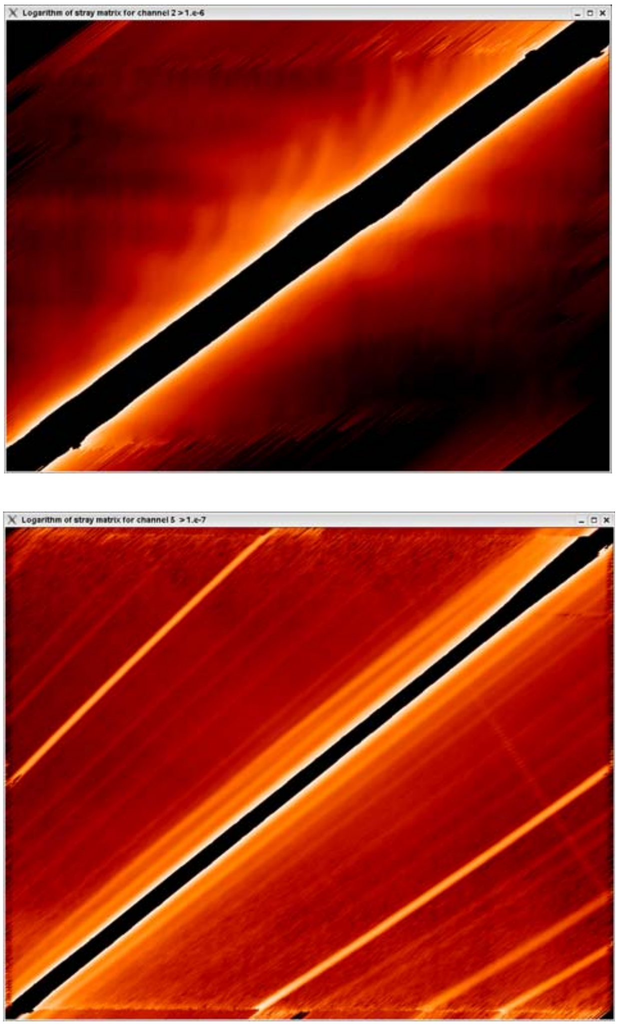

Figure 2: Straylight in channel 2 (upper panel) and channel 5 (lower panel).
The plot shows the logarithm of the 1024x1024 stray light matrix (truncated at the 1E-6 level for channel 2 and 1E-7 level for channel 5).
Each row (*,y) shows the straylight spectrum due to a unit input in pixel y. The region around the diagonal is defined as being free from straylight:
this is light contained in the slit function.

calibration polynomials for each channel, resulting in channel-specific stray light matrices of typically 100 input wavelengths and 1024 output pixels. These matrices were interpolated and smoothed to a 1024 by 1024 pixel grid. The stray light matrices cover all spectral stray light observed within the instrument. For modeling purposes, in particular for a reduced matrix allowing faster processing speeds, it is beneficial to separate the ghosts from the non-ghost stray light. A smooth stray light matrix can readily be reduced without losing too much information, while the sharply focused rowland ghosts are in principle delta functions for a given monochromatic parent wavelength, which would suffer from a reduced matrix approach.

Fig. 2 shows the stray light matrices for channels 2 and 5 as derived from the on-ground stray light calibration measurements (note that these matrices describe the transpose of the matrix in Fig.1). This illustrates the difference between holographic (channel 2) and ruled (channel 5) gratings. Holographic gratings show no rowland ghosts [3], while ruled gratings may show many ghosts at wavelengths which obey the equation:

$$\lambda\_ghost = \lambda\_parent * (1 + N * \alpha) \qquad (1)$$

where λ_parent and λ_ghost are the wavelengths of the parent peak and the ghost, N is an integer value which may be negative, and α is a number which is coupled to a periodic ruling error (or different order) of the grating, of which several different ones may be present. When viewed as a wavelength versus wavelength plot, the rowland ghosts should lie on lines which all pass through the origin, but when regridded to an arbitrary pixel grid the ghosts do no longer line up perfectly and curvature may exist if the projection of wavelength on pixel grid is not strictly linear, which is the case in SCIAMACHY. .

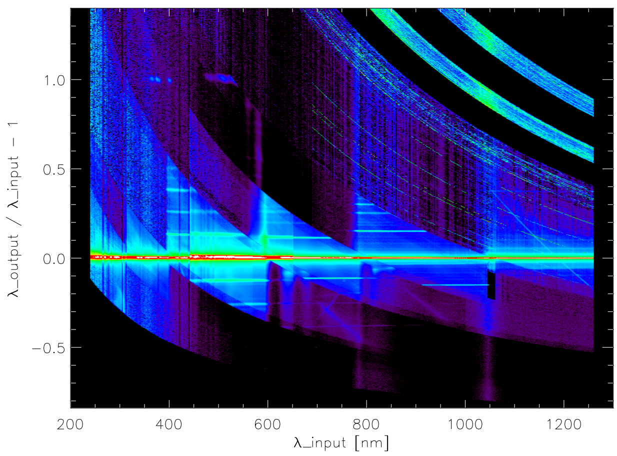

Figure 3: SCIAMACHY response matrix, plotted as N$*\alpha$ from Eq.(1) versus input wavelength

Using the SCIAMACHY wavelength calibration and expressing wavelengths as a fraction of the parent wavelength, the SCIAMACHY response matrix transforms to that shown in Fig 3. Straight horizontal lines represent constant values for N∗α, with the parent peak having N∗α = 0 by definition

A few focused ghosts exist which do not follow the rowland ghost behaviour. These ghosts are most likely bright rowland ghosts which are specularly reflected off vertical sections of the detector housing as the rowland ghosts walk out of the channel, and get project back onto the detector.

Careful investigation of Fig. 3 reveals that the ghosts do not fall on perfectly straight lines. This is because some of the dispersion in SCIAMACHY is obtained by the pre-disperser prism, which adds an extra dispersion term to the large dispersion obtained by the gratings. Jumps of the lines between channels are the result of the different ruling errors for the gratings in the various channels.

3. IMPLEMENTATION IN OPERATIONAL LEVEL 0-TO-1b PROCESSING

As mentioned in the Introduction, using the full 8192 by 8192 straylight matrix as input to operational Level 0-to-1 processing is not feasible, due to run-time considerations. But even the use of eight 1024 by 1024 matrices (neglecting cross-channel straylight) would increase the processing time by a factor of 10 compared to the current time required for straylight correction - which is a very significant part of the total Level 0-to-1b processing time.

Depending on the processing speed allowed by the SCIAMACHY data-processor, these matrices may have to be reduced to approximately 300 by 300 pixels. A problem here is how to handle sharply focussed ghosts.

The implementation of the new straylight algorithm will start with channel 2, which is currently the most important channel for deriving the operational Level 2 data-products from the UV-VIS region. This channel has no ghosts, and therefore the interpolation to a reduced matrix is in principle straightforward.

To test the sensitivity of the reduction process in channel 2, we selected the crudest possible method of taking every third pixel in the measurement as input, and every third value in the straylight matrix.

After calculating the straylight on the 330 pixel grid, linear interpolation was used to obtain the straylight for the full resolution (the latter interpolation needs only be done for the pixels in the cluster actually read out; but as input spectrum the full wavelength range must be taken or extrapolated - as routinely done in the current straylight algorithm [1]).

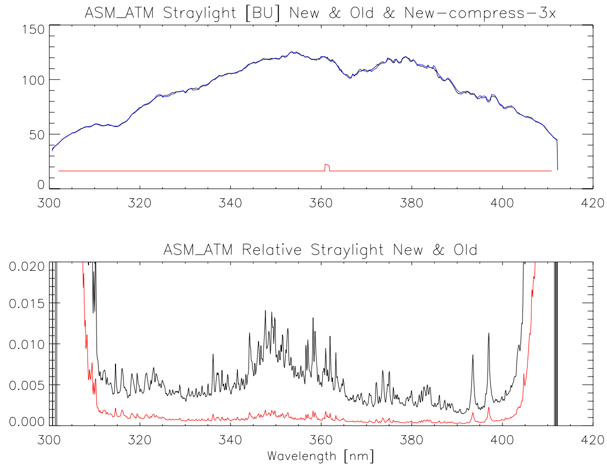

Figure 4: Straylight in channel 2, calculated by the old algorithm (red), and by the new algo with 1024x1024 matrix (black), or with reduced matrix (blue). Upper panel: absolute straylight level Lower panel: straylight-to-signal ratio

The results of this crude reduction method were compared to results using the 1024 x 1024 matrix, and to results obtained with the current operational algorithm.

Fig. 4 shows the straylight comparison for channel 2, for one of the measurements described in Section 4. There is very little difference between the 1024x1024 matrix and the reduced matrix. However, both yield up to an order of a magnitude more straylight than the current method. Fig. 4b shows that the new straylight now reaches the 1% level, in accordance with the result from [1].

4. ALGORITHM VERIFICATION

4.1 Straylight in Solar measurements

Straylight has been verified using a special SCIAMACHY measurement state, where the Sun is observed through the Earth's atmosphere, but with the ASM diffuser in the light path. The diffuser ensures a complete filling of the instrument slit, as in Nadir and Limb observations (Solar occultation measurements usually have a small aperture which only illuminates the centre of the slit). In these measurements, the atmosphere acts as an UV cut-off filter, thereby enlarging the straylight-to-signal ratio at short wavelengths.

The measurements start with the Sun low in the atmosphere (strong UV cut-off) and follow the Sun as it rises above the atmosphere. Fig. 5 shows results of two measurements in the atmosphere, ratio-ed with a measurement of the Sun above the atmosphere - this gives the slant path atmospheric transmission

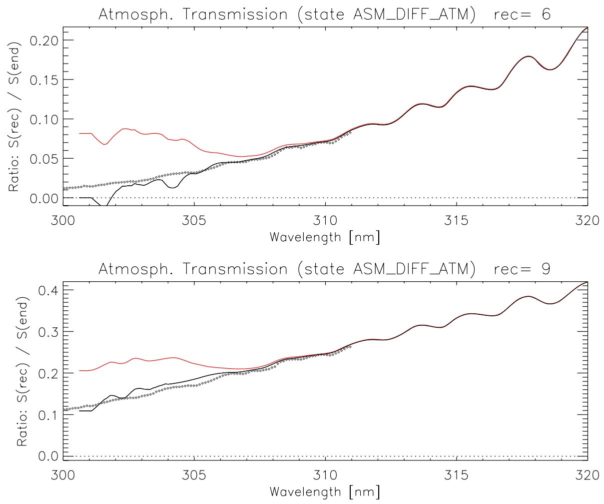

Figure 5: SCIAMACHY atmospheric transmission spectra, at the beginning of channel 2.
Red: current operational algorithm, Black: new algorithm. Dots: data from channel 1 overlap. Upper panel: strong UV cut-off (Sun low in atmosphere), Lower panel: moderate UV cut-off

Fig. 5 shows the atmospheric transmission at the beginning of channel 2, calculated with the currently used straylight (red curves) and the new straylight (black). As reference we show also data from the overlap in channel 1. In this channel, the instrument transmission (and thus signal-to-straylight ratio) is higher near 300 nm than for channel 2; moreover the current straylight correction is quite reliable there.

The figure shows that the new algorithm yields a substantial improvement over the currently used one. There just may be a slight overestimation of the straylight for the case with strong UV cut-off (Fig.5a) and a slight underestimation for the case of moderate UV cut-off (Fig.5b), compared to the channel 1 results.

4.2 Results from Level 2 processing

Ozone column retrievals have been carried out for one orbit of data, on SCIAMACHY Level 1b products generated with the current and with the new straylight correction. The results show that in the Ozone fitting window (325-335 nm) the fitting errors are slightly smaller with the new straylight correction than with the current operational one, see Fig.6 (the improvement ranges from ~1-15%). However, more work is needed to analyse the impact on level 2 processing, especially for the weaker trace gases.

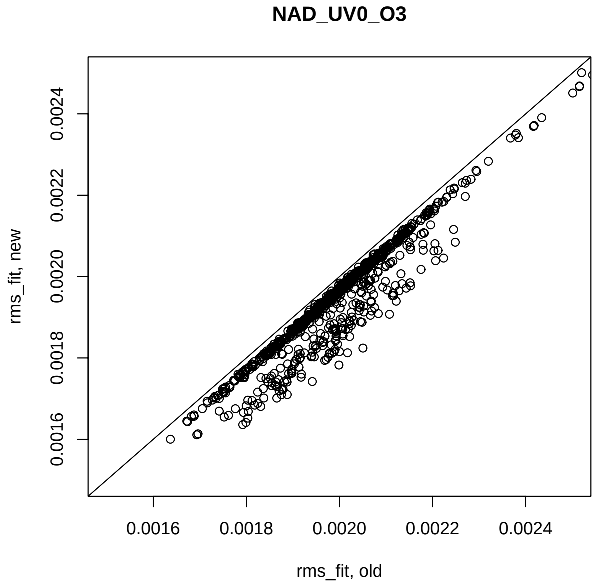

Figure 6: Comparison new versus old of the RMS fitting errors for Ozone retrieval from SCIAMACHY, using L1b data generated from new and current straylight algorithm

5. CONCLUSIONS

We have presented results from the re-analysis of the on-ground calibration Keydata for straylight correction. This provides an interesting insight in the SCIAMACHY stray light properties. Test with a new operational algorithm, based on the new calibration, show a significant improvement in straylight calibration.

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6. REFERENCES

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