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Interactive comment on “In-Flight Calibration of SCIAMACHY’s Polarization Sensitivity” *by* Patricia Liebing et al.

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The paper by Liebing et al, investigates the capability of determining the in-flight evolution of the polarisation sensitivity of SCIAMACHY using two empirical model and one rigorous instrument system modelling approach. This is a quite extensive study and readers with less experience in satellite instrument calibration - and especially of those instruments which are sensitive to polarization - may find it difficult to digest. Here is my own, though limited, attempt to summarize the many detailed findings of the paper.

In order to address the observed deficiencies in characterising the in-flight instrument end-to-end response (here expressed in terms of Mueller Matrix elements, MMEs) of polarisation sensitive grating spectrometers like SCIAMACHY, the authors start off by evaluating two different strategies of using an empirical modelling approach for the SCIAMACHY nadir and limb scanner plus the optical bench module (OBM) common to both based on the observation of "depolarisation" (difference between the expected maximum degree of polarisation under a observed geometry and the measured one). This approach is used in order to establish an empirical relationship between observation geometry and the degree of polarization (involving the observation and/or derivation of q=Q/I and u=Q/I Stokes fractional parameters) based on the large SCIAMACHY measurement data-sets.

The first approach used for the nadir scan-system uses a RTM (Sciatran) to pre-calculate the maximum polarisation for a range of geometries covering all observation types and expresses the observed deviation from the modelled maximum values in a three-parameters empirical functional form for "depolarization". Using this functional form the maximum polarisation can be evaluated for all geometries by a fit to the real observations which are usual all depolarized to some extend (avoiding glint, glory and rainbow conditions). This establishes a relationship between observation geometries and maximum expected q,u Stokes values.

The second approach for the limb scan-system is a LUT relationship established between the degree of polarisation and the ratio of the real signal to the RTM for a given geometry and given q and u values provided by the RTM. This is established using the large limb data-set from SIAMACHY.

Both approaches provide q,u values as they should be observed by the instruments broad-band Polarisation Measurement Devices (PMDs) under (maximum) polarisation conditions and therefore allow the calibration of mu_P (the polarisation sensitivity party of the end-to-end MME of the instrument) values for PMDs, however not for the high spectral resolution main science channels (subscript D). For the latter the authors use a famous SCIAMACHY 350 nm polarisation feature, which is a hot spot of polarisation sensitivity of the grating for channel 2. For this feature a relationship of polarisation signal is established by using the ratio of observed signals to RTM ratios at 350 nm

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Discussion paper

and outside the feature at 370 nm, which allows to derive the expected mu_d values for science channels at 350 and 370 nm. The observation (san angle) dependence of both mu_P and _D is then parameterized in turn in a polynomial of second order.

In this way end-to-end MMEs for polarisation sensitivity can be established for the limb and the nadir scan-mirror systems plus the OBM, however limited to SCIAMACHY PMD 1 and 2 because of decreasing performance of the approach at higher PMD wavelength and to the 350 nm region of the main science channels.

The paper now moves on to compare these empirical model results to results from a scan-mirror optical model based on first optical principles as previously established by Krijger et al 2014 for SCIAMACHY. The latter is used together with the on-ground OBM MMEs to provide model output over the full SCIAMACHY lifetime for the end-to-end MMEs for PMD 1, 2 and the main channel at 350 nm.

For the nadir scan-mirror system the model reproduces mu2 and mu3 for the three cases quite well when compared to the empirical model results, with a tendency of the model to overestimate mu3 (which is generally increasing in time until approx. 2008) and a tendency of the model to underestimate the observed decrease of mu2 over the same time period, especially for the main science channel 2.

For the limb scan-mirror system the model deviations from the empirical end-to-end MME representation is larger than for the nadir case, with an overestimation of mu2 and an underestimation of mu3 for the whole time period.

The observed deviation are referred to a potential on-ground to in-orbit change of the OBM MME, with a focus on induced stress on the pre-disperser prism during launch, which indeed is usually observed to have changed with respect to on-ground, as observed in a shift of the main science channel overlap points with respect to what was measured on-ground for both the GOME/GOME-2 and SCIAMACHY instruments. Since stress on the pre-disperser prism already was expected to be critical for the instrument performance, the effect of induced stress on this optical component has been modelled before and is expected to result, apart from a shift in the channel overlap regions, in a phase shift inside the prism.

The authors therefore introduce a retarder model in addition to the OBM and scan mirror MMEs, which models a phase shift based on induced stress, and this retarder model matrix should apply in the same way to the limb and nadir scan-mirror system, i.e. it should improve both model results with respect to the empirical results at the same time. Therefor the authors attempt to minimize the difference between model and empirical model output by fitting the retardance and retarder angle assuming Gaussian distributed errors on the involved MMEs (which for end-to-end MME key-data is generally unrealistic, although attempts have been made in the past to provide such errors using Monte-Carlo simulations). It however turns out that only for the beginning years the retarder model can explain the deviations of the end-to-end MME in a similar way and at the same confidence level for both limb and nadir. Nevertheless the fitted retradance and retarder angle significantly improve the comparison between model and empirical model results, although the induced stress on the pre-disperser seems unrealistically high. Even though the physical interpretation of the retarder model results point at a correlation with a different mechanism not explicitly described, an important result of the study is that this effect seems to be stable over time, as the retarder fit derived from 2003 data improves the results everywhere. So the difference between model and empirical model indeed points at a “one off” on-ground to in-orbit change of the OBM MMEs.

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The paper is generally very well written, although some introductions to equations and models could be clearer at various points (see detailed comments). The two empirical models established for the limb and the nadir scanner- and OBM system provide a very important extension to the existing tools for polarisation data quality monitoring (like e.g. the well-established “special geometry” method used for near-real time Stokes fraction correction for GOME-2). They will be especially useful for any future mission data reprocessing from the GOME, GOME-2 and SCIAMACHY instrument types. The paper also demonstrates that the scan mirror model by Krijger et al can be successfully applied to test and compare the end-to-end MMEs and may even be adjusted to account for on-ground to in-flight OBM MME changes (like the to be expected pre-disperser prism stress during launch).

I am generally missing a discussion of the applicability of the empirical approach to other wavelength providing the appropriate measurements would exist. One can see that empirical representations of mu_P can be derived for e.g. a GOME-2 instrument with many more accurate PMD measurements at different wavelength and for both 90 degree polarisation directions. But the 350 nm feature is an unwanted case for SCIAMACHY and the polarisation sensitivity of the rest of the large spectral range is therefore completely unobserved. The users for other instrument cases would therefore need to rely on the validity of the model.

I recommend the manuscript for publication in AMT providing the following detailed but minor comments and editorial and a few lines in the discussion on the applicability of the end-to-end model for other wavelength regions are addressed.

Detailed comments:

p.3, l.1: “The transformation . . .”. The transformation of what... the OBM model? Or the scanner on-ground model?

p.4, l.18: “The Mueller matrix needs. . .”. The sentence is not very clear... better: "... and if necessary, the reference frames defined...".

p.5, l.15: “Realistically, . . .”. Sentence and comma needs to be checked. though? ... -> of the?

Section 2.3 2nd paragraph. The orientation of the slit for the ESM configuration should be mentioned. Along flight direction and also parallel to q=-1?

p.8/9, l5ff, Eq 6 to 8: The derivation of Equation 8 is confusing since you want to determine the ratio but you start with the absolute signal. Suggestion “In the following we determine the polarization from the ratio.... by first determining the signal measured by the PMD S_P as....” Then in line 12 you need to add that you now calculate a ratio P of the polarized signal to the unpolarized signal, which you define as the virtual sum S_D. “By additionally (!) assuming that the ...”

Eq 6.: Why is mu2 and mu3 for P also detector pixel dependend? Isn’t the sum over i not only referring to science channel detector pixels covering one PMD measurement?

p.8, l.11: Better mu_ni instead of m_i

p.8, l.7: The -> the

p.8, l15. C1B is not explained where and how it is applied in the previous equations so far.

p.11, Eq 15 and previous paragraph: What you are trying to say here is not very clear. I guess what meant is that every measurement R with R<=R_RTM is corrected with cPRTM derived at the limit R=R_RTM, for which cpRTM = Eq15.

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