SCIAMACHY MONITORING FACTORS: OBSERVATION AND END-TO-END CORRECTION OF INSTRUMENT PERFORMANCE DEGRADATION

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ABSTRACT

SCIAMACHY (SCanning Imaging Absorption spectroMeter for Atmospheric CHartographY) is a grating spectrometer in the UV-Vis-NIR spectral range. SCIAMACHY is part of the ENVISAT payload and since April 2002 in a sun-synchronous orbit, observing Earth's atmosphere in nadir, limb and occultation geometry. To ensure the SCIAMACHY data quality over the life-time of the instrument, its performance is continuously monitored. The throughput of the instrument is monitored end-to-end by regular observations of the sun. From these measurements, the so-called monitoring-factors (m-factors) are calculated. Each light path of the instrument has its own set of m-factors. By applying the m-factors, a stable radiometric calibration of the radiances and irradiances from SCIAMACHY over mission lifetime can be ensured.

We describe the measurements, the calculations and the operational implementation of the m-factors. Based on the m-factors, the performance of the SCIAMACHY over seven years in orbit is assessed. Furthermore, first examples will be shown how the retrieval of atmospheric parameters benefits from m-factors.

Key words: SCIAMACHY; m-factors; degradation; monitoring.

1. INTRODUCTION

SCIAMACHY [1] is now seven years in orbit, exposed to the space environment. As already known from experience with the SCIAMACHY's precursor Global Ozone Monitoring Experiment (GOME), the performance of the instrument is degrading with time [2]. Main degrading components are the mirrors in the optical path of the instrument. SCIAMACHY has got to mirrors: one is mounted on the elevation scan mechanism (ESM), used for horizontal scanning in nadir mode and the vertical movement in limb and occultation mode. The other mirror is on azimuthal scan mechanism (ASM), which controls the horizontal movement of the line of sight in limb and occultation mode. These two components dominates the throughput loss of the instrument in the UV. SCIAMACHY's NIR channels 7 and 8 suffer from an ice layer growing on the detectors itself, rapidly reducing the throughput of these channels. Decontaminations by heating these detectors remove the ice-layers. However, after cooling down the detectors to their working temperatures, the ice layers start growing again. After the decontamination in January 2005, the ice layer stabilized. In January 2009, the last decontamination took place, driven by the need to decontaminate the radiant cooler.

An end-to-end degradation correction (the so-called monitoring factors: m–factors) has been foreseen for all SCIAMACHY L0-L1b processors so far [3], but were not used (the m–factors were always set to 1.0). In the upcoming version 7 of the Level 0-1b, for the first time m–factors are calculated for the operational system. They are not (yet) directly fed into the L0-1b processor, but used in L1b-2 processor for dedicated products (section 3 and 5).

2. MONITORING MEASUREMENTS USED FOR M–FACTORS

Fig. 1 shows a schematic view of SCIAMACHY's light paths and the measurements monitoring these paths. The light path via the ESM mirror used for SCIAMACHY's nadir measurements can be monitored using the on-board white light source (WLS) or observing the sun via the subsolar port. Subsolar measurements are performed in fast sweep and pointing mode. Until October 2005, the fast sweep measurements were the default measurement for monitoring the nadir light path. This measurement

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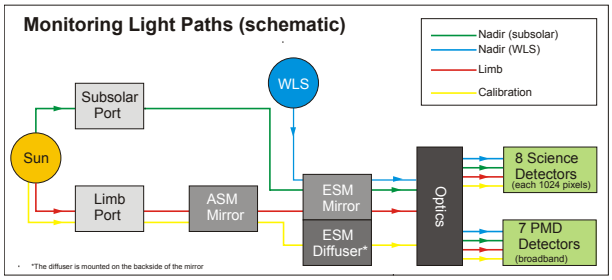

Figure 1. Schematic view of SCIAMACHY's monitoring light paths.

type was part of the daily calibration. However, the results for monitoring the polarization measurement devices (PMD) were not reliable. Therefore, it was decided to use further on the pointing mode of the subsolar measurements. The pointing mode is now performed every three days, whereas the fast sweep mode is done in the monthly calibration instead.

Until December 2002, all subsolar measurements failed because of a timing problem in the mission planning. The WLS is used for this part of the mission. However, the WLS is degrading (mainly in the UV) and it cannot be used as a longterm stable light source.

The limb light path via ASM and ESM mirror is monitored using the solar occultation measurements. The calibration light path via ASM mirror and ESM diffuser is monitored using the nominal solar diffuser measurements. Fig. 2 illustrates the usage of the monitoring measurements.

2.1. Calculating m–factors

M-factors as end-to-end throughput loss correction uses as completely as possible calibrated monitoring states. In this section, we briefly describe the steps of the m–factor calculation [4].

The solar measurement via the ESM diffuser is the nominal solar measurement, which provides a fully calibrated solar irradiance spectrum. The WLS, the sub-solar and the occultation measurements are only pseudo-calibrated, e.g. the intensity values are not in absolute units but the scan angle dependence is correctly represented. From the individual readouts of the monitoring state a mean spectrum is calculated.

Solar measurements show variable Fraunhofer lines (Mg II and Ca II), which have to be masked out by interpolating these parts of the spectrum from adjacent, undisturbed detector pixels. The solar spectra are normalized for sun–earth distance. The spectra are smoothed in spectral direction (triangular smoothing over 9 pixels) to avoid artificial differential structures introduced by ratioing two (fine structured) solar spectra.

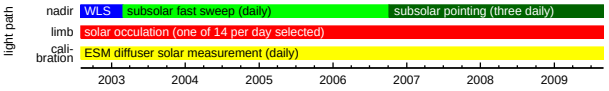

Figure 2. Usage of monitoring measurements for SCIAMACHY's light paths.

The "simple m-factors" $M(d)$ for day d with reference day d_0 are calculated by:

$$M(t) = S(d_0)/S(d) \quad . \tag{1}$$

For the simple m–factors, the reference day 27-Feb-2003 is chosen, because all types of measurement are available for that day. The following steps lead to the final m–factors, for which the reference day is moved to 02-Aug-2002 (begin of nominal measurements).

The three time series for the nadir light path have to be combined: the m–factors of the continuing time series is assumed to be equal to the ending time series at the day of glueing. WLS and sub-solar fast sweep are glued 27-Feb-2003, fast sweep and pointing 05-Oct-2006 (Fig. 2).

For each of the three light paths, the m–factors are interpolated onto a daily grid: If a measurement is available for that day, it is used, otherwise the adjacent measurements are used for an interpolation. If SCIAMACHY was not in nominal state during a monitoring measurement, this measurement is not used and marked as unavailable.

The detector temperatures have been changed in February 2002 to the final settings, which corresponds to the settings assumed for calibration key-data. Therefore, a quantum efficiency correction for the reference day 02-Aug-2002 is necessary for channel 5 and 6, which are sensitive to small temperature changes. This means, the m–factor for the reference day is not 1.0 for these channels.

M–factors M shall be multiplied to the calibrated spectra S_{cal} to get throughput corrected spectra $S_{\mathrm{cal,mf}}$:

$$S_{\mathrm{cal,mf}} = S_{\mathrm{cal}} \cdot M \quad . \tag{2}$$

A detailed description of the calculation can be found in a technical note [4], available from the m–factor webpage [5].

3. M–FACTORS IN THE OPERATIONAL PROCESSING

The upcoming operational processor system is the combination of the L0-1b version 7 and the L1b-2 version 5 processor. Fig. 3 is a sketch of the data flow in SCIAMACHY's forward processing. SCIAMACHY's raw measurements are stored as near-real-time (NRT) level 0 products. The L0-1b processor generates the L1b products, which contain the raw spectra and the geolocation

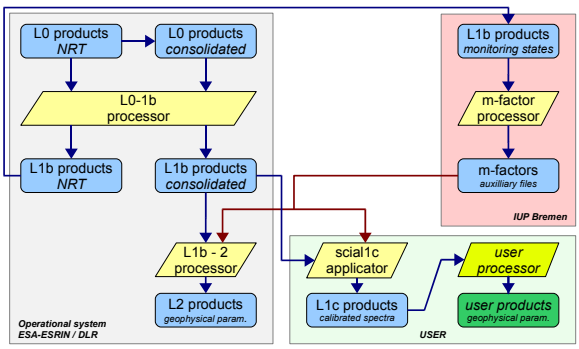

Figure 3. The data flow in SCIAMACHY's forward processing in L0-1b version 7 / L1b-2 version 5.

and calibration information. The monitoring states of the NRT L1b products are used by the m–factor processor to calculate the m–factors.

In case of re-processing the whole mission, the monitoring states are processed prior to the complete dataset, so the m–factors can be calculated before re-processing.

The NRT L0 products are consolidated in the ground segment and processed by the L0-1b processor to consolidated L1b products. These are taken by the L1b-2 processor to derive the geophysical parameters. If the retrieval uses the absolute radiometric calibrated spectra, the m–factors can be used to correct for the instrument degradation. In version 5, this will be the case for the Aerosol Absorption Index (AAI) and the total ozone column.

Users developing there own retrievals can use the applicator *scial1c* to apply the m–factors [6]. The applicator calibrates the raw data in the L1b product with the accompanying calibration information to the so-called L1c products. With m–factors as additional input, the program can also perform the degradation correction. The actual L1b-2 processor uses the same source code as *scial1c* to apply the calibration and the m–factors.

4. SCIAMACHY THROUGHPUT MONITORING 2002 - 2009

The relative throughput of the instrument is the reciprocal of the m–factors. Fig. 4 shows the observed throughput for all channels and light paths.

The UV channels show the largest degradation. After 7 years in orbit, 40-70%, 30-50%, and 12-20% throughput loss in channel 1 are observed for the limb, nadir, and calibration light path, respectively. In channel 2, the values are 20-35%, 20-30%, and 15-18% throughput loss. Channel 3 and 6 show up to 10% throughput loss, whereas channel 4 and 5 show almost now degradation.

Channel 7 and 8 suffer from the varying ice layers on the

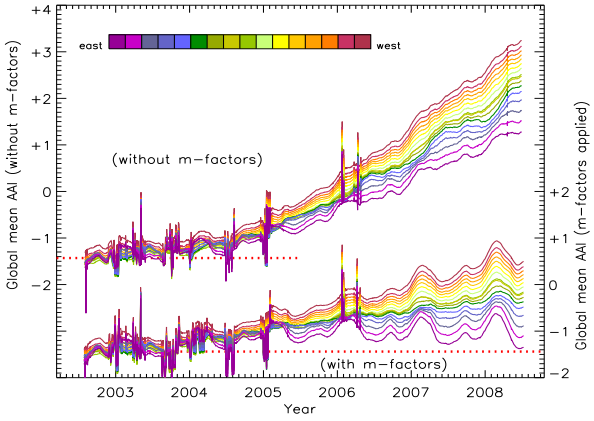

Figure 5. Global mean (SCIAMACHY) AAI with and without m–factors.

detectors, which were occasionally reduced by a decontamination (heating of the detectors).

In general, the limb light path shows highest degradation, followed by the nadir light path and (with lowest degradation) by the calibration light path. For limb, both mirrors are used. Nadir uses only the ESM mirror and the calibration light path uses only the ASM mirror. The ESM mirror degrades faster than the ASM mirror, because it is used most frequently.

5. APPLICATION OF M–FACTORS

5.1. Aerosol Absorbing Index AAI

Fig. 5 presents the global mean (SCIAMACHY) AAI [7] as a function of time, for each individual scan mirror position (indicated by the colors and the legend), for (i) the standard case without m-factors applied, and for (ii) the situation where m-factors have been applied to correct for the effects of instrument degradation. The global mean AAI for each individual scan mirror position was determined by averaging all AAI values of the respective day and the respective scan mirror position between 60°N and 60°S. Some smoothing was applied. The remaining outliers are in most cases related to instrument decontamination events.

Clearly, the standard case without application of m-factors shows a large increase in the global mean AAI as of the beginning of 2004. The initial value (of roughly -1.3 index points) has since then increased to a value of ∼2 index points (at July 2008), depending on the actual scan mirror position. The spread between the different scan mirror positions has increased from the initial zero spread to a spread of about 2 index points at July 2008, indicating that the instrument degradation shows a large scan-angle dependent component. The situation improves considerably when m-factors are applied. Now the increase found in the global mean AAI for July 2008

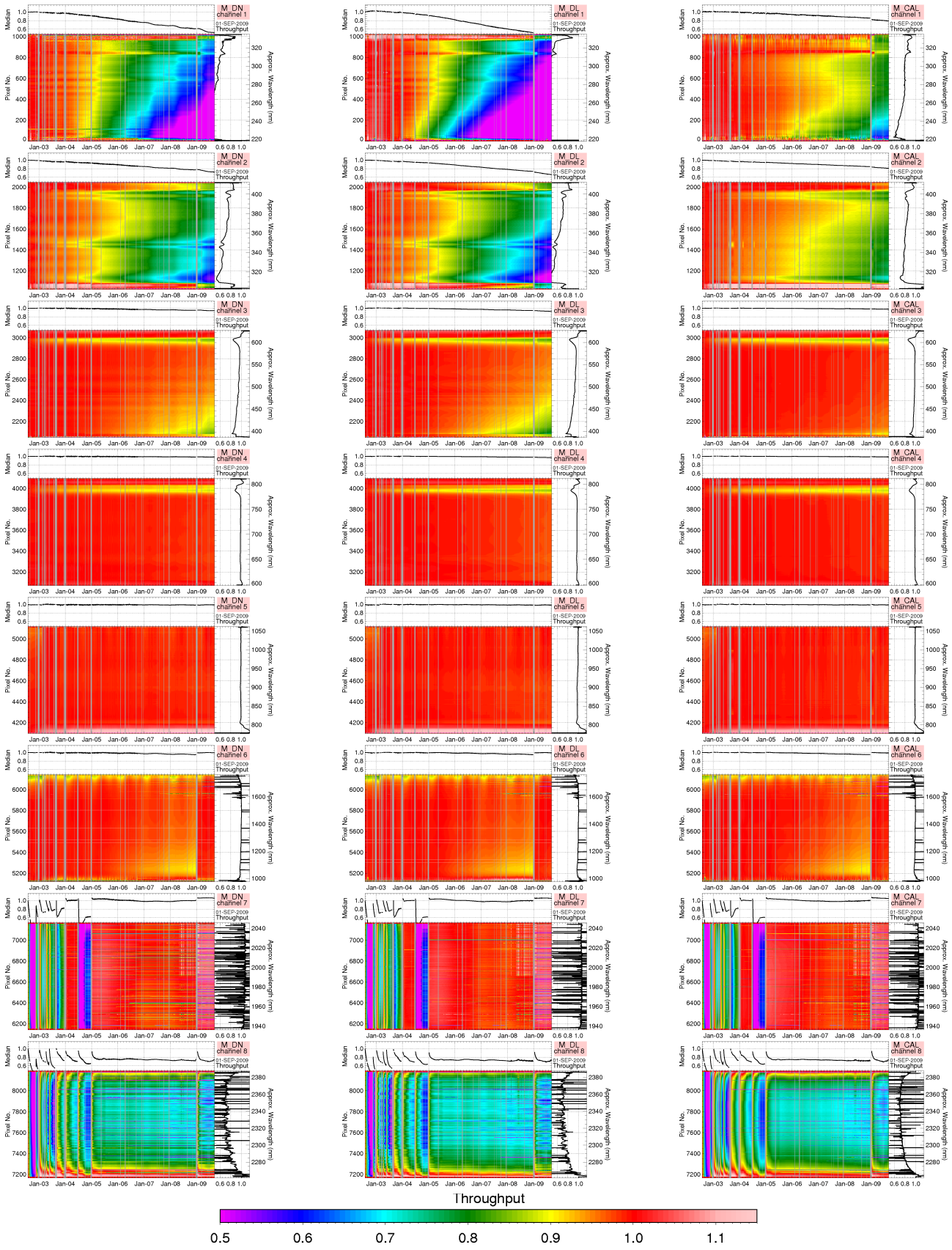

Figure 4. Visualization of SCIAMACHY's science channels throughput (the reciprocal m-factor) over time. Each individual plot has three panels: The colored area shows the spectrally resolved throughput. The top panel is the median of the channel throughput, the right panel gives throughput of the last available day. The vertical grey bars masks times of instrument unavailability. From ***left to right****: nadir, limb and calibration light path, from* ***top to bottom****: channel 1 to 8.*

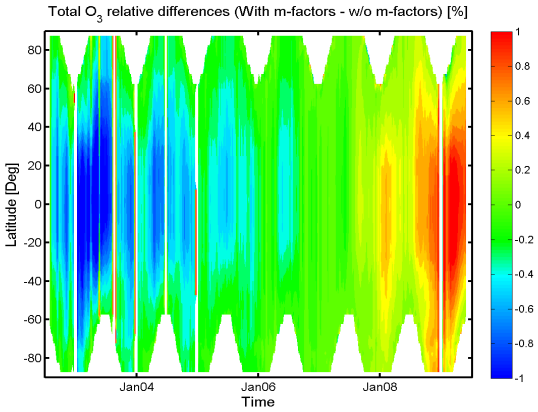

Figure 6. Difference in total ozone columns, retrieved with and without using m–factors.

lies somewhere between 0 and 2 index points, depending on the scan mirror position. Note that the m-factors are clearly better able to correct the east-viewing geometries than the west-viewing geometries.

This is because the scan-angle of sub-solar measurements (used for the nadir light path m–factors) corresponds to an east nadir view.

5.2. Total ozone column

For investigating the influence of m–factors on SCIAMACHY's total ozone product (a DOAS type retrieval [8]), two datasets have been calculated with the reference algorithm: One set without any degradation correction in the calibration of the spectra (as in version 3 of the Level 1b-2 processor), one with m–factors applied in the radiometric calibration (as it will be the case in the upcoming version 5). This is the only change between these datasets, although there will be additional improvements in version 5.

The difference between these two datasets (fig. 6) shows a clear trend from 2003 to 2009. The order of magnitude and the sign of the increasing difference is comparable to the differences observed for SCIAMACHY's version 3 ozone product with other measurements [8]. Thus, the degradation correction by m–factors will at least reduce the unexpected trend in SCIAMACHY's total ozone product.

6. CONCLUSION AND OUTLOOK

M–factors will ensure the quality of the radiometric calibration of the instrument over lifetime. They monitor end-to-end the throughput loss. For products relying on absolute calibration, they are necessary for a successful retrieval. M–factors are available and used for SCIAMACHY's operational processing environment in the upcoming L0-1b version 7 / L1b-2 version 5. Download of m–factors is possible from the m–factor homepage [5]. SCIAMACHY's Aerosol Absorbing Index and total ozone column both clearly benefit from m–factors.

However, m–factors will be further improved. The throughput loss is scan angle dependent (see fig. 5), a mirror degradation model to include this is necessary. M–factors for the PMDs are derived, there benefit for SCIAMACHY's polarization correction and PMD dependent cloud products is under investigation.

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